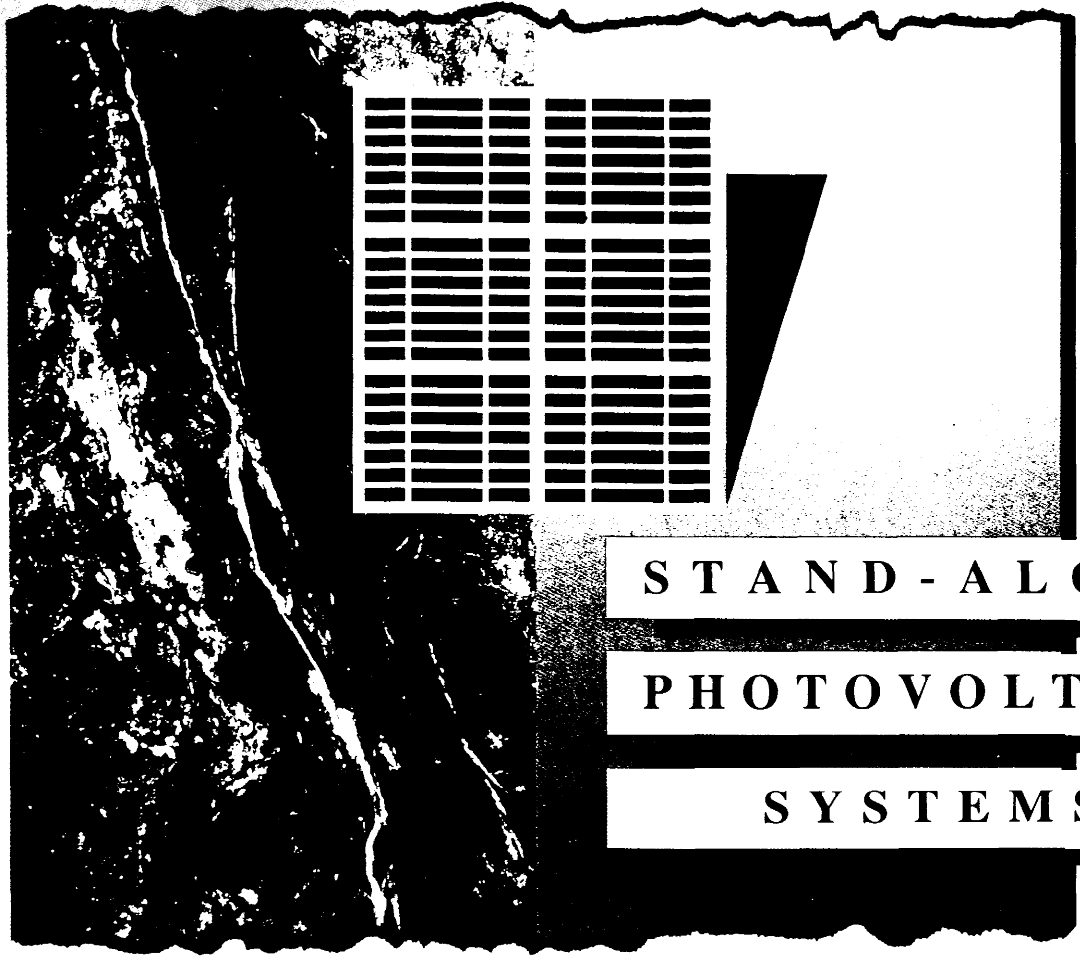

STAND-ALONE PHOTOVOLTAIC SYSTEMS

A Handbook of Recommended Design Practices

Sandia
National
Laboratories

Issued by Sandia National Laboratories operated for the United States Department of Energy by Sandia Corporation

The hardware available for use in photovoltaic systems will vary from country to country. The reader is urged to make comparisons between competitors' products before buying any photovoltaic systems hardware. The use of a specific manufacturer's product in these design examples is not intended as an endorsement.

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STAND-ALONE PHOTOVOLTAIC SYSTEMS
A HANDBOOK OF
RECOMMENDED DESIGN PRACTICES

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Denver, Colorado

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ABSTRACT

This document presents recommended design practices for stand-alone photovoltaic (PV) systems. Sixteen specific examples of PV systems, designed for different applications, are presented. These include warning signals, lighting, refrigeration, communications, residential, water pumping, remote sensing, and cathodic protection. Each example presents a system sizing technique that can be completed using the worksheets provided. The calculations are simple and straight-forward. In addition to sizing calculations, each example includes information about available hardware, wire sizes, and a line-drawing to illustrate installation techniques. However, the focus of this document is the presentation of a consistent system sizing technique.

Stand-alone PV systems operate reliably and are the best option for many remote applications around the world. Obtaining reliable long-term performance from a PV system requires:

- consistent sizing calculations,
- knowledge of hardware availability and performance,
- use of good engineering practices when installing equipment, and
- developing and following a complete operation and maintenance plan.

These issues and others are discussed in this handbook.

FOREWORD

This popular handbook presents a consistent method for sizing PV systems. Over 25,000 copies have been distributed worldwide since it was first published in 1988. It was written by systems engineers with hands-on experience with PV system design, installation, and operation. It has been updated several times to stay current with the latest hardware and engineering techniques. This version reflects recent field experience with component reliabilities and system lifetime.

The selection and proper installion of appropriately-sized components directly affects system reliability, lifetime, and initial cost. The designs presented here represent real applications and illustrate some of the trade-offs necessary in system design and component selection. The example systems are adequate for the application, and the initial cost is reasonable. Using more batteries and increasing PV array size may extend the life and reliability of a PV system designed for a specific application but will increase the initial cost. It's a trade-off.

This Handbook includes many details on system hardware, installation, and operation. However, exhaustive coverage of all issues is not intended. The information on operating and maintaining (O&M) a PV system is intentionally brief because Sandia National Laboratories publishes a companion document titled *Maintenance and Operation of Stand-Alone Photovoltaic Systems*. Likewise, the electrical drawings may not show all components required by the National Electrical Code (NEC). Information on applying the NEC to PV systems is discussed in the document *Stand-Alone Photovoltaic Systems and the National Electrical Code.* Both documents are noted in Recommended Reading, page 86, and are available from the PV Design Assistance Center at Sandia National Laboratories.

Brand names for components used in the representative systems were available commercially in the United States in 1994. Use of a specific product does not constitute an endorsement of that product by Sandia National Laboratories or the United States Government, nor indicate that it is the only (or best) option. Each reader is encouraged to compare component performance and cost from known vendors. The number of equipment dealers is increasing throughout the world. Most dealers have experience with system design and installation using compatible components. The PV system vendors in your country are your best information resource.

ACKNOWLEDGMENTS

The original version of this handbook, produced in 1988, was the product of a collaborative effort between the Photovoltaic Systems Design Assistance Center at Sandia National Laboratories (SNL) and its prime contractor for this work, the Southwest Technology Development Institute (SWTDI) at New Mexico State University. V. Vernon Risser, Project Manager at SWTDI, and Hal Post, Project Manager at SNL, directed the effort and served as technical editors for the handbook. Subcontractors of the Southwest Technology Development Institute were the Solar Technology Institute (now Solar Energy International); Solar Works of Vermont; Remote Power, Inc.; Solar Engineering Services (now Applied Power Corporation); and Olive Corrosion Control Inc. Many members of the solar photovoltaics community reviewed the draft document and provided substantive comments and contributions.

The handbook was revised extensively in November 1991 by V. Vernon Risser, Daystar, Inc., Las Cruces, New Mexico. Marty Lopez did the page layout and publication design. Selena Heide did the illustrations and Voni Whittier designed the cover. Hal Post was the Sandia contract manager and Anne Van Arsdall, SNL, provided editorial support.

Spanish versions were prepared in 1990 and 1993. Translation was performed Mr. Ralph Costa of Costa Foreign Language Services of San Carlos, California. Ron Pate was the Sandia Project Manager. The page layout and publication design were done by Marty Lopez. Selena Heide did the illustrations and the worksheets.

This revision was completed by V. Vernon Risser, Daystar, Inc., Las Cruces, New Mexico in March 1995. Hal Post was the project manager for Sandia. Marty Lopez did the page layout and Selena Heide did the illustrations and worksheets.

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STAND-ALONE PHOTOVOLTAIC SYSTEMS
A HANDBOOK OF
RECOMMENDED DESIGN PRACTICES

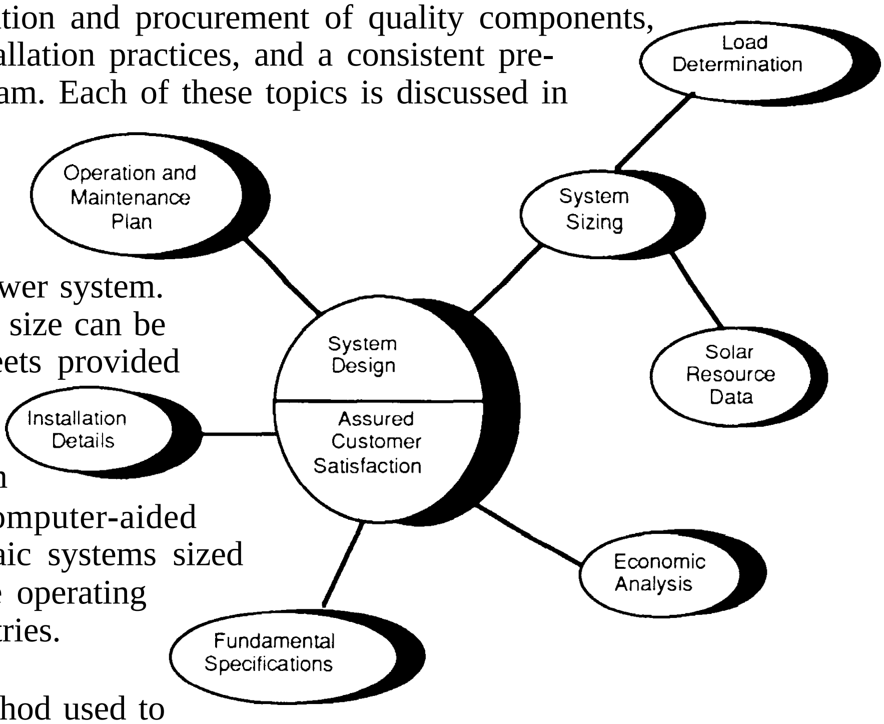
This handbook contains:

- **Recommended practices for design, installation, operation, and maintenance of stand-alone PV systems.**
- **A consistent method of determining system size and specifications.**
- **Complete PV system designs for 16 applications.**

This handbook on photovoltaic (PV) systems is intended for a broad audience--from beginners to professionals. It includes 16 sample system designs for practical applications. The number of PV system installations is increasing rapidly. As more people learn about this versatile and often cost-effective power option, this trend will be accelerated.

The goal of a stand-alone system designer is to assure customer satisfaction by providing a well-designed, durable system with a 20+ year life expectancy. This depends on sound design, specification and procurement of quality components, good engineering and installation practices, and a consistent preventive maintenance program. Each of these topics is discussed in this handbook.

System sizing is perhaps the easiest part of achieving a durable PV power system. A good estimate of system size can be obtained with the worksheets provided and the latest component performance specifications. The resulting system sizes are consistent with computer-aided sizing methods. Photovoltaic systems sized using these worksheets are operating successfully in many countries.



Regardless of the method used to size a system, a thorough knowledge of the availability, performance, and cost of components is the key to good system design. Price/performance tradeoffs should be made and reevaluated throughout the design process. Study the example systems. They illustrate how these design decisions were made for specific applications. Then, when you start your design, obtain as much information as you can about the components you might use. You can design a reliable PV system to meet your needs.

SUMMARY OF RECOMMENDED DESIGN PRACTICES

Recommendations for designing, installing, and operating stand-alone PV systems are included in this handbook. These recommendations come from experienced PV system designers and installers. The best are based on common sense. Realizing that "the more specific the rule, the greater the number of exceptions," some practical recommendations are given here.

- **Keep it simple** - Complexity lowers reliability and increases maintenance cost.
- **Understand system availability** - Achieving 99+ percent availability with any energy system is expensive.
- **Be thorough, but realistic, when estimating the load** - A 25 percent safety factor can cost you a great deal of money.
- **Cross-check weather sources** - Errors in solar resource estimates can cause disappointing system performance.
- **Know what hardware is available at what cost** - Tradeoffs are inevitable. The more you know about hardware, the better decisions you can make. Shop for bargains, talk to dealers, ask questions.
- **Know the installation site before designing the system** - A site visit is recommended for good planning of component placement, wire runs, shading, and terrain peculiarities.
- **Install the system carefully** - Make each connection as if it had to last 30 years--it does. Use the right tools and technique. The system reliability is no higher than its weakest connection.
- **Safety first and last** - Don't take shortcuts that might endanger life or property. Comply with local and national building and electrical codes.
- **Plan periodic maintenance** - PV systems have an enviable record for unattended operation, but no system works forever without some care.
- **Calculate the life-cycle cost (LCC) to compare PV systems to alternatives** - LCC reflects the complete cost of owning and operating any energy system.

HOW TO USE THIS HANDBOOK

Finding information. *Introducing the Brown Family.*

ORGANIZATION

This handbook will assist those wishing to design, specify, procure, or operate a stand-alone photovoltaic (PV) system. A straightforward sizing method is presented and illustrated with 16 detailed examples of common PV system designs. The manual has four color-coded sections as shown in Figure 1: Tan--Contents, Organization, and Use; White--System Design and Specifications; Yellow--Sample Designs; and Green-Appendices. Appendix A contains monthly solar data for selected cities in the United States plus worldwide solar insolation maps. Appendix B contains sample sizing worksheets with instructions. A glossary of commonly used terms starts on page 87. A list of recommended reading is provided on page 86 for those who desire more information.

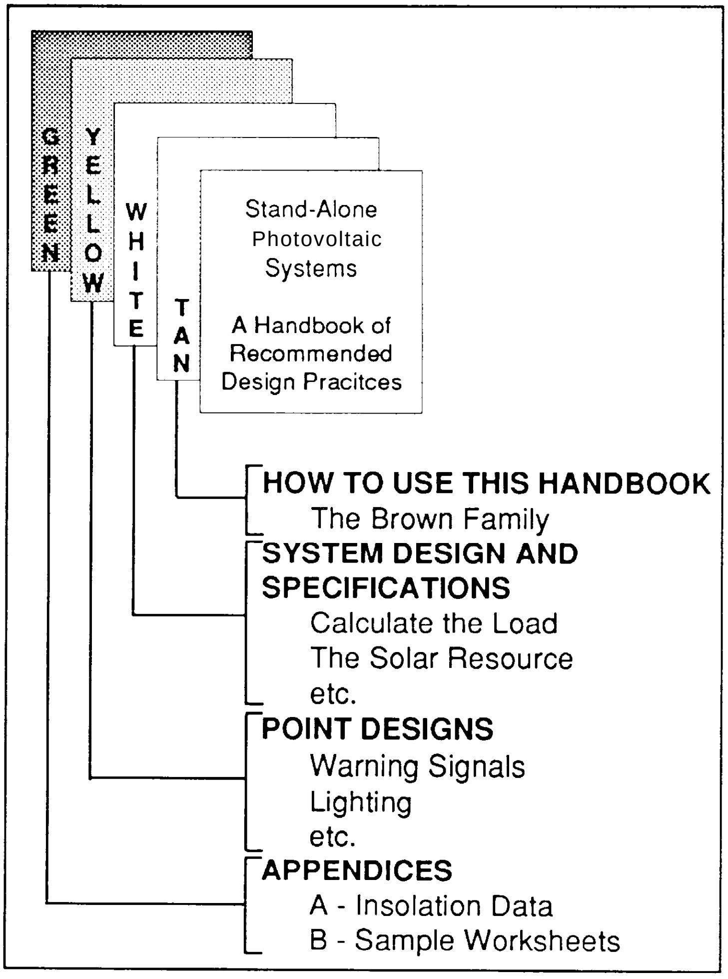
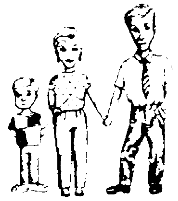


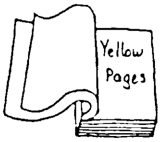
Figure 1. Handbook Layout.

Information about designing PV systems is given in the white pages of this manual. Topics include solar insolation, system availability, different loads, system sizing, specifying components, installation techniques, maintenanceand troubleshooting procedures, and economic aspects. Many chapters include an episode about the hypothetical Brown Family who are planning a PV system to provide power for their home. The Browns' use the techniques and practices described in this manual to size, design, install, and maintain their ac/dc residential system. Their decisions and experiences are presented for those readers who do not



The Brown Family designs an ac residential PV system want to design a system at this time but merely become familiar with the design process. By reading consecutively the Brown Family sections in each chapter, the reader can obtain an overview of PV power system design issues.

The heart of the handbookis in the yellow pages section. Sixteen specific system designs are presented and discussed. The experienced reader may wish to proceed directly to this section to study a sample design and see how the system size was determined, how system hardware was selected, and what installation practices were used. These systems were designed by experienced systems engineers who know what components are available and which ones perform reliably and efficiently. They use this knowledge to make informed design tradeoffs. The reader should do the same.

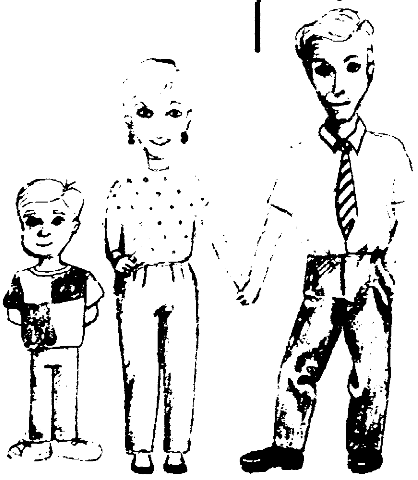


contain sample PV system designs.

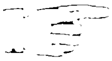
The worksheets in Appendix B are accompanied by detailed instructions and rule-of-thumb estimations of key parameters (defaults). The defaults can be used if performance data cannot be obtained from other sources.

THE BROWN FAMILY ESTIMATES THEIR LOAD

The Browns and their ten-year-old son plan to build a home in a remote area of northern New Mexico. Their land is over one mile from a utility line and they have been told it might cost over $30,000 to extend the line to their property. They learn some people are using PV power systems for summer cabins in that area. They want to investigate using a PV system if it can be done without sacrificing their suburban life-style. They visit a company in town that advertises photovoltaic modules for sale. They describe their plans to the dealer and he encourages them to install a PV power system. He describes his product and gives them some literature on modules, batteries, controllers, and inverters. He also tells them about some magazines that describe owner-designed systems and presents practical advice for the owner/operator. They visited several other dealers and picked up literature on the components offered by each. They also visited those families who owned the W-powered cabins to see how they liked their power system.



Know what you want--
know what you need--
know the difference



The Brown Family liked the idea of using clean solar power but they wanted to know "How much it would cost?" They found there was no set answer--it all depended on what appliances they wanted to use. Their first step was to estimate the average daily power demand of each appliance they wanted to use. This was the first of a 3-step quick sizing method that one of the dealers told them about.

1. Estimate the energy demand of the load by multiplying the power of each appliance by the average number of hours of use. Add 20 percent to allow for losses caused by wiring, dc to ac conversion, dirty modules, etc.

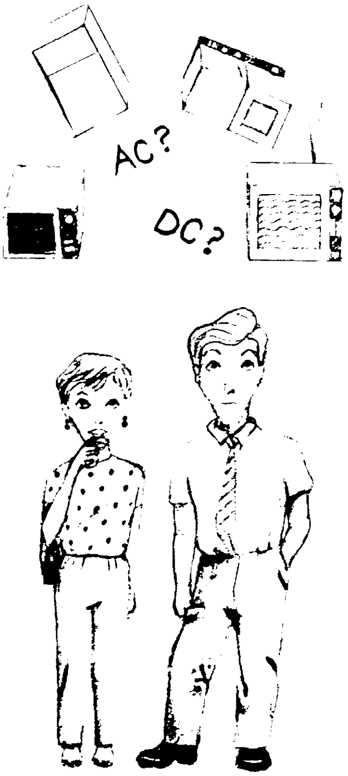
2. Set the number of continuous cloudy days that the system must supply power. Multiply this number by the energy demand estimated in Step 1. This will determine the amount of usable battery storage. Usable battery storage is typically 50-80 percent of the battery capacity claimed by a battery manufacturer. Add a factor equal to 20 percent because you have to put more energy into a battery than you can get out of it.

Average Appliance Power Demand

AC	Power (Watts)
Blender	350
Dishwasher	1,200
Freezer	450
Refrigerator	330
Iron	1,000
Microwave Oven	800
Toaster	1,190
Washing Machine	450
Coffee Maker	1,200
Vacuum Cleaner, Large	1,260
Electric Water Heater	5,000
Radio	75
Television, Color 19"	150
Lighting per Room	100
DC	**Power (Watts)**
Submersible Pump	150
Ceiling Fan	25
Refrigerator	65
Television, Color 10"	60
Swamp Cooler	50
Radio/Tape Player	35
Blender	80
Fan, 8"	15
Lighting per Room	25

3. Determine the average daily solar energy (peak sun hours per day) and divide this number into the daily energy demand determined in Step 1. This will give the array size.

For this first cut at the system size, the Browns listed all the appliances they might want to use and estimated how much time each would be used on an average day. They found a list of the power demand of some common ac and dc appliances and calculated how much energy would be required to run them for the desired amount of time. For instance, they figured the TV would run three hours per day and this would require 150 watts times three hours or 450 watt-hours of energy. When they made the list the first time, they included the use of an electric stove and dishwasher and the energy demand was over 9,000 watt-hours per day including losses. They thought the system should provide power



for 5 cloudy days, so they calculated they would need 45,000 watt-hours of usable energy stored in their battery. Using the 20 percent factor to allow for battery efficiency, they calculated they would have to put 54,000 watt-hours into the battery to get 45,000 watt-hours out. This would mean a charge of about 11,000 watt-hours into the battery on an average day. One of the PV dealers had told them that their location receives about 5,800 watt-hours per square meter on an average day in January if the PV array is tilted at 55° from horizontal. This is equivalent to 5.8 peak sun hours. They divided their daily need, 11,000 watt-hours, by 5.8 peak sun hours and estimated their PV array size at about 1,900 watts. When they next visited their PV dealer they found this system would cost more than $20,000 installed on their property. (This was the initial cost-they would learn about life-cycle cost calculation later.)

They liked the idea of burning solar fuel instead of fossil fuel but this was more than they could afford. They were learning about tradeoffs in PV system design. Cost, performance, and their own life-style and expectations would cause revisions to their design. We leave them reevaluating their use of appliances and the number of days of storage they would need.

STEP 1 - DAILY ENERGY DEMAND

Total Energy Used (Watts)		Loss Factor (20%)		Daily Load (Watt-hours)
	*		=	
7,500	*	1.2	=	9,000

STEP 2 - BATTERY STORAGE

Number No-Sun Days	*	Daily Load (Watts)	*	Battery Loss Factor	=	Battery Storage (Watt-hours)
5	*	9,000		1.2	=	54,000

STEP 3 - SOLAR INSOLATION & ARRAY SIZE

Daily Load Watt-hours	*	Batttery Loss Factor	÷	Peak Sun (Hrs/Day)	=	Array Power (Watts)
9,000	*	1.2	÷	5.8	=	1,860

SYSTEM DESIGN AND SPECIFICATIONS

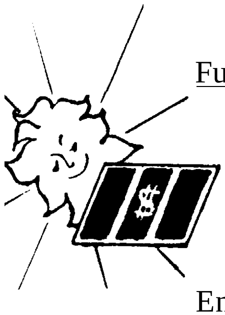
Why should I consider a PV system-aren't they expensive?

OK, life-cycle cost analysis shows PV is a good option for my application. What do I do now?

ECONOMICS

A PV system should be used if it will cost less than alternatives. This section discusses some factors that affect long-term system cost.

The cost of energy produced by PV systems has dropped significantly since 1980. However, the cost of PV energy is still higher than energy bought from your local utility. Also, the initial cost of PV equipment is still higher than an engine generator. Yet, there are many applications where the low operation and maintenance cost of PV systems outweighs the low initial cost of the generator and makes PV the most cost-effective long-term option, The number of installed PV systems increases each year because their many advantages make them the best option. A potential PV system owner should consider the following issues:



For many applications, PV power is the most cost-effective option.

Site Access - A well-designed PV system will operate unattended and requires minimum periodic maintenance. The savings in labor costs and travel expense can be significant.

Modularity - A PV system can be designed for easy expansion. If the power demand might increase in future years, the ease and cost of increasing the power supply should be considered.

Fuel Supply - Supplying conventional fuel to the site and storing it can be much more expensive than the fuel itself. Solar energy is delivered free.

Environment - PV systems create no pollution and generate no waste products.

Maintenance - Any energy system requires maintenance but experience shows PV systems require less maintenance than other alternatives.

Durability - Most PV modules available today are based on proven technology that has shown little degradation in over 15 years of operation.

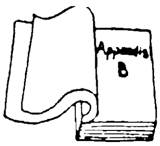
Cost - For many applications, the advantages of PV systems offset their relatively high initial cost. For a growing number of users, PV is the clear choice.

System designers know that every decision made during the design of a PV system affects the cost. If the system is oversized because the design was based on unrealistic requirements, the initial cost is increased unnecessarily. If less durable parts are specified, maintenance and replacement costs are increased. The overall system life-cycle cost (LCC) estimates can easily double if inappropriate choices are made during system design. Examples can be cited where PV systems were not installed because unrealistic specifications or poor assumptions created unreasonable cost estimates, As you size your PV system, be realistic and flexible.

Unrealistic requirements can drive system costs out of sight.

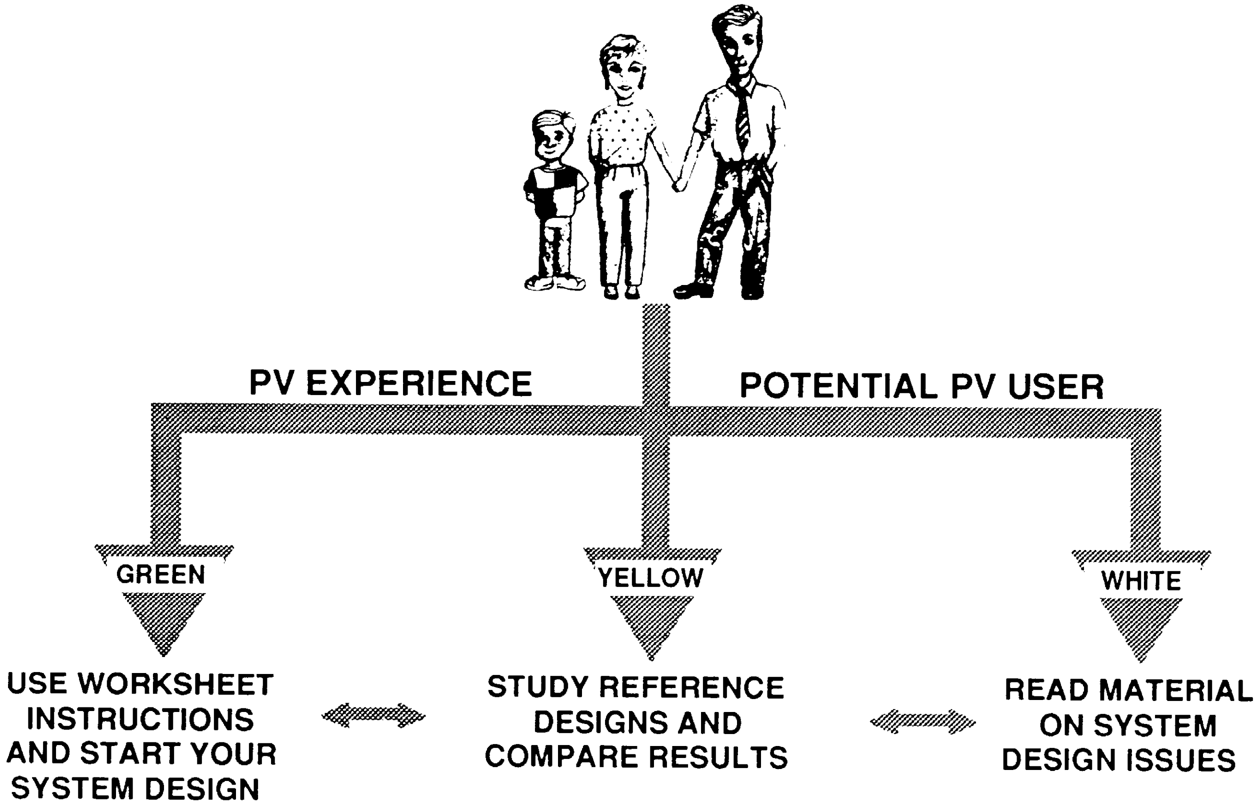
DESIGN APPROACH

After studying all the issues, you have decided that a PV system should be considered for your application. Now what? This handbook is intended to help you do an initial sizing of the PV system and give you some ideas about specifying system components. First, go to Appendix B and extract Worksheets 1-5, pages B-3 to B-8. These worksheets are basic to any design for a PV system with battery storage. Using them, you will



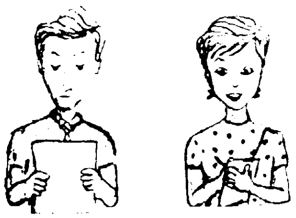
These worksheets show what you need to know to size a PV system.

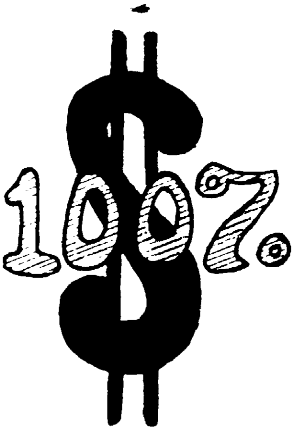
- Calculate the loads,
- Determine the PV array current and array tilt angle,
- Calculate the battery size,
- Calculate the PV array size, and
- Determine if a PV/generator hybrid system should be used.



If you are familiar with the terms used above, you may elect to start your design. (Worksheet instructions begin on page B-9). However, you may want to check the yellow pages to see if there is a complete design for a similar application. Read the white pages if you are uncertain about sizing or design issues. These contain background information and discuss some of the tradeoffs necessary in any PV system design. If this is your first introduction to PV systems, you may want to read only the Brown Family episodes which are interspersed throughout the manual.

THE BROWN FAMILY STUDIES SYSTEM AVAILABILITY





It is not easy or cheap to obtain 100% availability from any system.

The Brown Family reassessed their plans, life-style, and their need for all those electric appliances. They eliminated the dishwasher and decided to use propane for cooking and laundry needs. They also reevaluated their ideas about having electric power available during all kinds of weather--400 percent availability. Availability has a unique meaning for a PV system because it depends not only on reliable equipment but on the level and consistency of sunshine. Because the weather is unpredictable, designing a PV system to be available for all times and conditions is expensive, and in their case unnecessary. They learned that PV systems with long-term availabilities greater than 95 percent are routinely achieved at half the cost or less of systems designed to be available 99.99 percent of the time. When the Browns thought about their life-style, they knew they could decrease their energy use during periods of cloudy weather with only minor inconvenience. They would conserve energy by turning off lights and appliances when not in use and they could do chores such as vacuuming on sunny days. This would decrease the size of their battery and array and save them many dollars.

The Browns were determined to design and install a safe system that would last 25 years or more. They understood that quality would cost more initially but would save money in the long run. Since they would not cut comers on quality they kept the initial cost low by designing a system with a 95 percent availability. Their plan for an energy conscious life-style made them feel good-they were doing their part to conserve energy.

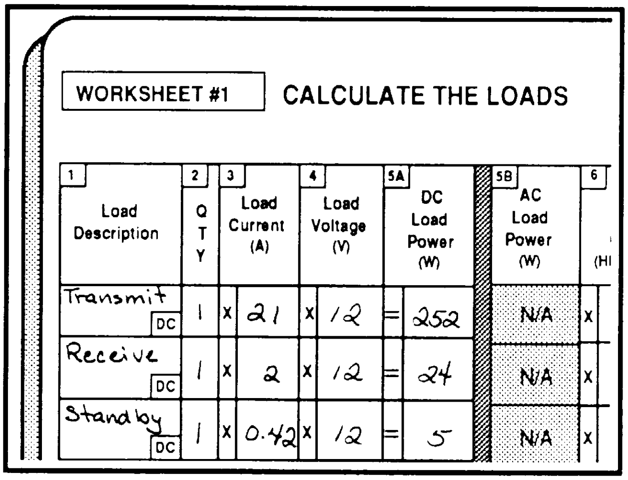
CALCULATE THE LOAD

Make a list of all loads. ***Group the loads by type and voltage.*** ***Select the system voltage.***

ESTIMATION

Accurately estimate your load.

The first task for any photovoltaic system designer is to determine the system load. This load estimate is one of the key factors in the design and cost of the stand-alone PV system. Worksheet 1, a portion of which is shown in the insert, should be used to calculate average daily loads and the result will be the sum of the estimated loads for both ac and dc appliances. If the load demand changes significantly with time, you should complete a copy of Worksheet 1 for each month or season. Copies of all worksheets and instructions are provided in Appendix B. The following steps are required:



WORKSHEET #1 CALCULATE THE LOADS

1 Load Description	2 QTY		3 Load Current (A)		4 Load Voltage (V)		5A DC Load Power (W)	5B AC Load Power (W)		6 (HI
Transmit DC	1	x	21	x	12	=	252	N/A	x	
Receive DC	1	x	2	x	12	=	24	N/A	x	
Standby DC	1	x	0.42	x	12	=	5	N/A	x	

- Identify each load and the number of hours of use per day. Enter the load current in amperes and the operating voltage for each load and calculate the power demand.* List the dc loads at the top of the worksheet and ac loads, if any, at the bottom. A power conditioning unit (PCU) is required for ac loads. A PCU, commonly called an inverter, adds complexity to a system and causes a 10-15 percent loss of power because of the efficiency of converting dc power to ac power. If only a small percentage of the loads require ac power, it may be better to replace those devices with ones that use dc power.

- Group the loads by type and operating voltage and sum the Dower demand for each group. The recommended voltage of the stand-alone PV system will be determined by considering this information. (See the next section for more on system voltage selection.)

- After selecting the system voltage, calculate the total daily ampere-hours required at this voltage.

The load determination is straightforward; just calculate the power requirements of any electrical device that will be included in the system and multiply by the amount of time that specific appliances will operate each day. The power required

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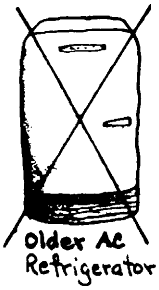
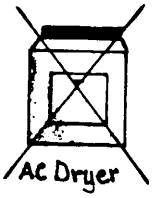
* The power factor is not considered in the calculation of ac power. For information on calculating ac power, see any basic electrical engineering textbook.

by an appliance can be measured or obtained from manufacturers' literature. (See the list on page 5.) However, the amount of time the appliance will be used per day, week, or month must be estimated. Remember for residential systems (and many others) the hours of use can be controlled by the system owner/operator. Be realistic. Resist the temptation to add 10, 20, or 50 percent to each appliance use estimate. The cumulative effect can cause the size and cost of your PV system to skyrocket.

The selection of appliances is an important determinant of the size and cost of a residential PV system.





The designer should consider energy conserving substitutes for items that are used often. Identify large and/or variable loads and determine if they can be eliminated or changed to operate from another power source. Fluorescent lamps should be used in place of incandescent lamps. They provide the same light levels with much lower power demand. Consider using dc appliances to avoid the loss in the dc/ac power conversion process. DC lights and appliances usually cost more, but are more efficient and last longer. The number of ac appliances available is greater but efficiencies are usually lower because these appliances were designed for use on an "infinite" utility power supply.

Use dc appliances whenever possible—they are often more efficient than ac appliances.

Consider the following:

Electric Ranges - It is impractical to power these with PV; use a propane stove as an alternative.

Refrigerators - Older ac units are often inefficient. The compressor may operate 60-80 percent of the time. Units made after 1993 are much more efficient. Efficient dc units are an option, but they cost more than similar size ac units.

Clothes Washers - Some dc to ac inverters* may have a problem starting the large motor on the washer. A ringer type washer is an option.

Clothes Dryers - Consider a gas dryer or use an outdoor rack to dry the clothes.

Dishwashers - There are no dc units available. This is a large load, especially on the dry cycle.

Microwave Ovens - These are a large load but operating time is usually short; few dc units are available; some inverters may not start a microwave oven and/or may cause inaccurate timer operation.

Water Pumps - PV power is used for many small water pumping applications but PV may not be the best option for pumping large amounts of water for irrigating crops.

VOLTAGE SELECTION

The operating voltage selected for a stand-alone PV system depends on the voltage requirements of the loads and the total current. If the system voltage is set equal to the

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*See page 39 for discussion of dc to ac inverters.

voltage of the largest load then these loads may be connected directly to the system output. However, it is recommended that the current in any source circuit be kept below 20 with a 100 amperes limit for any section of the system. Keeping the current below these recommended levels will allow use of standard and commonly available electrical hardware and wires. When loads require ac power, the dc system voltage should be selected after studying available inverter characteristics. See Table 1. Another consideration is the possible increase in the size of your system in the future. Choose a voltage that will work with the future enlarged system.

TABLE 1
Selecting System Voltage

AC Power Demand (Watts)	Inverter Input Voltage (Volts dc)
<1,500	12
1,500-5,000	24 or 48
>5,000	48 or 120

Some general rules are:

- DC loads usually operate at 12 volts or a multiple of 12--i.e., 24 volts, 36 volts, or 48 volts, etc. For dc systems, the system voltage should be that required by the largest loads. Most dc PV systems smaller than 1 kilowatt operate at 12 volts dc. (The maximum current would be 1,000 ÷ 12 = 83.3 amperes.)

- If loads with different dc voltages must be supplied, select the voltage of the load with the highest current demand as the system voltage. Electronic dc-dc converters can be used to power loads at voltages different from the system voltage. If a lower voltage is required, it is sometimes possible to connect to only a portion of a series-connected battery string. This can cause problems with charging the batteries and should not be done without a charge equalizer if the current required at the lower voltage is more than 5 percent of the total current taken from the battery strings. A battery charge equalizer is an electronic device that keeps all batteries in a series string at the same voltage.

Limiting system current to less than 100 amperes will save on switches and wire.

- Almost all ac loads for stand-alone PV systems will operate at 120 volts ac. Study inverter specifications that will provide the total and instantaneous ac power required. Select an inverter that will meet the load and keep the dc current below 100 amperes. Disregarding power facto; and losses, the following equations must balance.

ac power = (ac voltage)(ac current)
dc power = (dc voltage)(dc current)

For example, if the ac load is 2,400 watts and the ac voltage is 120 volts, the ac current will be 20 amperes. Excluding losses in the inverter, the dc power must be the same; 2,400 watts. If a 12-volt inverter is selected the dc current would be 200 amps--not recommended. Use a 24-volt inverter or a 48-volt inverter to make the input current 100 or 50 amperes respectively. Remember, the cost of wire and switches goes up as the amount of current increases. A rule of thumb for selecting system voltage based on ac power demand is given in Table 1.

Selection of an inverter is important and affects both the cost and performance of the system. Generally, the efficiency and power handling capability are better for units operating at higher dc voltages, i.e., a 48-volt unit is usually more efficient than a 12-volt unit. The designer should obtain information on specific inverters, their availability, cost, and capabilities, from several manufacturers before making the decision on system voltage. Another fact to consider is the basic building block in the array and storage subsystems gets larger as the voltage increases. For example, a 48-volt system has four PV modules connected in series to form the basic building block. Fine tuning the design, i.e., adding a little more current to the system, means buying four additional modules. However, the advantage of the higher operating voltage is the lower current required to produce the same power. High current means large wire size, and expensive and hard to get fuses, switches, and connectors. Again, a prior knowledge of the cost and availability of components and switchgear is critical to good system design.

Selecting the system voltage is an important design tradeoff.

The inverter input voltage dictates the dc system voltage.

THE BROWN FAMILY SELECTS THEIR SYSTEM VOLTAGE

The Browns wanted both ac and dc appliances in their home.

$$\frac{1{,}800\text{ W}}{24\text{ V}} = 75\text{ Adc}$$

$$\text{plus } \frac{240\text{ W}}{24\text{V}} = 10\text{ Adc}$$

$$\text{plus } \frac{24\text{ W}}{12\text{ V}} = 2\text{ Adc}$$

The Browns used Worksheet 1 to make the final calculation of their load. They wanted the convenience of ac appliances, but they decided to use dc lights and some small appliances to conserve energy. They decided not to use a dishwasher and the) would hang their clothes out to dry. When they recalculated their loads, they had reduced their electrical demand to 1,800 watts at 120 volts ac, 240 watts at 24 volts dc, and 24 watts at 12 volts dc. They would get a 2,500-watt inverter that operated at 24 volts. Their 12-volt radio telephone could be operated by tapping off the center of their 24-volt battery bank since the current required at 12 volts was less than 2 percent of the total system current. They calculated the currents as shown. Considering losses, they felt their batteries would never have to supply more than 100 amperes. They knew that switches, wire, and fuses could be readily obtained to handle this current. Next they would determine the level of solar resource at their site and the amount of battery storage they would use.

THE SOLAR RESOURCE

What Insolation data are needed?
How does array tilt angle change the data?

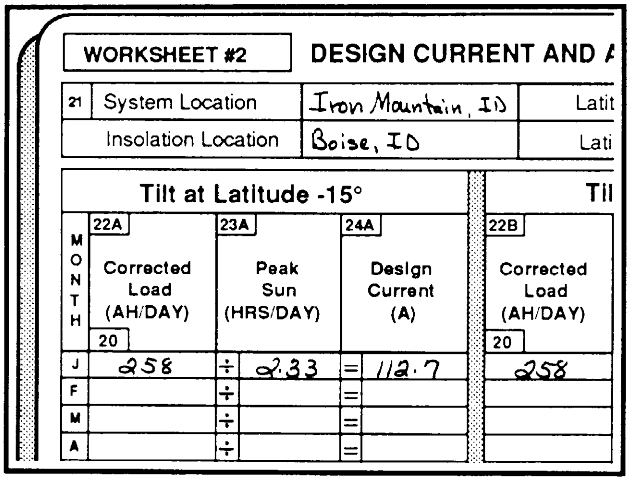
How accurate must my estimate be?
What about tracking the PV array?

DESIGN MONTH

Completing Worksheet 2 will give a "design month" that is the worst case combination of low insolation and high load demand. The recommended array tilt angle for that design month will also be determined. Using these criteria, the stand-alone PV system will be designed to meet the load and keep the battery fully charged in the worst month of the average year.

Monthly insolation data for fixed and tracking arrays are provided in Appendix A.

Inaccurate solar data can cause design errors so you should try to find accurate solar data that will reflect the long-term radiation available at your system site. However, these data, particularly for tilted or tracking surfaces, are not widely available. Check local sources such as universities, airports, or government agencies to see if they are collecting such data or know where you might obtain these values. If measured values on a tilted surface are not available, you may use the modeled data given in Appendix A. Data for fixed and single-axis tracking surfaces at three tilt angles (latitude and latitude ±15°) are provided. Two-axis tracking data are given also, as well as a set of world maps that show seasonal values of total insolation at the three tilt angles. All data are in units of kilowatt-hours per square meter. This is equivalent to peak sun hours--the number of hours per day when the sun's intensity is one kilowatt per square meter. (These data estimate total radiation at the given orientation. They do not represent direct beam radiation and should not be used to estimate performance of concentrating PV systems.)



WORKSHEET #2 **DESIGN CURRENT AND**

21	System Location	Iron Mountain, ID	Latit
	Insolation Location	Boise, ID	Lati

	Tilt at Latitude -15°					Til
MONTH	22A Corrected Load (AH/DAY) 20		23A Peak Sun (HRS/DAY)		24A Design Current (A)	22B Corrected Load (AH/DAY) 20
J	258	÷	2.33	=	112.7	258
F		÷		=		
M		÷		=		
A		÷		=		

Determine the worst case month for insolation.

Worksheet 2, a portion of which is shown in the inset, provides a place for the load current for each month and for solar insolation data for each month at three different tilt angles. For most applications, it is possible to identify the design month without working through each of the 12 monthly calculations. For instance, if the load is constant throughout the year, the design month will be the month with the lowest insolation and the array should be installed with a tilt angle that yields the highest value of insolation during that month. If the load is variable, the design month will be that month with the largest ratio of load demand to solar insolation. Incorporated into the selection of the design month is the recommended array tilt angle that will maximize solar insolation for that month.

If tracking the PV array is an option, Worksheet 2 should be completed using tracking data. Do not mix tracking data and fixed-tilt data on the same worksheet. Completion of a preliminary sizing with both fixed and tracking data will allow an economic comparison to be made between the two techniques. Single-axis east-to-west trackers are the only ones generally used for small stand-alone PV systems. Two-axis tracking is not recommended because of the added complexity.

SELECTING DATA

The availability and amount of sunshine must be estimated because it is unlikely that long-term data will be available for your specific site. The data in Appendix A give average values for a regional area. If you can't find long-term weather records for sites near your system, these data are sufficient for initial sizing of stand-alone PV systems. Local solar conditions may vary significantly from place to place, particularly in mountainous areas. Your site may receive more or less than the weather data used for the system sizing. You may want to increase or decrease the solar data by 10-15 percent and see how this affects your system design. In other words, do a best-case and a worst-case estimate for radiation. Do not deviate from recorded data more than 20 percent unless you are certain the radiation at your site is significantly different. Remember, the estimate of the solar resource directly affects the performance and cost of the stand-alone PV system.

Check local weather sources for long-term data.

Solar conditions can vary significantly over a short distance, particularly in the mountains.

DESCRIPTION

Solar irradiance is the amount of solar power striking a given area. It is a measure of the intensity of the sunshine and is given in units of watts (or kilowatts) per square meter (w/m²). Insolation. is the amount of solar energy received on a given area measured in kilowatt-hours per square meter (kwh/m²)--this value is equivalent to peak sun hours. Sometimes, insolation will be presented in units of Btu's per square foot (Btu/ft²), Langleys (L), or megajoules per square meter (MJ/m²). The conversion factors are:

$$\text{kWh/m}^2 = \frac{\text{Langley}}{86.04} = 317.2 \text{ Btu/ft}^2$$
$$= 3.6 \text{ MJ/m*}$$

A nearly constant 1.36 kilowatts per square meter (the solar constant) of solar radiant power impinges on the earth's outer atmosphere. This is the value obtained by integrating the area under the graph in Figure 2. The extraterrestrial radiation spectrum is shown along with an estimate of the radiation spectrum at ground level. It is evident that the atmosphere is a powerful absorber and reduces the solar power reaching the earth, particularly at certain wavelengths. The part of the spectrum used by silicon PV modules is from 0.3 to 0.6 micrometers. These wavelengths

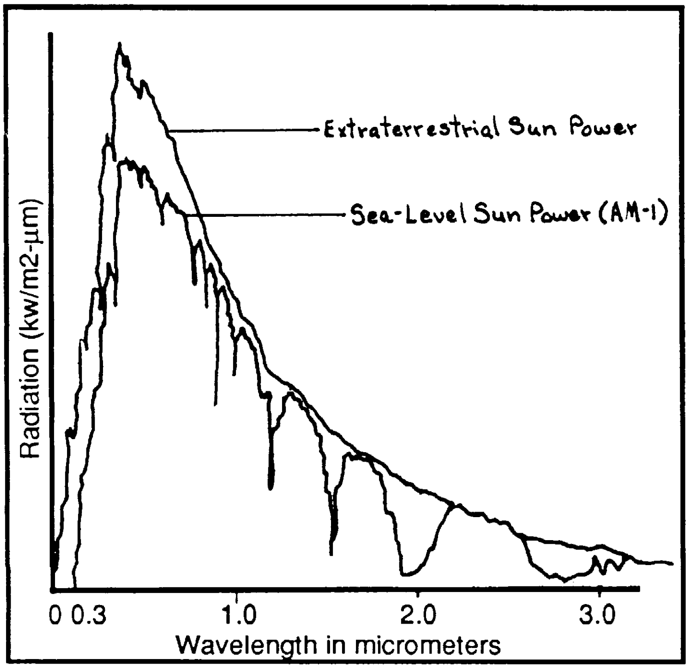
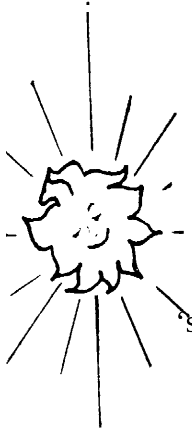
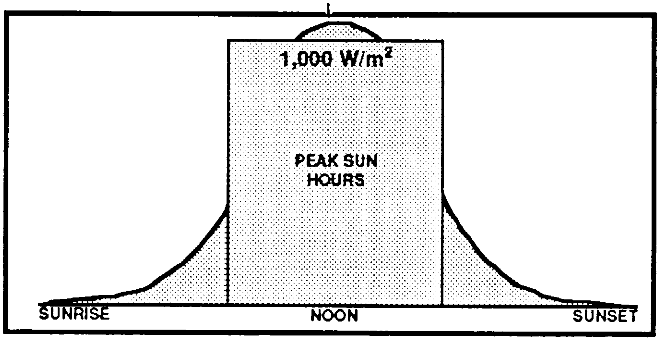


Figure 2. Radiation Spectrum.

encompass the highest energy region of the solar spectrum. On a sunny day the total irradiance striking the earth will be about 1,000 w/m².

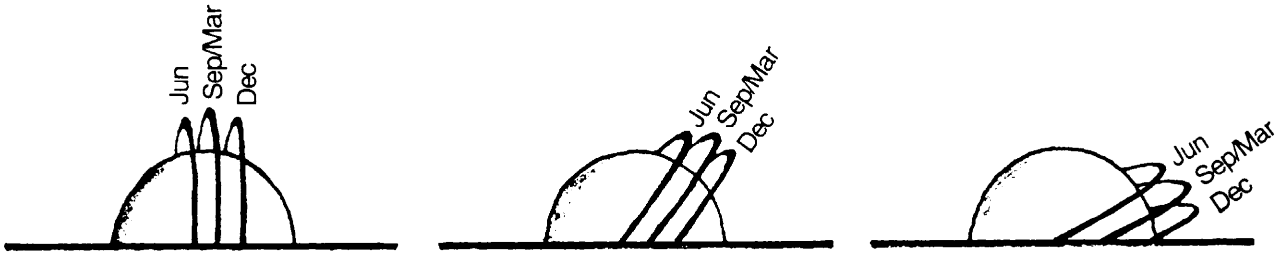


Solar radiation data are often presented as an average daily value for each month. Of course, on any given day the solar radiation varies continuously from sunup to sundown. The maximum irradiance is available at solar noon which is defined as the midpoint, in time, between sunrise and sunset. The term "peak sun hours" is defined as the equivalent number of hours per day, with solar irradiance equaling 1,000 w/m², that would give the same amount of energy. In other words, six peak sun hours means that the energy received during total daylight hours equals the energy that would have been received had the sun shone for six hours with an irradiance of 1,000 w/m². Therefore, peak sun hours correspond directly to average daily insolation in kwh/m², and the tables provided in Appendix A can be read either way.



In the southwestern United States, the solar irradiance at ground level regularly exceeds 1,000 w/m². In some mountain areas, readings over 1,200 w/m² are recorded routinely. Average values are lower for most other areas, but maximum instantaneous values as high as 1,500 w/m² can be received on days when puffy-clouds are present to focus the sunshine. These high levels seldom last more than a few seconds.

Insolation varies seasonally because of the changing relation of the earth to the sun. This change, both daily and annually, is the reason some systems use tracking arrays to keep the array pointed at the sun. For any location on earth the sun's elevation will change about 47° from winter solstice to summer solstice. Another way to picture the sun's movement is to understand the sun moves from 23.5° north of the equator on the summer solstice to 23.5° south of the equator on the winter solstice. On the equinoxes, March 21 and September 21, the sun circumnavigates the equator. These three sun paths are shown in Figure 3a on the next page. At 40°N. latitude the sun paths for the solstices and equinoxes



3a. 0° LATITUDE **3b. 32° N. LATITUDE** **3c. 64° N. LATITUDE**

Figure 3. Seasonal Sun Trajectories at Varying Latitudes.

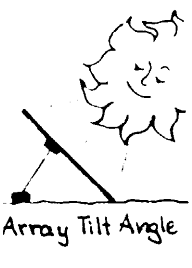
are shown in 3b. Figure 3c shows the paths for 64°N. latitude. For any location the sun angle, at solar noon, will change 47° from winter to summer.

The power output of a PV array is maximized by keeping the array pointed at the sun. Single-axis tracking of the array will increase the energy production in some locations by up to 50 percent for some months and as much as 35 percent over the course of a year. The most benefit comes in the early morning and late afternoon when the tracking array will be pointing more nearly at the sun than a fixed array. Generally, tracking is more beneficial at sites between ±30° latitude. For higher latitudes the benefit is less because the sun drops low on the horizon during winter months.

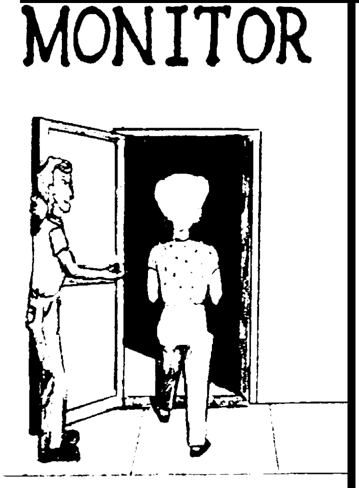
For tracking or fixed arrays, the <u>annual</u> energy production is maximum when the array is tilted at the latitude angle; i.e., at 40°N latitude, the array should be tilted 40° up from horizontal. If a wintertime load is the most critical, the array tilt angle should be set at the latitude angle plus 15° degrees. To maximize summertime production, fix the array tilt angle at latitudeminus 15° degrees.

MEASUREMENTS

A pyranometer measures both the direct and diffuse components of sunlight. These values may be integrated over time to give an estimate of insolation. Some of the more accurate pyranometers are precisely calibrated and expensive. Less expensive pyranometers that use a calibrated section of a PV cell to measure the irradiance are available. These are accurate enough for small PV system owners who want to monitor system performance. If you are able to find a record of solar insolation data at a site near your system it will most likely be from a pyranometer mounted on a horizontal surface. Unfortunately, there is no easy way to use these data to estimate the insolation on a tilted surface. If data are not available from a local source, use the data given in Appendix A.



THE BROWN FAMILY ESTIMATES THE SOLAR RESOURCE



The Browns adjusted the insolation used for their system design after consulting local weather data.

The Browns acreage is located in the mountains at an elevation of 1,500 meters. The location is in a protected valley with mountains on both east and west sides. The Browns knew the mountains would limit morning and late afternoon sun, so they decided that array tracking would not be practical for them. They wanted to maximize the amount of radiation received in the winter so they thought they expected to fix their array tilt angle at latitude plus 15° and facing South.

The city nearest their building site with local weather data was Albuquerque, New Mexico. However, their site was about 1,700 feet higher than Albuquerque. They searched for local weather data and found that the newspaper in Los Alamos, New Mexico, (elevation 7,700 feet) printed the daily solar insolation received. They visited the newspaper office and listed the insolation values for each day for one year. These values were averaged for each month to get a daily average. This was compared with recorded values for Albuquerque and Denver, Colorado. The insolation at Los Alamos was consistently higher, particularly in the winter months. Since their site was somewhat protected by mountains, they elected to use 95 percent of the monthly insolation received at Los Alamos. They expected to get some increased irradiance from snow reflection because they were going to install their array with a 55° tilt. The Browns used January as the design month and estimated the insolation at 4.5 peak sun hours per day. Their design current was 94 amperes. They expected their system to give 95 percent availability during an average January.

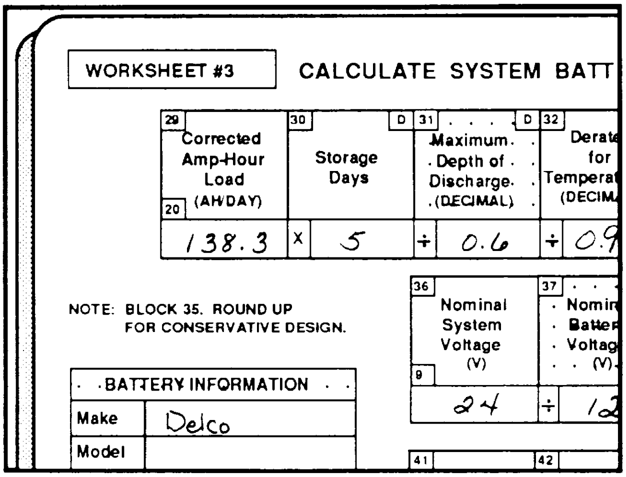
BATTERIES

How many days of storage do I need?

What system availability will I need?
How can I ensure a safe battery installation?

SIZING

Worksheet 3, a portion of which is shown in the inset, can be used to determine the size of the battery storage required for a stand-alone PV system. You will be required to make a number of decisions. Before making these choices, you should study and understand battery parameters and the concept of system availability.



WORKSHEET #3 CALCULATE SYSTEM BATT

29 Corrected Amp-Hour Load (AH/DAY) 20		30 Storage Days D		31 Maximum Depth of Discharge (DECIMAL) D		32 Derat for Tempera (DECIM
138.3	x	5	÷	0.6	÷	0.9

NOTE: BLOCK 35. ROUND UP FOR CONSERVATIVE DESIGN.

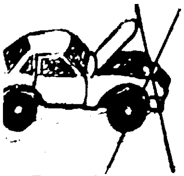
36 Nominal System Voltage (V) 9		37 Nomin Batte Voltag (V)
24	÷	12

BATTERY INFORMATION	
Make	Delco
Model	

41 42

First, you must choose the amount of back-up energy you want to store for your application. This is usually expressed as a number of no-sun days, in other words, for how many cloudy days must your system operate using energy stored in batteries. There is no “right answer” to this question. It depends on the application, the type of battery, and the system availability desired. (A discussion of system availability for PV systems is given in the next section.) When specifying the amount of storage you must be aware of the difference between rated battery capacity and usable capacity. Battery manufacturers publish a rated battery capacity--the amount of energy that their battery will provide if discharged once under favorable conditions of temperature and discharge rate. This is much higher than the amount of energy you can take out of the battery repeatedly in a PV application. For some shallow-cycle, sealed batteries the usable capacity is only 20 percent of the rated capacity, i.e., taking more than 20 ampere-hours from a 100 ampere-hour battery will cause the battery to quickly fail. Other types of batteries designed for deep cycling will have usable capacities up to 80 percent of rated capacity. For most PV applications the bigger and heavier the battery the better. The best recommendation for the number of days of storage is to put in as much battery capacity as you can afford. Obviously, if you live in an area with extended periods of cloudiness you will need more storage capacity to keep the load going during these periods of inclement weather. Also, if it is critical that your load have power at all times, you will want to have a large battery capacity. A smaller battery size can be specified if you can live with some power outage.

The PV system designer has to consider all these aspects plus more when choosing the battery type and size. Some factors can outweigh the technical sizing decision. For instance, you may be able to obtain batteries locally and the savings in shipping cost will allow you to buy more batteries. Also, there are many types of batteries with a large variance in quality and cost. You must know the performance, cost, and availability of batteries in your country. Figure 4 gives you a starting point for making your battery size selection using the design month peak sun hours for your site. Just find the peak sun hours for your design month and read up to the days of storage for system availabilities of 95 or 99 percent.



Batteries are designed for different purposes—do not use a car battery in a PV system.

It is important to buy quality batteries that can be discharged and recharged many times before failure. Automobile batteries should not be used if there is any alternative. Automobile batteries are designed to produce a high current for a short time. The battery is then quickly recharged. PV batteries may be discharged slowly over many hours and may not be recharged fully for several days or weeks. Specify a battery that can withstand this type of operation.

Finally, it is important to understand the close interrelation between the battery and the charge controller. When you buy your batteries you should also buy a compatible charge controller. A charge controller is an electronic device that attempts to maintain the battery state-of-charge (SOC) between preset limits. The battery voltage is measured and used as the primary estimator of SOC. (Some charge controllers measure battery temperature in addition to voltage to improve the estimate of SOC.) If the charge controller does not operate properly the battery may be overcharged or allowed to discharge too much. Either way the lifetime of the battery will be shortened and you will have to spend money to replace batteries. Charge controller operation is described in the section starting on page 36. Also, be sure to ask your battery dealer what charge controller she recommends.

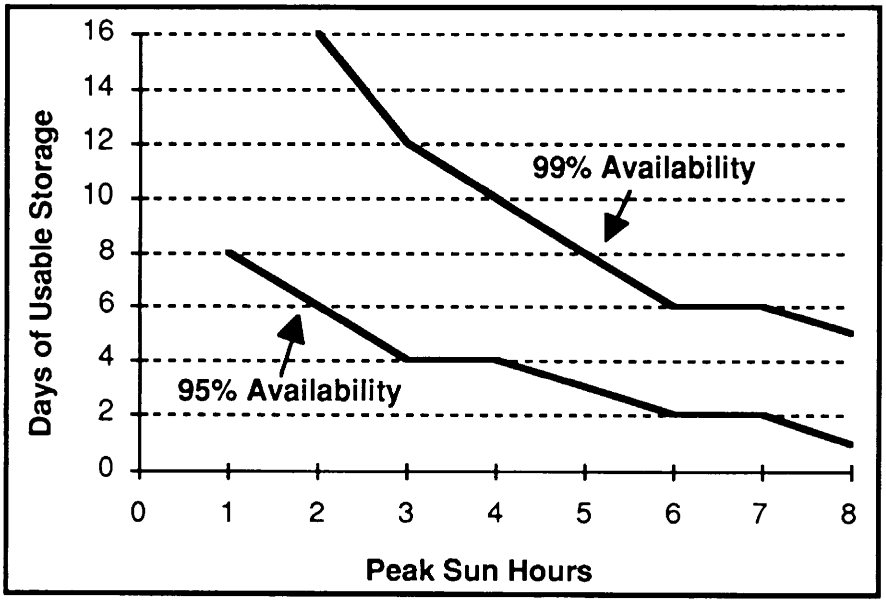
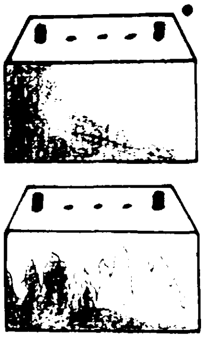


Figure 4. Days of Storage.

The following terms will help you specify batteries for your PV system.

- **Depth of Discharge** - This term is the percentage of the rated battery capacity that has been withdrawn from the battery. The capability of a battery to withstand discharge depends on its construction. The most common batteries have electrically active lead alloy plates immersed in a mild acid electrolyte. Plate types are Planté (pure lead), pasted, or tubular. The plates can be made with different thicknesses and different alloys, such as lead calcium, or lead antimony, for different applications. Generally, the more massive the plates the better the battery will withstand discharge and recharge (cycling). Two terms, shallow-cycle and deep-cycle, are commonly used to describe batteries. Shallow-cycle batteries are lighter, less expensive, and will have a shorter lifetime particularly if recommended discharge levels are exceeded regularly. Many sealed (advertised as no maintenance) batteries are shallow-cycle types. Generally, the shallow-cycle batteries should not be discharged more than 25 percent. Deep-cycle batteries are more often used for stand-alone PV systems. These units have thicker plates and most will withstand discharges up to 80 percent of their rated capacity. Most of these are flooded batteries which means the plates are covered with the electrolyte. The electrolyte level must be monitored and distilled water added periodically to keep the plates fully covered.

Maintaining a state of charge at 80 percent is allowing a 20 percent depth of discharge. Don't confuse the two terms.



A fully charged battery will withstand -20°C. A discharged battery will freeze at temperatures slightly below 0°C.

Another type of battery using nickel cadmium (NiCd) plates can be used. NiCd batteries are more expensive but can withstand harsh weather conditions. NiCd batteries can be completely discharged without damage and the electrolyte will not freeze.

The maximum depth of discharge value used for sizing should be the worst case discharge that the battery will experience. The battery charge controller should be set to prevent discharge below this level. Because nickel cadmium batteries can be discharged nearly 100 percent without damage, some designers do not use a controller if NiCd batteries are used.

Temperature Correction - Batteries are sensitive to temperature extremes and a cold battery will not provide as much power as a warm one. Most manufacturers provide temperature correction curves like those shown in Figure 5 for their batteries. For instance, a battery at 25°C has 100 percent capacity if discharged at a current rate of C/20. (The discharge rate is given as a ratio of the rated capacity, C, of the battery.) However, a battery operating at 0°C would have only 75 percent of the rated capacity if discharged at a C/20 rate. If the discharge rate is higher, say C/5, only 50 percent of the rated capacity will be available when the temperature is minus 20°C. Although the chart shows you can get more than rated capacity from when the battery temperature is high, hot temperatures should be avoided because they will shorten battery life. Try to keep your batteries near room temperature.

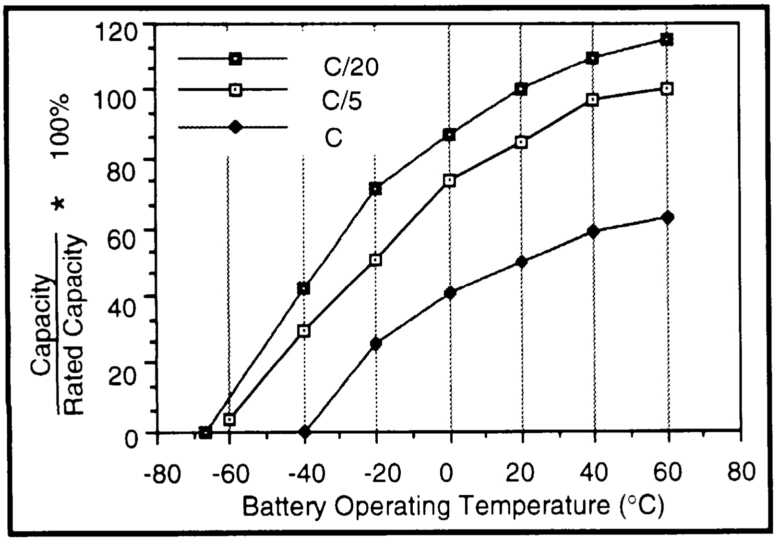


Figure 5. Lead-Acid Battery Capacity vs. Temperature.

- **Rated Battery Capacity** - This term indicates the maximum amount of energy that a battery can produce during a single discharge under specified conditions of temperature and discharge rate. You will not be able to obtain rated capacity repeatedly when the batteries are used in PV systems. However, rated capacity sets a baseline on which to compare battery performance. When comparing the rated capacity of different batteries, be sure the same discharge rate is being used.

- **State-of-Charge (SOC)** -This is the amount of capacity remaining in a battery at any point in time. It is equal to 1 minus the depth of discharge given in percent.

- **Battery Life (cycles)** - The lifetime of any battery is difficult to predict because it depends on a number of factors such as charge and discharge rates, depth of discharges, number of cycles, and operating temperatures. It would be unusual for a lead acid type battery to last longer than 15 years in a PV system but many last for 5-10 years. Nickel cadmium batteries will generally last longer when operated under similar conditions and may operate satisfactorily for more than 15 years under optimum conditions.

System availiability has a unique meaning for a PV system.

Battery life depends on how the battery is used and abused.

SYSTEM AVAILABILITY

System availability is defined as the percentage of time that a power system is capable of meeting load requirements. The number of hours the system is available divided by 8,760 hours will give the annual system availability. A system with availability of 95 percent would be expected to meet the load requirements 8,322 hours during an average year for the useful life of the system. Annual availability of 99 percent would mean the system could operate the load for 8,672 of 8,760 hours.

Failures and maintenance time are the primary contributors to lowering system availabilities for any energy system. However, for PV systems, availability takes on added uncertainty because of the variability of the system's fuel source. PV system design requires an estimate of the average amount of sunlight available. Using these average values means that in a year with above average solar insolation, the system may not experience any downtime (due to fuel supply--obviously, failures cannot be predicted). However, in a year with much cloudy weather the system may be unavailable more than the expected number of the hours per year. A PV system designed to have 95 percent availability will, on the average, provide power to the load 95 percent of the time. The number of hours when the system is unavailable will likely be in the winter months when solar radiation is the lowest.

The plots shown below were developed by studying the variation in year-to-year weather for selected sites. For any location, there will be a distribution of weather patterns over the years. This variation gives an indication of possible downtime over a PV system's lifetime. A study of this weather distribution shows that for a system with 95 percent availability, the 5 percent downtime (Figure 6) will be distributed over the assumed 23-year system life as follows: 1.2 years will have less than 24 hours downtime per year, 2.3 years will have 25-240 hours, 11.3 years will have 241-538 hours, 5.6 years will have 539-912 hours and 2.7 years will have over 913 hours.

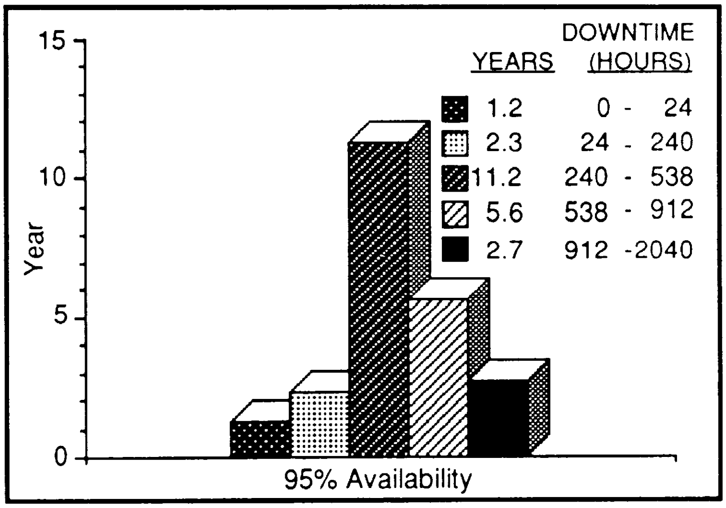


Figure 6. Downtime Per Year (95%).

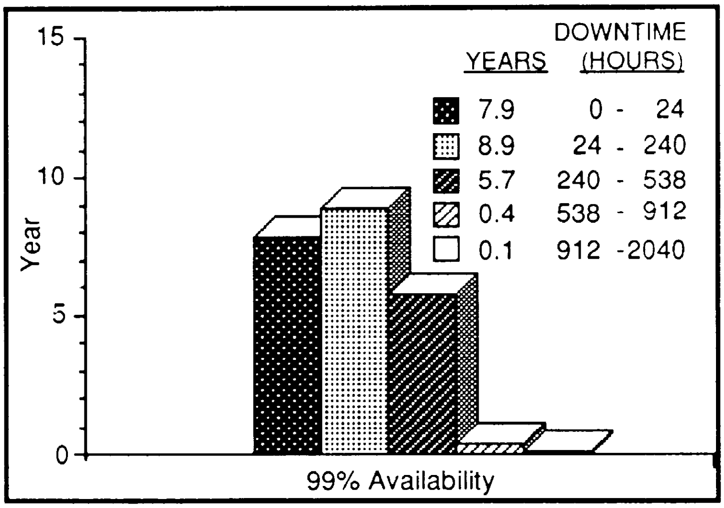


Figure 7. Downtime Per Year (99%).

A similar chart is shown as Figure 7 for 99 percent availability. Note the different distribution. The system designed for 99 percent availability will have less than 240 hours of downtime in 17 of the 23 years, whereas the 95 percent available system will have less than 240 hours of downtime in only 3.5 years. However, the system designer must consider the cost required to increase the system availability. If the system size is increased to lower the downtime in winter, more energy will be wasted in summer when the array will produce more than is needed by the load. The system cost increases rapidly--and the efficient utilization of energy decreases--as you try to obtain the last few percent, i.e., increasing availability from 95 to 99 percent. This is particularly true for locations where the difference between winter and summer insolation values is large. An example of system cost increase for two sites is given in Figure 8. For a

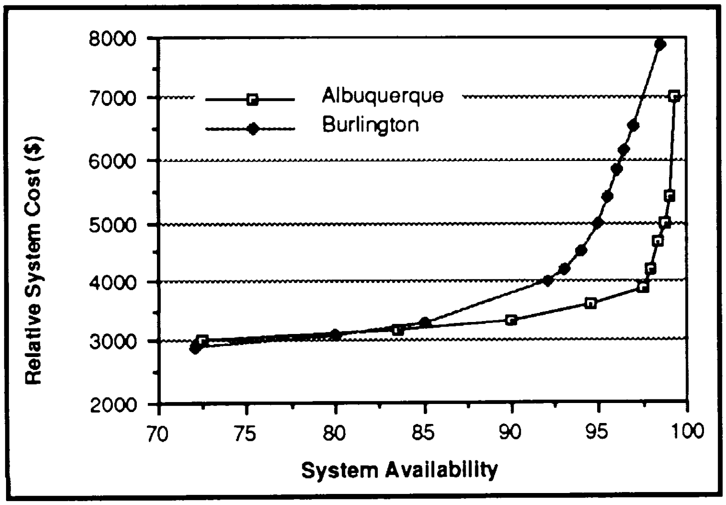
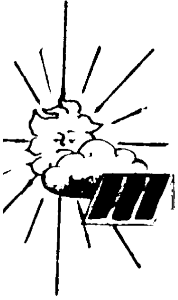


Figure 8. Cost vs. Availability–Albuquerque, New Mexico, and Burlington, Vermont.

sunny site, the incremental cost does not climb steeply until about 98 percent availability. For a site with poor solar insolation in winter the cost of increasing availability starts to climb rapidly after 90 percent.

In the PV system designs presented here, two levels of system availability are defined and used; 95 percent for noncritical loads and 99 percent for critical loads. Critical loads are those where a system failure might cause loss of life or expensive equipment. A railroad crossing signal or a navigation beacon for aircraft would be examples of critical loads. A residential system and most water pumping systems would not.

Do not specify 99+ percent availability unless you are ready to pay the price.



In summary, the system designer should understand the relationship between cost and availability. Experience shows that PV system customers have a tendency to over-specify the requirements and thereby drive the initial system cost unreasonably high. They should keep in mind that no energy producing system is available 100 percent of the time. Utilities obtain high system availability by using multiple and redundant power sources. There are few single generators, coal fired, nuclear, or hydropower, that achieve 90 percent availabilities. Many PV systems exceed this figure even when component reliability, maintenance, and solar variability are accounted for.

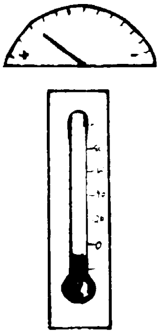
MAINTENANCE

Any battery requires periodic maintenance; even sealed "maintenance-free" batteries should be checked to make sure connections are tight and the cases are clean and intact. For flooded batteries, the electrolyte level should be kept above the plates, and the voltage and specific gravity of the cells should be checked for consistent values. Variations between cells of 0.05 volts/cell or 0.05 points of specific gravity may indicate problems with the battery. The specific gravity of the cells should be checked with a hydrometer with the SOC of the battery about 75 percent.

Most manufacturers of flooded batteries recommend overcharging their batteries every few months to reduce stratification of the electrolyte. This may occur if the battery operates in the same regime, say 60-90 percent state of charge, for a long period. This equalization charge, 30-60 minutes long, thoroughly mixes the electrolyte. It is usually done with a generator but can be done with a PV array if the controller and load are disconnected. Ask the battery manufacturer for recommendations on equalization charges.

In cold environments, the electrolyte in lead-acid batteries may freeze. The freezing temperature is a function of the battery's state of charge. When a battery is completely discharged, the electrolyte is nearly water and the battery may freeze at a few degrees below 0°C. However, a fully charged battery will have a specific gravity of about 1.24 and could withstand temperatures as low as minus 50°C. In cold climates, batteries are often buried below the frost line in an insulated battery box to maintain a constant temperature. Nickel cadmium batteries will not be damaged by cold weather.

The temperature at which a battery will freeze depends on its state of charge.



TYPES

Many terms are used to describe batteries.

You should be familiar with commonly used terms such as deep-cycle or shallow-cycle, gelled or captive electrolyte, liquid electrolyte, and sealed or flooded. Deep-cycle batteries are made with larger plates and are rated to withstand a specified number of charge/discharge cycles. The number of cycles depends on the depth of discharge, the rates of discharge, the length of time before recharge, and the recharge rate, among other things. Shallow-cycle batteries use lighter plates and cannot be cycled as many times as the deep-cycle batteries. Completely discharging them once or twice will often ruin them. For this reason, they should not be used in some PV systems. Some batteries have captive electrolyte. One of the most common ways of constraining electrolyte is the gel-cell battery. The captive electrolyte battery is easy to maintain because it is usually sealed and there is no possibility of spillage should the battery be tipped. Most sealed batteries are actually valve regulated and permit the release of hydrogen gas but do not allow electrolyte to be added. They may be rated as deep-cycle batteries but they will usually withstand fewer cycles than the industrial-grade flooded batteries. Batteries with liquid electrolyte may be sealed or have caps where distilled water may be added to the electrolyte. Usually if the capacity is greater than about 100 ampere-hours, the batteries are open. Electrolyte can (and should) be added regularly to flooded batteries,

The batteries used in stand-alone photovoltaic systems should be deep-cycle heavy-duty types. These batteries may be available with either liquid electrolyte (flooded or sealed) or captive electrolyte (gel cells). Because lead is a soft metal, other elements such as antimony or calcium are often added to strengthen the lead plates and customize the characteristics of the batteries. The lead-antimony battery will withstand deeper discharge cycles but require regular maintenance because they have higher water consumption, Lead-calcium batteries can be used for applications in which few deep discharges are anticipated. Their initial cost is less, but the lifetime is shorter than for the lead-antimony batteries.

Nickel cadmium batteries are available in some countries. They usually cost more than lead-acid batteries. Some advantages of the nickel cadmium batteries, include their long-life expectancy, low maintenance requirements, durability, their ability to withstand extreme hot or cold temperatures, and their tolerance to complete discharge. Because of this tolerance, the controller can be eliminated in some applications. A design note: if a controller is to be used with NiCd batteries, the controller supplier should be told. Commonly available controllers are designed to work with lead-acid batteries and the charging regimen is different for NiCd batteries. The controllers are not interchangeable.

NiCd batteries can be discharged and recharged many times.

Nickel cadmium batteries are more expensive but offer many advantages.

HAZARDS

Most batteries contain acid or caustic materials that are harmful or fatal if mishandled. Also, open batteries with caps produce explosive hydrogen gas when charging. These batteries must be located in a well-ventilated area. Other electric system components should not be installed in the battery compartment since sparking could ignite the gases. Also, the gases from lead-acid batteries are corrosive and may damage electrical components. Recombiners or catalytic converter cell caps that capture the vented hydrogen gas, recombine it with oxygen, and return the liquid water to the battery electrolyte are available. These caps have a life expectancy of three to five years, but they must be checked and cleaned periodically to ensure proper operation.

Use care when working with batteries.

Batteries produce explosive gas when charged--keep them in a well ventilated place.

Any battery should be considered dangerous, particularly to children and animals. Access should be limited to experienced persons. Keep the terminals covered--a typical battery used in a PV system can produce over 6,000 amperes if the terminals are shorted. Although this high current will last only a few milliseconds, it is enough to arc weld a tool to the terminals. The higher the voltage the more the hazard. Above 24 volts a shock hazard exists that can be fatal in worst-case conditions. Even at 12 volts, the high current can cause burns if the battery is inadvertently shorted. Use insulated tools and wear protective gloves, footwear, and goggles when working around batteries. Finally, remember batteries are heavy. Use your legs--not your back when lifting and moving the batteries.

SELECTION AND BUYING

In some countries there are many types of batteries available and the variation in manufacturers specifications make it difficult to compare performance characteristics. In other countries, the battery selection may be limited to batteries for automotive uses. In these cases, try to get a battery designed for trucks or heavy equipment. These are usually heavier and should give better performance in a PV system. The best advice is to talk to people who have used batteries in similar applications and conditions. If you cannot find such people, prepare a list of questions for your battery supplier. See the dialog of the Brown Family for some sample questions.

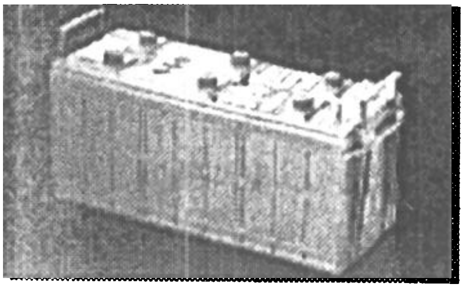
THE BROWN FAMILY SELECTS A BATTERY

The Browns had to choose the number of days of storage and select the batteries they were going to use. Like many others, the Browns knew little about what characteristics were important for PV system batteries. They obtained specification sheets from several battery manufacturers and found there was no commonly accepted method of presenting performance data. They also found the wide range of prices confusing. In many instances it was difficult to find a correlation between features and price. Their first visit to a battery dealer was not helpful. Even though the dealer had advertised as a solar supplier, they found he had not sold any batteries for PV systems. However, their visit did allow them to come up with a set of questions they would ask each dealer they contacted.

	BROWNS		**SELLER**
Q	Do you sell batteries for photovoltaic systems?	A	For what?
Q	PV systems—solar electric systems.	A	Oh yes, our company has a solar battery.
Q	Have you sold any batteries locally for PV systems?	A	No, but I will call the company and ask how many have been installed.
Q	What kind of battery is it?	A	Lead calcium.
Q	What is the rated capacity?	A	The 12-volt battery has 105 ampere-hours.
Q	At what hourly rate?	A	10 hours.
Q	At what temperature?	A	Room temperature.
Q	Is the battery sealed?	A	Yes, it is a no maintenance battery.
Q	What's the maximum depth of discharge?	A	No more than 20 percent.
Q	OK, if we keep the state of charge greater than 80 percent, what lifetime can we expect?	A	I don't like to discuss battery lifetime, because I don't know how the battery will be used.
Q	Five years? Ten years?	A	It should last more than five years—if you're careful.
Q	How much does it weigh?	A	44 pounds.
Q	How much does the battery cost?	A	$100 for one unit.
Q	That's about $1 per rated ampere-hour. Is there a discount if I buy ten batteries?	A	I will make you a good deal.
Q	Thanks, we will get back to you after we have talked to some of your competitors.	A	Take this brochure—it gives a description of the battery.

The Browns generated the list shown. They knew the batteries were a key subsystem. They wanted to buy the best batteries available. They wanted to check out nickel cadmium batteries because of their long life and ability to handle deep discharges. They found some NiCd batteries listed in a catalog but the cost was about 4 times higher than the lead-acid batteries available locally. After considering cost, size, availability, and local service, they decided to use flooded deep-cycle batteries. They knew they would be available to do preventive maintenance and add water as needed. Their local dealer recommended a controller that had been used with their type of battery before. He suggested they limit the depth of discharge to 50 percent to extend the life of the battery. They thought this would allow them to keep the batteries operating for over 8 years. They continued their design assuming three days of storage, and a maximum allowable discharge of 50 percent.

QUESTIONS	MANUFACTURER 1	MANUFACTURER 2	MANUFACTURER 3
Type of Plates?			
Type of Electrolyte?			
Open or Sealed?			
Rated Capacity?			
Allowable Depth of Discharge?			
Number of Cycles?			
Equalization Charge Required?			
Allowable Temperature Range?			
Temperature Derate?			
Cost?			
Size?			
Weight?			
Expected Life?			
$/Ampere-Hour?			
$/kg?			
Shipping Charges?			
Salvage Value?			

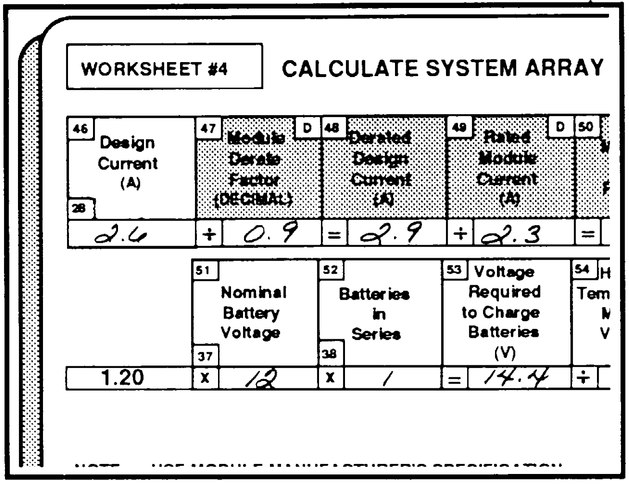


PHOTOVOLTAIC ARRAYS

How many modules do I need? *How do I compare module performance?* *How should I install the modules?*

SIZING

Completion of Worksheet 4, a portion of which is shown in the inset, will determine the size of the PV array for your system. This sizing technique is designed to generate enough energy during the design month to meet the load and cover all losses in the system. This means that in an average year the load will be met and the battery state-of-charge will be the same on the last day of the design month as on the first day.



WORKSHEET #4	CALCULATE SYSTEM ARRAY

46 Design Current (A) 28		47 Module Derate Factor (DECIMAL) D		48 Derated Design Current (A)		49 Rated Module Current (A) D		50
2.6	÷	0.9	=	2.9	÷	2.3	=	

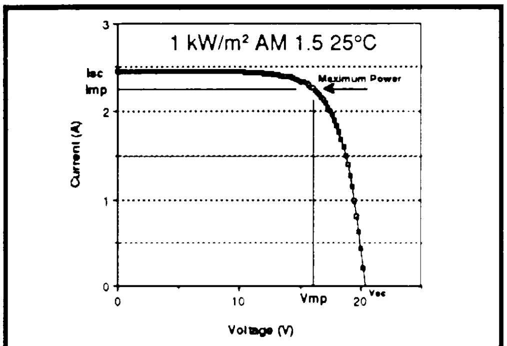
		51 Nominal Battery Voltage 37		52 Batteries in Series 38		53 Voltage Required to Charge Batteries (V)		54
1.20	x	12	x	1	=	14.4	÷	

The design method uses current (amperes) instead of power (watts) to describe the load requirement because it is easier to make a meaningful comparison of PV module performance, i.e., ask for PV modules that will produce 30 amperes at 12 volts and a specified operating temperature rather than try to compare 50 watt modules that may have different operating points. You should obtain module specifications for available modules so you can compare performance, physical size, and cost. Generally, there are several modules that will meet a given set of requirements.

Consult several module manufacturers and distributors.

In a PV system with batteries, the modules seldom operate at their peak power point.

The worksheet requests the entry of rated module current. This is the current produced at standard test conditions (STC) of 1,000 w/m² irradiance and 25°C temperature. The module specifications given by one module manufacturer are shown in Figure 9. The current values given are at short circuit, I_{SC}, and at the peak power point, I_{mp} The value used in the worksheet for rated module current should be I_{mp}. The voltage at the peak power point is stated as 16 volts. However, the operating voltage of a PV array is determined by the battery voltage. This varies over a narrow range depending on the battery state-of-charge and ambient temperature but is usually 1 to 4 volts

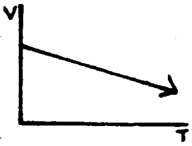


Short Circuit Current, I_{sc}	2.44 A
Open Circuit Voltage, V_{oc}	20.1 V
Current at Peak Power Point, I_{mp}	2.2 A
Voltage at Peak Power Point, V_{mp}	16 V
Power	35.2 W

Figure 9. PV Module Specifications.

lower than the voltage at which peak power figures are quoted by module manufacturers. Fortunately, the current changes little from the peak power voltage (17 volts) to normal system operating voltages (12 volts).

For crystalline silicon modules, the operating voltage will decrease about one-half of one percent for each degree centigrade rise in temperature. The module described in Figure 9 has a peak power voltage of 16 volts at 25°C. If this module operates at 50°C in a specific application, the peak power voltage would drop to about 14 volts. This is still adequate for use in a nominal 12-volt battery system, but the designer must make sure the current supplied by the module is adequate under the hottest expected conditions. Also, if a blocking diode is used between the module and the battery, this will cause a voltage drop of about 0.7 volts. The module must be able to sustain this drop plus any voltage drop caused by the wires and still supply enough voltage to fully charge the battery. The module parameters at standard test conditions and at the highest expected temperatures should be recorded in the space provided on the worksheet.



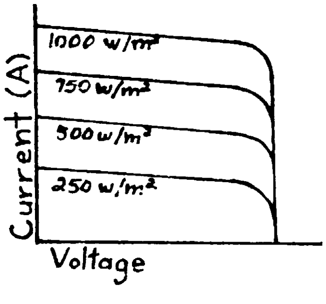
Voltage of a PV module decreases 0.5 percent per degree centigrade increase in operating temperature.

The number of parallel-connected modules required to produce the design current is rarely a whole number. Obviously, the designer must make a decision whether to round up or round down. The system availability requirements should be considered when making this decision. Since the design presented here is intended to just meet the load during the design month of an average year, the conservative approach is to round up to the nearest whole module.

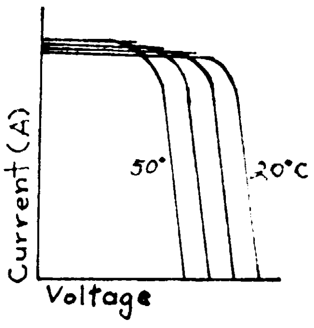
The number of series-connected modules is calculated by dividing the system voltage by the nominal module voltage--12 volt modules are commonly used for stand-alone PV systems.

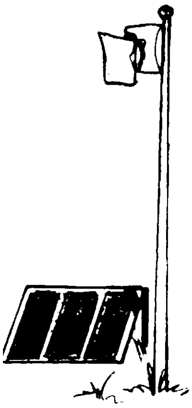
CHARACTERISTICS

A photovoltaic array consists of two or more PV modules connected to obtain a desired voltage and current. A photovoltaic module is an encapsulated group of solar cells and is the least replaceable unit in the array. The majority of PV modules are manufactured using single crystal or polycrystalline silicon cells. These cells are embedded in a laminate, usually with a tempered-glass front plate and a soft pliable covering to seal the back.



There are four factors that determine any photovoltaic module’s output--load resistance, solar irradiance, cell temperature, and efficiency of the photovoltaic cells. Theoutput of a given module can be estimated by studying a family of current and voltage (I-V) curves like those shown in the center column. Three significant points of interest on the I-V curve are the maximum power point, the open-circuit voltage, and the short circuit current. For a given solar cell area, the current is directly proportional to solar irradiance (S) and is almost independent of temperature (T). Voltage and power decrease as temperature increases. The voltage of crystalline cells decreases about 0.5 percent per degree centigrade temperature increase. Therefore, arrays should be kept cool and mounted so air is not restricted from moving over and behind the array. Do not mount modules flush on a roof or support structure. Testing results show that modules mounted 3 inches above a roof will operate up to 15°C cooler than a directly mounted array -- a difference of 7.5 percent in power. See the installation section for details on mounting PV arrays.





Shading of a single cell can lower the array's power significantly.

No part of a PV array can be shaded. Unlike solar thermal collectors, the shading of small portions of a PV module may greatly reduce output from the entire array. PV modules connected in series must carry the same current. If some of the PV cells are shaded, they cannot produce current and will become reverse biased. This means the shaded cells will dissipate power as heat, and over a period of time failure will occur. However, since it is impossible to prevent occasional shading, the use of bypass diodes around series-connected modules is recommended. You do not need bypass diodes if all the modules are in parallel, i.e., a 12-volt array using 12-volt modules and many designers do not use them on 24-volt arrays. However for array voltages higher than 24 volts, bypass diodes should be used around each module to provide an alternative current path in case of shading. Figure 10 shows the use of bypass diodes on a 48-volt series string. Note the bypass diodes are reverse biased if all modules are operating properly. Many module manufacturers will provide modules with the bypass diodes integrated into the module junction box. If you need to connect modules in series, ask the supplier for this feature. Using bypass diodes may postpone failure, but it does not prevent the loss of energy production from the shading. It is important to check for potential shading before installing the PV array. Consider the seasonal changes in foliage and sun angle. After installation, the area must be maintained to prevent weeds or tree branches from shading the array.

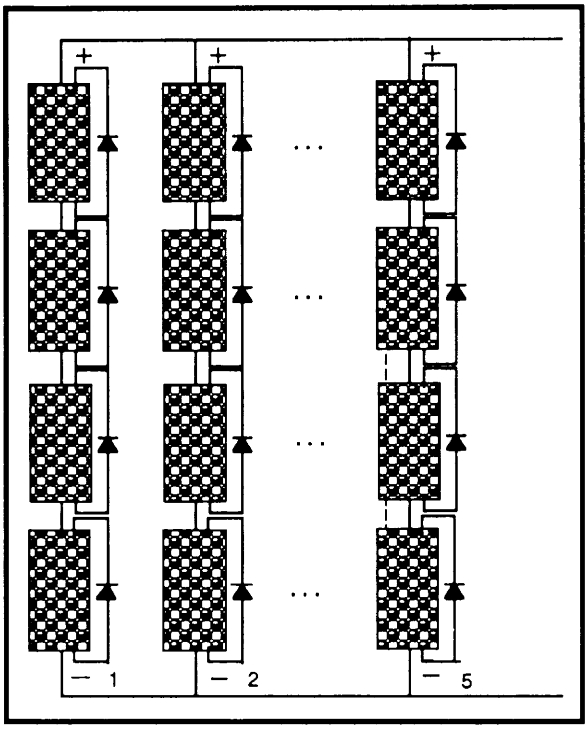


Figure 10. Series String with Bypass Diodes.

PV arrays include panels and source circuits. A panel is a group of PV modules packaged in a single name. Each panel should be sized for easy handling and mounting. A source circuit, sometimes called a string, may include any number of PV modules and panels connected in series to produce the system voltage.

All PV modules should have durable connectors on the module. The connectors should be sturdy, and the method of attaching the wire should be simple, yet provide a secure connection. Most modules have sealed junction boxes to protect the connections. Field testing experience shows that PV cells and connections between cells within the module laminate rarely fail. Most problems occur in the module junction box where the interconnections between modules are made. These can often be repaired in the field without replacing the module. Before buying a PV module, look at the junction box and see if it is easy to make the connections. Are the terminals rugged and is there a place to connect bypass diodes? Is the junction box of good quality?

Blocking diodes are used to control current flow within a PV system. Any stand-alone PV system should have a method to prevent reverse current flow from the battery to the array and/or to protect weak or failed strings. Individual blocking diodes are sometimes used for this purpose if the controller used does not contain this feature. Figure 11 shows the location of blocking diodes that can be installed in each parallel-connected string or in the main wire connecting the array to the controller. When multiple strings are connected in parallel, as in larger systems, it is recommended that blocking diodes be used in each string as shown on the left to prevent current flow from strong strings into weak strings (due to failures or shading). In small systems, a single diode in the main connection wire is sufficient. Do not use both. The voltage drop across each diode, 0.4-0.7 volt, represents about a 6 percent drop in a 12-volt system.

Blocking diodes are used to prevent unwanted current flow.

Fuses and switches are used to protect wires, equipment, and people.

A switch or circuit breaker should be installed to isolate the PV array during maintenance. This same recommendation applies to the battery circuit so another switch or circuit breaker is required. Also circuit breakers are normally installed to isolate each load. Fuses are used to protect any current carrying conductor. Fuses and cables in the array circuit should be sized to carry the maximum

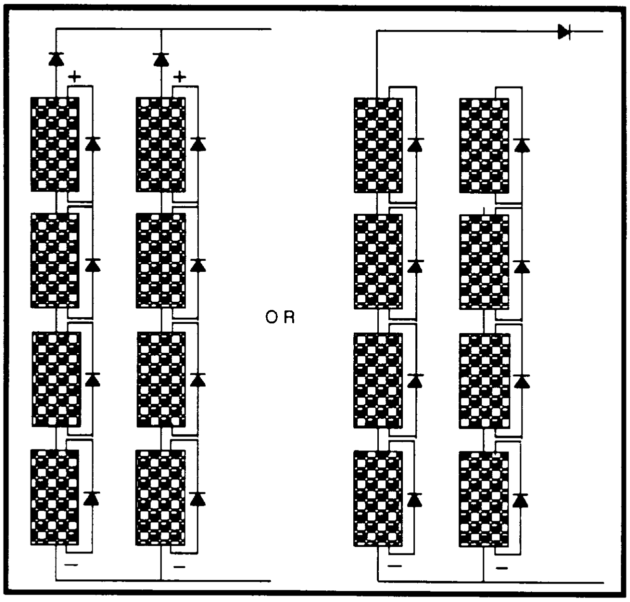
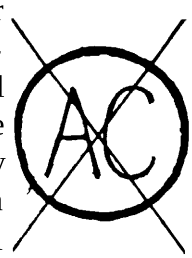


Figure 11. 48-Volt Array Showing Use of Blocking Diodes.

current that could be produced by short-term “cloud focusing” of the sunlight--up to 1.5 times the short circuit current at 1,000 w/m^2 irradiance. Slow-blow fuses are recommended. Only fuses rated for dc current should be used. (Automotive fuses should not be used.) All metal in a PV array should be grounded to help protect the array against lightning surges, and as an added safety feature for personnel working on the system. The negative conductor on most PV systems is also grounded to the same grounding electrode used for the equipment ground. Other disconnect and grounding requirements are given in the National Electrical Code® (NEC). This code is intended to ensure that safe, durable PV systems are installed.

Use only dc rated components.



ORIENTATION

A photovoltaic array can be mounted at a fixed angle from the horizontal or on a sun-tracking mechanism. The preferred azimuth for arrays in the northern hemisphere is true south. The decrease in energy production for off-south arrays roughly follows a cosine function, so if the azimuth of the array is kept to ±20° of true south, annual energy production is not reduced significantly. Some arrays are sited west of south to skew the production toward an afternoon peak load demand. The effect of array tilt angle on annual energy production is shown in Figure 12. For most locations, a tilt angle near the latitude angle will provide the most energy over a full year. Tilt angles of latitude ±15° will skew energy production toward winter or summer, respectively.

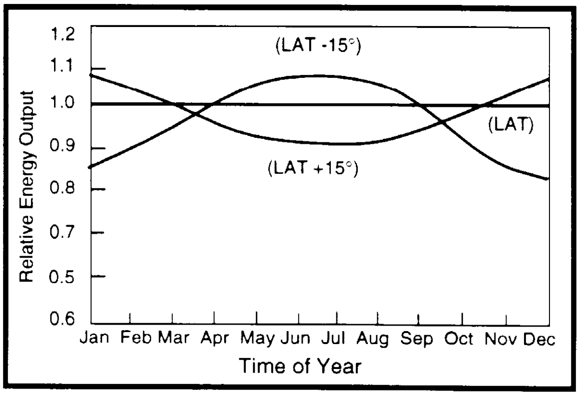
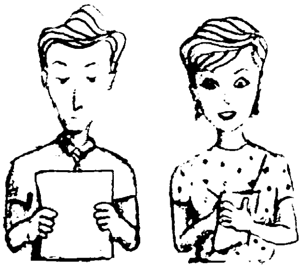


Figure 12. Effect of Array Tilt Angle on Annual Energy Production.

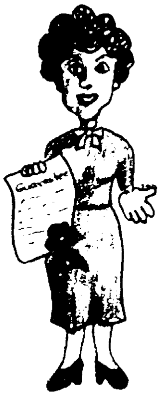
THE BROWN FAMILY SELECTS THEIR PV MODULES

The Browns obtained performance data for two different crystalline silicon modules. They completed Worksheet 4 and selected a candidate module that would meet their requirements. Because they considered their load noncritical, they rounded down the number of modules from 13.5 to 12 modules. Using a rule of thumb that the array might be 20°C warmer than the peak ambient temperature, they thought their array would reach about 55°C on the hottest day. They made sure that the voltage of the module would be greater than 14.5 V when it was operating at 55°C. This would give them enough voltage to fully charge the battery. They intended to use a controller that would give them reverse current protection so they did not have to allow for blocking diode voltage drop.



Before they made their final decision they carefully inspected the module junction boxes. They wanted an easy-to-make connection, but they also wanted a rugged connection that would last more than 20 years. When they were satisfied, they bought modules from the local dealer.

The Browns planned to configure their array with six parallel strings of two series connected modules (6P X 2S). With this configuration, they would not use bypass diodes across the modules. They asked about array mounting structures, and their dealer was able to supply some that were tailored to the mechanical and electrical characteristics of the modules. They were less expensive than any the Browns could make themselves so they ordered all the hardware they needed to do a ground mount of their PV array. They used cables to anchor the array frames so they would withstand the winds in their area.



They asked the dealer how they could tell if the array was performing as specified without installing a great deal of expensive instrumentation. He suggested installing only an ammeter and told them to expect greater than 80 percent of the module rating at noon on a clear day. The Browns calculated that this meant their array should produce over 15 amps on the meter. If it dropped below this value consistently, they would look for problems. The modules had a warranty and would be replaced in the first 10 years at no cost if they failed.

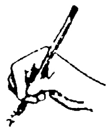
With their major purchases made, the Browns were ready to install their system. They studied the local electrical codes on wiring, grounding, and disconnecting power sources. They talked to a local electrical supply store and asked for recommendations on wire type and installation techniques. They visited their site and marked the location for the array and the wire runs to the control center. They were excited and anxious to get their system operating.

HYBRID INDICATOR

When should I consider using a generator with my PV system?

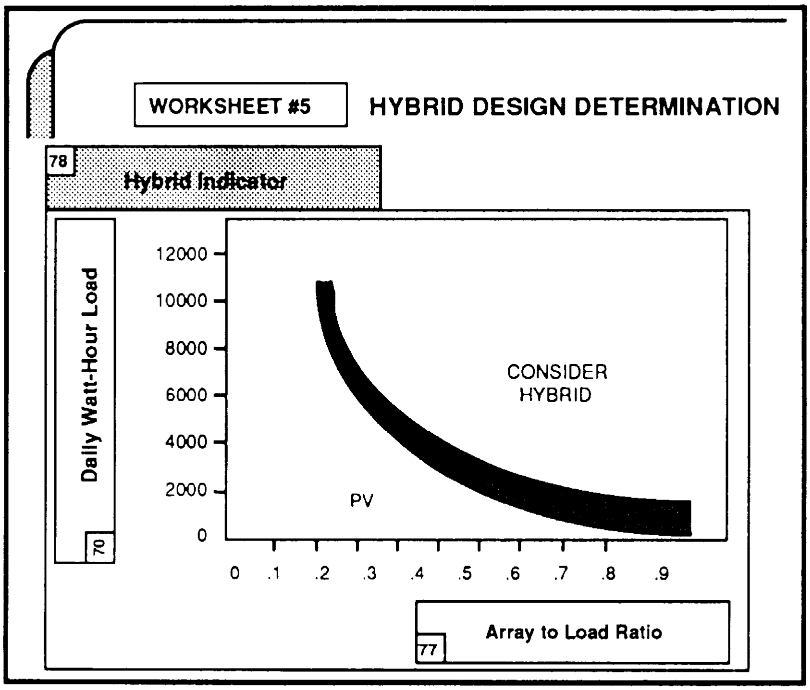
ARRAY TO LOAD RATIO

At this point, the basic PV system configuration and size have been determined. Before proceeding to specify components for the system, a simple test is recommended to see if the application might be a candidate for a hybrid system. Two main indicators work together to alert the designer to a possible hybrid application; the size of the load, and the seasonal insolation variability at the site. These two factors have been combined into the graph on Worksheet 5 (see inset below), which plots the daily load in watt-hours versus the array/load ratio. The larger the load the more likely a hybrid PV-generator system will be a good economic choice. Likewise, in cloudy climates you need a larger system to meet the load demand; thus having a higher array/load ratio. Plotting the load versus the array/load ratio gives an indication of whether a hybrid system should be considered. If the point falls in or above the gray area, then sizing a hybrid system is recommended so that cost comparisons with the PV-only design can be made.



Calculate the array-to-load ratio and check the hybrid indicator graph.

There may be other reasons to consider a hybrid system. For example, systems with high availability requirements, or applications where the load energy is being provided by an existing generator. Request a copy of the booklet *"Hybrid Power Systems--Issues and Answers"* from Sandia for more information on hybrid systems. The worksheets for hybrid systems, provided in Appendix B, can be used to size a PV/generator hybrid system if one is desired. A word of caution--the controls required for a hybrid system are more complex because the interaction between engine generator, PV array, and battery must be regulated. Obtaining advice from an experienced designer is recommended if you decide to install a hybrid system.

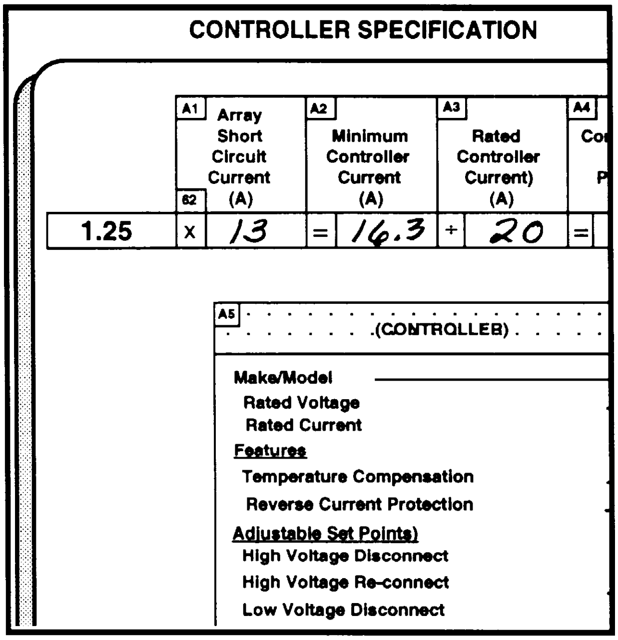


CONTROLLERS

Do I need a controller?	*What features are required?*	*Where should it be installed?*

SPECIFICATION

Charge controllers are included in most photovoltaic systems to protect the batteries from overcharge or excessive discharge. Overcharging can boil the electrolyte from the battery and cause failure. Allowing the battery to be discharged too much will cause premature battery failure and possible damage to the load. The controller is a critical component in your PV system. Thousands of dollars of damage may occur if it does not function properly. In addition, all controllers cause some losses (tare loss) in the system. One minus these losses, expressed as a percentage, is the controller efficiency.



CONTROLLER SPECIFICATION

		A1 Array Short Circuit Current (A)		A2 Minimum Controller Current (A)		A3 Rated Controller Current) (A)		A4 Co P
		62						
1.25	x	13	=	16.3	÷	20	=	

A5 . . . .(CONTROLLER) . . . . .

Make/Model
Rated Voltage
Rated Current
Features
Temperature Compensation
Reverse Current Protection
Adjustable Set Points)
High Voltage Disconnect
High Voltage Re-connect
Low Voltage Disconnect

Keep it simple—added features lower reliability.

A controller's function is to control the system depending on the battery state-of-charge (SOC). When the battery nears full SOC the controller redirects or switches off all or part of the array current. When the battery is discharged below a preset level, some or all of the load is disconnected if the controller includes the low voltage disconnect (LVD) capability. Most controllers use a measurement of battery voltage to estimate the state-of-charge. However, this does not give a precise indication because, as shown in Figure 13 on the next page, the voltage changes little until the battery nears the extremes of SOC. Battery temperature, age, type, and rate of charge/discharge also affect this curve. Measuring battery temperature improves the SOC estimate and many controllers have a temperature probe for this purpose. These compensated controllers are recommended if the battery temperature is expected to vary more than ±5°C from ambient.

Determining battery state of charge under all conditions is virtually impossible, but battery voltage is a commonly used indicator.

There are two voltage thresholds or activation setpoints, at which the controller will take action to protect the battery. Each threshold has a complementary-action setpoint. For instance, the array disconnect voltage is usually set near 14 volts for a nominal 12-volt battery. When the array is disconnected, the battery voltage will drop immediately to about 13 volts. The array re-connect voltage is usually set near 12.8 volts.

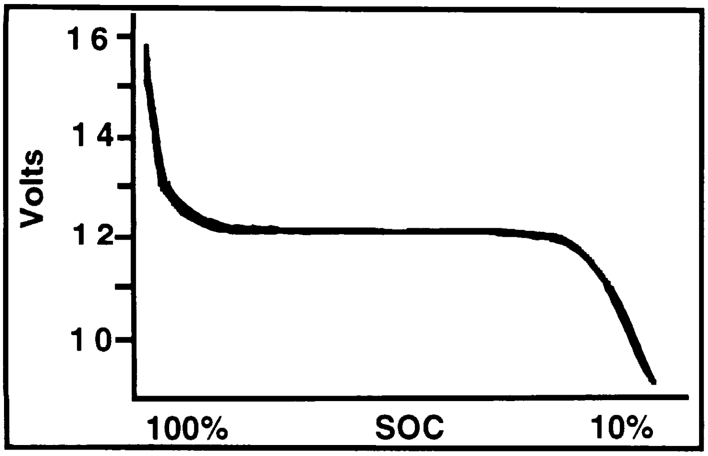


Figure 13. Typical Battery State-of-Charge Curve.

Similarly, when the voltage reaches about 11.5 the load is disconnected and not re-connected until the voltage reaches about 12.4 volts. On some controllers these connect/disconnect voltages may be adjusted in the field. This is a good feature if you have ready access to your system and can monitor battery performance. Otherwise, ask your battery manufacturer what controllers have been used successfully with your type of batteries.

A worksheet to help you specify a controller for your system is given in Appendix B. The controller voltage must be compatible with the nominal system voltage and it must be capable of handling the maximum current produced by the PV array. Multiply the array short-circuit current by at least 1.25 to allow for short periods of high irradiance produced by momentary cloud enhancement. (The document *Stand-Alone Photovoltaic Systems and the National Electrical Code* presents an argument for a conservative 1.56 multiplier.) This maximum current value and the system voltage are the minimum information needed to order a controller. Other features to specify are

- Efficiency (tare loss),
- Temperature compensation,
- Reverse current protection,
- Display meters or status lights
- Adjustable setpoints,
  - High voltage disconnect
  - High voltage re-connect
  - Low voltage disconnect
  - Low voltage re-connect
- Low voltage warning,
- Maximum power tracking

Reverse current protection is the prevention of current flow through the controller from the batteries to the PV array at night. Most controllers include a blocking diode or other mechanism that prevents this unwanted current. Also, most small controllers include built-in LVD capability to switch off the loads, activate lights or buzzers to alert users that action is required, or turn on a standby power supply.

The cost of the controller increases rapidly as the current requirement increases. Controllers for 12-volt and 24-volt systems with currents up to 30 amperes are available at a reasonable cost. Controllers with 30-100 amperes are available but 2-5 times more expensive. Controllers that will switch currents over 100 amperes are usually custom designed for the application. One way to work with currents over 100 amperes is to connect controllers in parallel. It is often less expensive to use five 20-ampere rated controllers in parallel than one 100-ampere unit. However, the array must be electrically divided and each controller wired separately with the controller outputs recombined before connecting to the battery. The activation levels of individual controllers will be slightly different but this presents no problem. All possible array current will be used to charge the batteries until the lowest activation voltage is reached; one controller will then shut off and the other controller(s) will allow current passage until the battery voltage exceeds their threshold.

TYPE

There are two basic types of controllers used for small PV systems. A shunt controller redirects or shunts the charging current away from the battery. These controllers require a large heat sink to dissipate the excess current. Most shunt controllers are designed for smaller systems producing 30 amperes or less. A series controller interrupts the charging current by open-circuiting the PV array. This switching controller is thus limited by the current handling capability of the components used to switch the dc current. There are many variations of both series and shunt controllers. Both types can be designed as single-stage or multistage. Single-stage controllers disconnect the array when the battery voltage reaches the high voltage level. Multistage controllers allow different charging currents as the battery nears full state-of-charge. This technique also provides a more efficient method of charging the battery. As the battery nears full SOC, its internal resistance increases and using a lower charging current wastes less energy. As the size and complexity of the system increase, the need for expert advice on controllers becomes greater. Check with your battery supplier about charge controllers and what features they should have. Most solar system dealers sell both batteries and charge controllers and will have determined the ones that work best together.

More systems have had problems caused by a poor control scheme than any other cause.

INSTALLATION

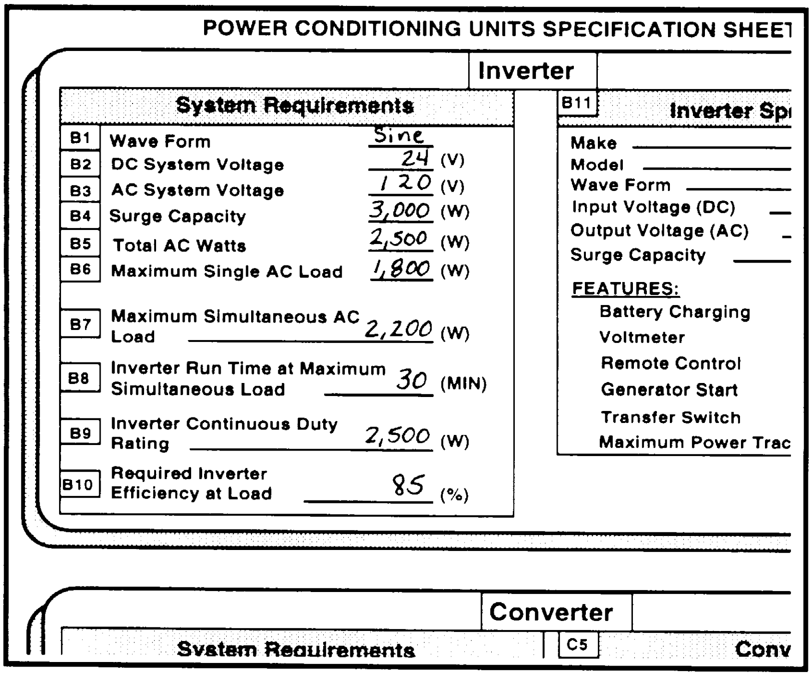
The controller must be installed in a weather resistant junction box and can be located with other components such as diodes, fuses, and switches. Excessive heat will shorten controller lifetime so the junction box should be installed in a shaded area and venting provided if possible. Controllers should not be mounted in the same enclosure with batteries. The batteries produce a corrosive environment that may cause failure of electronic components.

INVERTERS

What features do I need? | *Do I need a sine wave output?* | *Where should the PCS be installed?*

SPECIFICATIONS

Power conditioning units, commonly called inverters, are necessary in any stand-alone PV system with ac loads. The choice of inverter will be a key factor in setting the dc operating voltage of your system. When specifying an inverter, it is necessary to consider requirements of both the dc input and the ac output. All requirements that the ac load will place on the inverter should be considered--not only how much power but what variation in voltage, frequency, and waveform can be tolerated. On the input side, the dc voltage, surge capacity, and acceptable voltage variation must be specified. Selecting "the best inverter" for your application requires a study of many parameters listed by various inverter manufacturers. Some parameters are listed on the specification sheet provided, a portion of which is shown in the inset. This sheet, located in Appendix B, also includes the specification for a dc to dc converter if one is needed to supply dc loads operating at different voltages.



POWER CONDITIONING UNITS SPECIFICATION SHEET

Inverter

System Requirements

B1	Wave Form	Sine	
B2	DC System Voltage	24	(V)
B3	AC System Voltage	120	(V)
B4	Surge Capacity	3,000	(W)
B5	Total AC Watts	2,500	(W)
B6	Maximum Single AC Load	1,800	(W)
B7	Maximum Simultaneous AC Load	2,200	(W)
B8	Inverter Run Time at Maximum Simultaneous Load	30	(MIN)
B9	Inverter Continuous Duty Rating	2,500	(W)
B10	Required Inverter Efficiency at Load	85	(%)

B11 **Inverter Sp**

Make ______

Model ______

Wave Form ______

Input Voltage (DC) __

Output Voltage (AC) _

Surge Capacity ______

FEATURES:

Battery Charging

Voltmeter

Remote Control

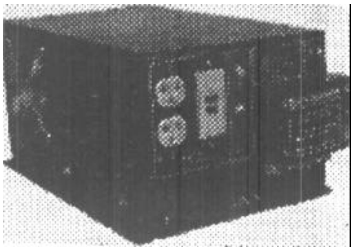
Generator Start

Transfer Switch

Maximum Power Trac

Converter

System Requirements C5 **Conv**



The choice of inverter will affect the performance, reliability, and cost of your PV system. Usually, it is the third most expensive component after the array and battery. Fortunately in 1994, there is a good selection of inverters for stand-alone PV systems in the United States. Characteristics that should be considered are

- output waveform,
- power conversion efficiency,
- rated power,
- duty rating,
- input voltage,
- voltage regulation,
- voltage protection,
- frequency,
- modularity,
- power factor,
- idle current,
- size and weight,
- audio and RF noise,
- meters and switches.

Added features available with some inverters are

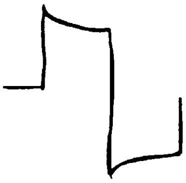
- battery charging capability,
- remote control operation,
- load transfer switch,
- capability for parallel operation.

CHARACTERISTICS

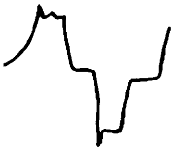
Stand-alone inverters typically operate at 12, 24, 48 or 120 volts dc input and create 120 or 240 volts ac at 50 or 60 hertz. The selection of the inverter input voltage is an important decision because it often dictates the system dc voltage; see the discussion of system voltage selection on page 12.

The shape of the output waveform is an important parameter. Inverters are often categorized according to the type of waveform produced; 1) square wave, 2) modified sine wave, and 3) sine wave. The output waveform depends on the conversion method and the filtering used on the output waveform to eliminate spikes and unwanted frequencies that result when the switching occurs.

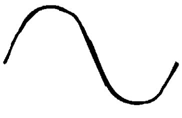
Square wave inverters are relatively inexpensive, have efficiencies above 90 percent, high harmonic frequency content, and little output voltage regulation. They are suitable for resistive loads and incandescent lamps. Modified sine wave inverters offer improved voltage regulation by varying the duration of the pulse width in their output. Efficiencies can reach 90 percent. This type of inverter can be used to operate a wider variety of loads including lights, electronic equipment, and most motors. However, these inverters will not operate a motor as efficiently as a sine wave inverter because the energy in the additional harmonics is dissipated in the motor windings. Sine wave inverters produce an ac waveform as good as that from most electric utilities. They can operate any ac appliance or motor within their power rating. In general, any inverter should be oversized 25 percent or more to increase reliability and lifetime. This also allows for modest growth in load demand. The efficiency of all inverters is lowest for small load demand and reach their nominal efficiency (around 90 percent) when the load demand is greater than about 50 percent of rated load.



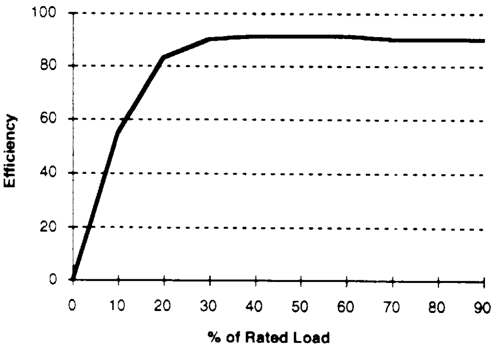
Square Wave



Modified Sine Wave



Sine Wave

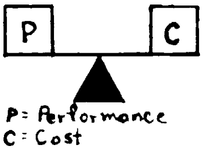


The manufacturers' specification sheets will list some of the following parameters.

Some appliances do not work with a square wave input.

- **Power Conversion Efficiency** - This value gives the ratio of output power to input power of the inverter. Efficiency of stand-alone inverters will vary significantly with the load. Values found in manufacturers' specifications are the maximum that can be expected.

- **Rated Power** - Rated power of the inverter. However, some units can not produce rated power continuously. See duty rating. Choose an inverter that will provide at least 125 percent of simultaneous peak load requirements (Block 11B, Worksheet 1) to allow for some growth in load demand.



- **Duty Rating** - This rating gives the amount of time the inverter can supply its rated power. Some inverters can operate at their rated power for only a short time without overheating. Exceeding this time may cause hardware failure.

The efficiency of inverters can be less than half of that claimed when they are used with certain loads.

- **Input Voltage** - This is determined by the total power required by the ac loads and the voltage of any dc loads. Generally, the larger the load, the higher the inverter input voltage. This keeps the current at levels where switches and other components are readily available.
- **Surge Capacity** - Most inverters can exceed their rated power for limited periods of time (seconds). Surge requirements of specific loads should be determined or measured. Some transformers and ac motors require starting currents several times their operating level for several seconds.
- **Standby Current** - This is the amount of current (power) used by the inverter when no load is active (power loss). This is an important parameter if the inverter will be left on for long periods of time to supply small loads. The inverter efficiency is lowest when load demand is low.
- **Voltage Regulation** - This indicates the variability in the output voltage. Better units will produce a nearly constant root-mean-square (RMS) output voltage for a wide range of loads.
- **Voltage Protection** - The inverter can be damaged if dc input voltage levels are exceeded. Remember, battery voltage can far exceed nominal if the battery is overcharged. A 12-volt battery may reach 16 volts or more and this could damage some inverters. Many inverters have sensing circuits that will disconnect the unit from the battery if specified voltage limits are exceeded.
- **Frequency** - Most loads in the United States require 60 Hz. High-quality equipment requires precise frequency regulation--variations can cause poor performance of clocks and electronic timers.
- **Modularity** - In some systems it is advantageous to use multiple inverters. These can be connected in parallel to service different loads.

Manual load switching is sometimes provided to allow one inverter to meet critical loads in case of failure. This added redundancy increases system reliability.

- Power Factor - The cosine of the angle between the current and voltage waveforms produced by the inverter is the power factor. For resistive loads, the power factor will be 1.0 but for inductive loads, the most common load in residential systems, the power factor will drop, sometimes as low as 0.5. Power factor is determined by the load, not the inverter.

INSTALLATION

An inverter should be installed in a controlled environment because high temperatures and excessive dust will reduce lifetime and may cause failure. The inverter should not be installed in the same enclosure with the batteries because the corrosive gassing of the batteries can damage the electronics and the switching in the inverter might cause an explosion. However, the inverter should be installed near the batteries to keep resistive losses in the wires to a minimum. After conversion to ac power, the wire size can be reduced because the ac voltage is usually higher than the dc voltage. This means the ac current is lower than the dc current for a equivalent power load. All wiring and installation procedures described in Article 300 of the National Electrical Code (NEC) should be followed.

Protect the inverter circuits with fuses on both input and output.

Both the input and output circuits of the inverter should be protected with fuses or circuit breakers. These safety devices should be accessible and clearly labelled. Using a surge protection device on the inverter input to protect against nearby lightning strikes is recommended for most areas. A component such as a movistor shunts surge current to ground. If a nearby lightning strike occurs, this may destroy the movistor, but its destruction might prevent expensive inverter repair bills.

THE BROWN FAMILY SELECT AN INVERTER

QUESTIONS ABOUT INVERTERS

- Power Factor?
- Waveform?
- Rated Efficiency?
- Duty Rating?
- Surge Capability?
- Voltage Protection?
- Input?
- Output?
- Safety Features?
- Operator Alarm?
- Meters?

The Brown Family chose a 2.5-kilowatt inverter that operated at 24 volts dc and provided 120 volts ac single-phase sine wave output. This unit was adequate for their 1,800 watt domestic household loads, but it would not be large enough to run their water pump and washing machine simultaneously. This problem was avoided by installing a water storage tank on the hill behind their house and using a gravity-feed system for their domestic water system. This water storage would give them independence for several cloudy days and they could use the inverter to run the pump and fill the tank at night or at times when other household demands were low. This allowed the single 2.5-kilowatt inverter to meet all their needs. Before buying the inverter, they visited the local distributor and asked for a demonstration using both resistive and motor loads such as an electric blender. Also, they wanted to hear the unit operating and to know how much current the inverter used when it was in standby. They were concerned about audible noise levels because they planned to put their inverter on the wall in Mr. Brown's workshop. They asked questions about the technical performance of inverters and also questioned the dealer about the service policy and the warranty on the unit.

INTERCONNECTING THE SYSTEM

Where should I put the switches and fuses?

How do I select the wire type and size?

Now that the major components have been sized and selected, it is time to consider how to interconnect everything as a working system. It is important to select wire, connectors, and protection components such as switches and fuses that will last for twenty years or more. To obtain this long life, they must be sized correctly, rated for the application, and installed carefully. Connections are particularly prone to failure unless they are made carefully and correctly. Obtain a quality crimp tool and ask an experienced electrician for advice on ways to make and protect long lasting connections. Remember the performance and reliability of the entire system depends on each connection.

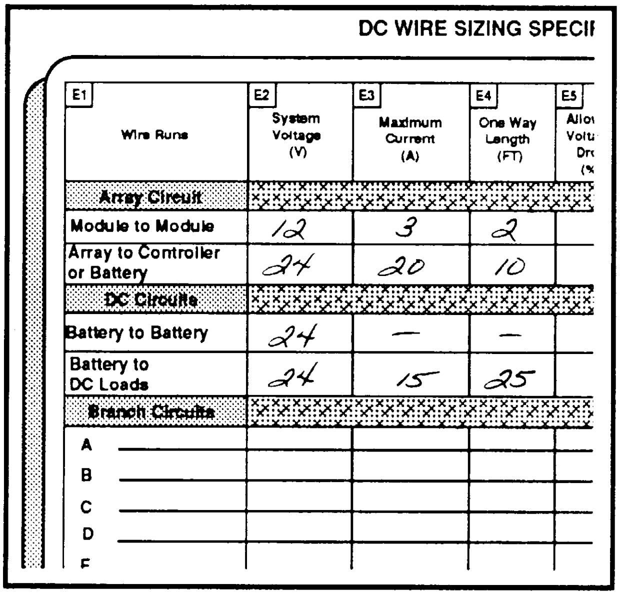
Use switches and fuses for safety of components and personnel.

Selecting wire for your application may seem confusing because there are so many types of wire and insulation available. However, only a few types are popular with PV system installers. In most cases you don't need special (and therefore expensive) wire. Talk to a local electrician or a wire supplier and describe how and where the wire will be used. Ask for recommendations.

WIRE TYPE AND SIZE

Consult Article 310 of the NEC for a discussion of wire types and sizes.

In the United States, the size of wire is categorized by the American Wire Gage (AWG) scale. The AWG scale rates wires from No. 18 (40 mil diameter) to No. 0000 (460 mil diameter). Multiple conductors are commonly enclosed in an insulated sheath for wires smaller than No. 8. The conductor may be solid or stranded. Stranded wire is easier to work with particularly for sizes larger than No. 8. Copper conductors are recommended. Aluminum wire is less expensive, but can cause problems if used incorrectly.* Many different materials are used to make the sheath that covers the conductors.



DC WIRE SIZING SPECI

E1 Wire Runs	E2 System Voltage (V)	E3 Maximum Current (A)	E4 One Way Length (FT)	E5 Allo Volt Dr (%
Array Circuit				
Module to Module	12	3	2	
Array to Controller or Battery	24	20	10	
DC Circuits				
Battery to Battery	24	—	—	
Battery to DC Loads	24	15	25	
Branch Circuits				
A				
B				
C				
D				
E				

---

* Aluminum is sometimes specified for applications requiring long wire runs, for instance, from array to controller. If aluminum is used, terminations must be made with connectors suitable for use with aluminum wire. These connectors will be stamped AL. Do not splice aluminum to copper wire.

You must select a wire with a covering that will withstand the worst-case conditions. It is mandatory that sunlight resistant wire be specified if the wire is to be exposed to the sun. If the wire is to be buried without conduit it must be rated for direct burial. For applications such as wiring to a submersible pump or for battery interconnections, ask the component dealer for recommendations. Often the dealer or manufacturer will supply appropriate wire and connectors.

Some wire types commonly used in the United States are listed below.

- **Underground Feeder (UF)** - may be used for interconnecting balance-of-systems (BOS) but not recommended for use within battery enclosures; single conductor UF wire may be used to interconnect modules in the array but this type of wire is not widely available.
- **Tray Cable (TC)** - multiconductor TC wire may be used for interconnecting BOS; TC has good resistance to sunlight but may not be marked as such.
- **Service Entrance (SE)** - may be used for interconnecting BOS
- **Underground Service Entrance (USE)** - may be used for interconnecting modules or BOS; may be used within battery enclosures,
- **THHN** - indicates wire with heat resistant thermoplastic sheathing; it may be used for interconnecting BOS but must be installed in conduit--either buried or above ground. It is resistant to moisture but should not be used in wet locations.
- **TW** - refers to moisture resistant thermoplastic sheathing; it may be used for interconnecting BOS but must be installed in conduit. May be used in wet locations.

Protect the wire from the sun if possible.

The use of NMB (Romex) is not recommended except for ac circuits as in typical residential wiring. Although commonly available, it will not withstand moisture or sunlight.

More useful information is contained in the NEC. It is recommended that any designer/installer review Article 300 before proceeding. This article contains a discussion of wiring methods and Table 310-13 gives the characteristics and recommended usage of different wire types. Table 310-16 gives temperature derate factors. Another useful reference available from the PVDAC at Sandia National Laboratories is *"Photovoltaic Power Systems and the National Electrical Code, Suggested Practices."*

Selecting the correct size and type of wire for the system will optimize performance and increase reliability. The size of the wire must be capable of carrying the current at the operating temperature without excessive losses. It is important to derate the current carrying capacity of the wire if high temperature operation is expected. A wire may be rated for high temperature installations (60-90°C) but this only means the insulation of the wire can withstand the rated temperature–it does not mean that ampacity is unaffected. The current carrying capability (ampacity) depends on the highest temperature to which the wires will be exposed when it is carrying the current. According to Table 310-16 in the NEC, a UF type wire operating at 55°C can safely carry only 40 percent of the current it can carry at 30°C–a significant derate. If the ampacity of the wire is exceeded, overheating, insulation break-down, and fires may occur. Properly sized fuses are used to protect the conductors and prevent this kind of damage.

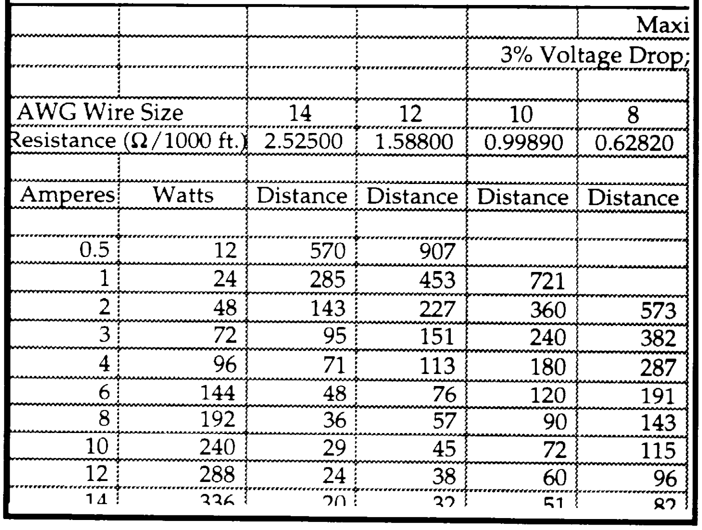
Loss in a dc circuit is equal to I^2R where I is the current and R is the resistance of the wire. For 100 ampere current this means 10,000 times the loss in the circuit. It is easy to see why resistance must be kept small. Also, the voltage drop in the circuit is equal to IR. Voltage drop can cause problems, particularly in low voltage systems. For a 12-volt system, a one volt drop amounts to over 8 percent of the source voltage. Avoid long wire runs or use larger wire to keep resistance and voltage drop low. For most applications AWG No. 8, No. 10, and No. 12 are used.

The wire sizing worksheets given in Appendix B, a portion of which is shown in the inset, provide a consistent way to record the minimum wire size for different subsystems. Four tables are included that give maximum length for selected wire sizes and currents. The tables are for 12-, 24-, 48-, and 120-volt dc systems and provide the minimum wire size that should be used if the voltage drop is to be limited to 3 percent for any branch circuit. A portion of the 24-volt table is shown in Table 2. (These tables can be adjusted to reflect different voltage drop percentages by using simple ratios. For example, a 2 percent table can be calculated by multiplying the values in Table 2 by 2/3.) The tables are calculated for one-way distance taking into account that the circuit consists of both positive and negative wires. As an example, assume the array is 30 feet from the controller and the maximum current is 10 amperes. Table 2 shows that a No. B-size wire can be used up to a one-way distance of 40 feet (no temperature derate included). While the general rule is to limit the voltage drop for any branch circuit to 3 percent, there may be low-voltage applications where it should be less than 1 percent. For the total wire run on any path from source to load, the loss should be no greater than 5 percent.

Fuses are used to protect the conductors in the system.

The sub-systems must be protected from the high current possible from the battery.

TABLE 2
Portion of 24-V Table



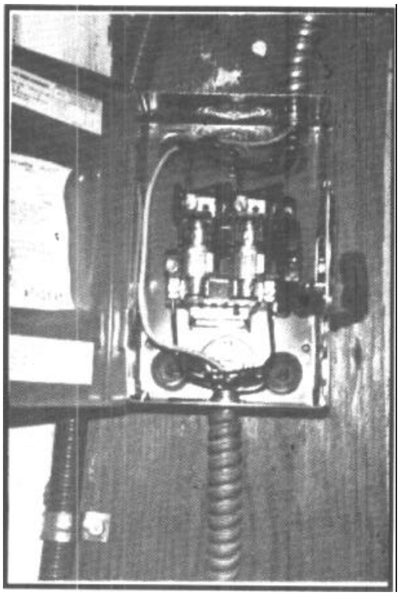
					Maxi
				3% Voltage Drop;	
AWG Wire Size		14	12	10	8
Resistance (Ω/1000 ft.)		2.52500	1.58800	0.99890	0.62820
Amperes	Watts	Distance	Distance	Distance	Distance
0.5	12	570	907		
1	24	285	453	721	
2	48	143	227	360	573
3	72	95	151	240	382
4	96	71	113	180	287
6	144	48	76	120	191
8	192	36	57	90	143
10	240	29	45	72	115
12	288	24	38	60	96
14	336	20	32	51	82

SWITCHES AND FUSES

Install switches in accessible places.

There is a specification sheet provided in Appendix B that can be used to size and record the switches, diodes, and fuses for the system. Switches, circuit breakers, and fuses are used to protect personnel and equipment. The switches provide the capability to manually interrupt power in case of emergency or for scheduled maintenance. The fuses provide overcurrent protection of the conductors in case of system shorting or ground faults. Diodes are used to control the direction of current flow in the system.

These protection components should be located throughout the stand-alone PV system. The designer should ask "What might happen?" and try to guard against reasonable failure scenarios. The largest current source in the system is the battery. A typical battery can provide over 6,000 amperes for a few milliseconds if faults occur and the battery is short-circuited. These levels of current can destroy components and injure personnel so an in-line fuse should be installed in all battery circuits. The fuses must be rated for dc operation and have an amperage interrupt capability (AIC) sufficient for these high currents. The NEC requires that there must be a method of disconnecting power from both sides of any installed fuse. This may require additional switches to be installed. Any switch used in a dc circuit should be specifically rated for dc operation, An ac switch may operate properly a few times, but it will probably fail when it is needed most. DC components are rated for voltage and current. Common voltage levels are 48, 125, 250, and 600 volts dc. Current ratings of 15, 30, 60, 100, and 200 amperes are common. The switch or breaker must be sized to handle the maximum possible current. This is the same current level used to specify the fuses. Fused disconnect switches with both devices incorporated into one assembly may be available. Using these will save on installation costs. DC rated circuit breakers can be used to replace both switches and fuses. They may be more difficult to find but the reliability is high and they are preferred by many system designers.



You can buy switch/fuse assemblies for installation in one box.

The current produced by the PV array is limited, but the array short-circuit current, multiplied by a safety factor of 1.56, is commonly used to specify the size of a slow-blow fuse in the array output circuit. Should a ground fault occur in the array while the controller is engaged, this fuse will protect the array modules and the conductors from high battery current. In the load circuits a fuse or circuit breaker is usually installed for each significant load.

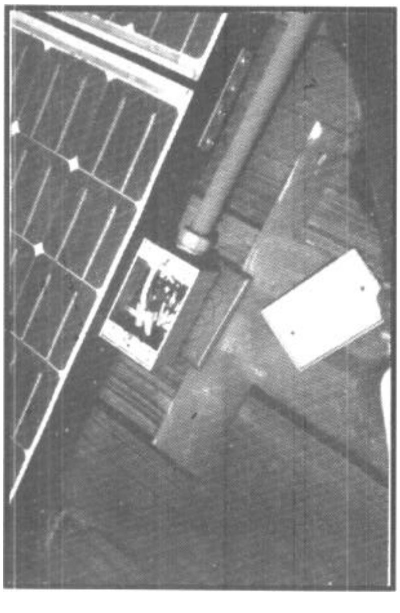
Switches, fuses, blocking diodes, movistors, and any sensors used for data acquisition are normally installed in a centrally located weather-proof junction box (J-box). The controller is often installed in the same J-box which may be referred to as the control center of the system. All negative wires should be attached to the negative buss and a solid copper wire used to connect this buss to the ground lug in the J-box. (The ground lug is connected to the common ground rod of the system). The positive leads are usually connected through a fuse to the positive buss. A surge protection device such as a movistor can be connected from each positive lead to ground. (See the wiring diagrams for the system design examples in this manual.)

Protect all connections. More system failures are caused by poorly made connections than by component failures.

CONNECTIONS

Poorly made connections are the biggest cause of problems in stand-alone PV systems. Making a good connection requires the correct tools and connectors. Do the following:

- Use connectors--do not try to wrap bare wire around a terminal. Make sure the connector size and wire size are compatible.
- Strip 3/8 to 1/2 inch of insulation from the wire and clean.
- Use a good quality crimp tool to attach the connector to the wire. A ring-type connector is superior to a spade-type connector because there is no possibility of the wire falling off the terminal.
- Solder the crimped connection. This is particularly important if the installation is in a marine environment or exposed to the weather. However, soldering makes a wire brittle and subject to breaking if the wire is repeatedly flexed near the connection.
- Use weather resistant boxes to make connections between subsystems. Do not try to make more than two connections to the same terminal. Make sure the terminals and connectors are clean and of the same type of metal. Tighten firmly. Split bolt connectors should be used instead of terminal strips if the wire size is greater than No. 8. If disassembly is not required, soldered connections may also be used but only if the connection is electrically and mechanically sound before the soldering.
- Allow plenty of wire for entry and exit of the boxes. Use boxes with strain relief entrances and tighten the clamps firmly around the wires. After making the connection to the terminal, check each wire for strain relief.
- Test thoroughly after installation. Check the connector attachment--give it a pull test. Look for places where the connections or bare wire might touch the metal box or other metal equipment. Make sure the wires to the terminal strip are neatly aligned and do not overlap. Check entry and exit points for nicks or cuts in the wire insulation.



SYSTEM INSTALLATION

How should the array be grounded?

What about wind damage or lightning?

What kind of battery enclosures are needed?

Stand-alone PV systems will be reliable power producers for more than two decades if properly sized for the application, engineered well, and installed carefully. All electrical wiring should be done in accordance with the NEC and local codes. Some general guidance is given here.

Trying to save $ on installation of system components is false economy.

ARRAYS

PV arrays for stand-alone systems are installed in many unique and innovative ways. However, there are common issues involved in any installation, whether the array is fixed or tracking, mounted at ground level, or on a pole or building. The array orientation and tilt angle considerations are discussed in the section on PV arrays, page 29.

The objective is a solidly mounted PV array that will last for many years and withstand all kinds of weather. Regardless of whether you buy or build the mounting structure make sure it is anchored and the modules are restrained. Many module manufacturers and distributors sell mounting hardware specifically designed for their modules. This hardware is intended for multiple applications and different mounting techniques and considerations like wind loading have been included in the design. Using this mounting hardware is the simplest and often the most cost effective. Customized array mounting structures can be expensive. Consider the characteristics of various mounting materials:

Use materials that will last 20+ years.

- **Aluminum** - lightweight, strong, and resistant to corrosion. Aluminum angle is an easy material to work with, holes can be drilled with commonly available tools, and the material is compatible with many PV module frames. Aluminum is not easy to weld.

- **Angle Iron** - easy to work with but corrodes rapidly. Galvanizing will slow corrosion but mounting brackets and bolts will still rust, particularly in a wet environment. The material is readily available and brackets can be welded easily.

- **Stainless Steel** - expensive and difficult to work with but will last for decades. May be a good investment in salt spray environments.

- **Wood** - inexpensive, available, and easy to work with but may not withstand the weather for many years--even if treated with preservative. Attaching modules to a wooden frame requires battens or clips to hold them in place.

Figure 14 shows one mounting technique that has been used for small PV systems. Aluminum or galvanized angle can be used for the support struts, steel fence posts can be driven into the ground and the cross-beam can be made from treated wood, metal, or concrete. Galvanized U-bolts can be used to hold the cross-beams. Stainless steel bolts and nuts are recommended because they will not rust and portions of the array can be removed if future maintenance is required. The foundation for the array should be designed to meet the wind load requirements of the region. Wind load depends on the size of the array and the tilt angle. Ask a local contractor or your module distributor how to anchor your array to withstand the wind expected in your area.

Ground mounting of PV arrays is recommended for stand-alone sytems.

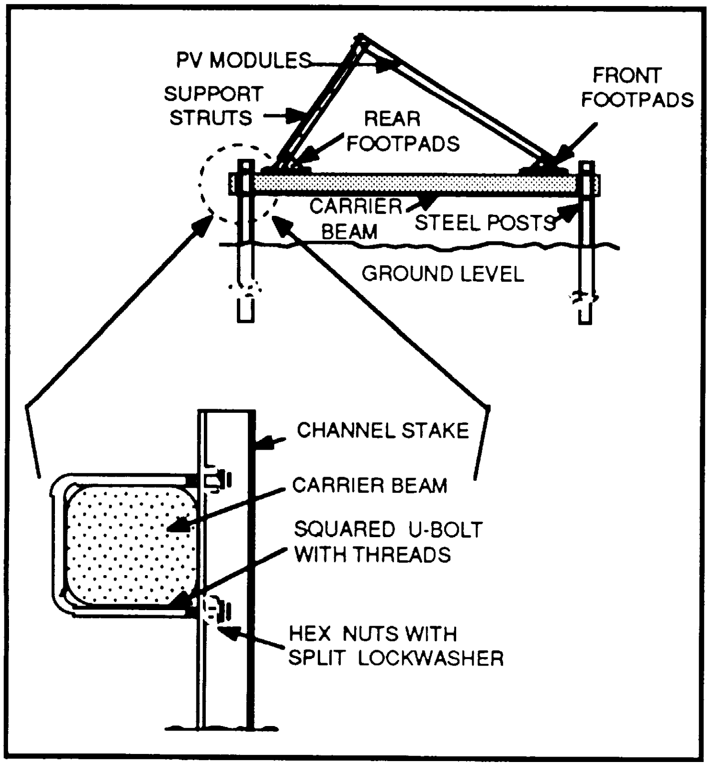


Figure 14. Simple Ground Mount for a PV Array.

Changing the tilt angle of an array to account for seasonal changes in sun altitude is not required. For mid-latitude locations, a tilt angle change every three months is estimated to increase energy production about 5 percent on an annual basis. For most applications, the additional labor and the added complexity of the array mount does not justify the small increase in energy produced.

If tracking of the flat-plate array is desired, the recommended trackers are single axis units that require little control or power; see Figure 15. These are passive trackers driven by a closed Freon system that causes the tracker to follow the sun with adequate accuracy for flat-plate PV modules. In high wind areas a powered tracker may be preferred. Pole mounted trackers that support 4 to 12 PV modules are available and often used for small stand-alone systems, particularly water pumping applications. The tracker manufacturer will provide

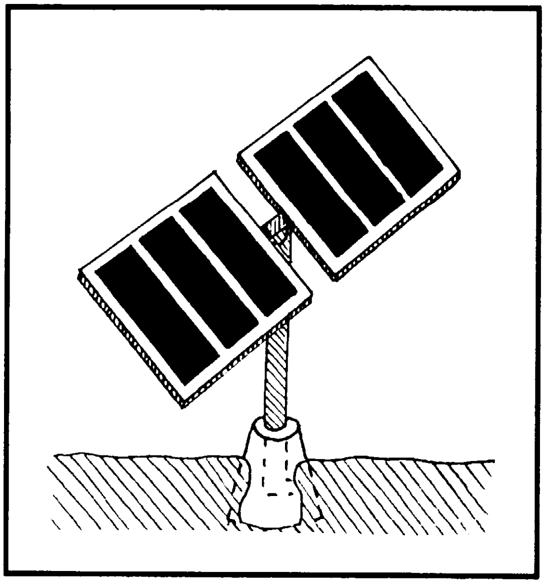


Figure 15. Passive Tracker for a PV Array.

all the array mounting hardware and instructions for securely installing the tracker. The amount and type of foundation for the pole-mounted tracker depends on the size of the array being supported. Reinforced concrete with anchor bolts is recommended. The foundation and frame should be designed to withstand the worst case wind expected in the area. The movement of the array should be checked to make sure the path is clear of obstructions.

In general, roof mounting of PV modules should be avoided. They are more difficult to install and maintain, particularly if the roof orientation and angle are not compatible with the optimum solar array tilt angle. Penetrating the roof seal is inevitable and leaks may occur. Also, it is important to achieve a firm and secure attachment of the array mounting brackets to the roof. Attaching the mounting brackets to the rafters will provide the best foundation, but this may be difficult because module size and rafter spacing are usually not compatible. If there is access to the underside of the roof, 2 x 6-inch blocks can be inserted between the rafters and the attachment made to the blocks. Attaching the array to the plywood sheathing of the roof may result in roof damage, particularly if high winds are likely.

If a roof mount is required, be sure to allow a clear air flow path up the roof under the array as shown in Figure 16. The array will operate cooler and produce more energy if it stands off the roof at least 3 inches, Flush mounting PV modules to the roof of a building is not recommended. The modules are more difficult to test and replace, and the performance of the array is decreased because of the higher operating temperatures,

Secure the array for worst-case windstorms.

BATTERIES

Batteries must be protected from the elements. If freezing temperatures are expected, the batteries can be buried below the frost line in a watertight enclosure or in a building where the temperature will remain above freezing. If the batteries are buried, a well-drained location should be selected and a drainhole provided in the battery enclosure. Batteries should not be set directly on concrete surfaces as self discharge will be increased,

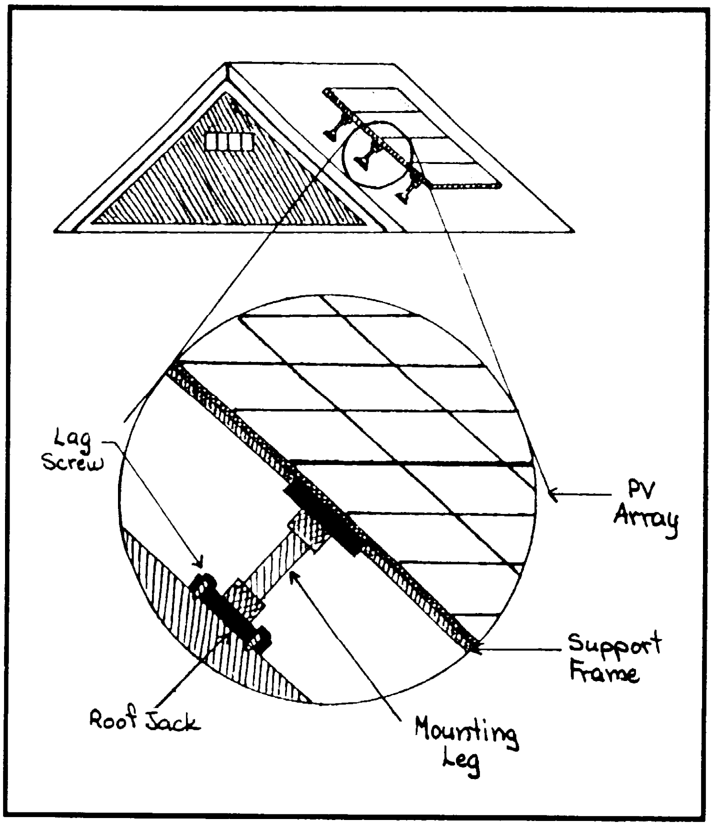


Figure 16. Roof Mount for a PV Array.

particularly if the surface gets damp. Adequate venting must be provided to minimize explosion hazard if open-cell batteries are used. Any battery should be stored in a location where access is limited to knowledgeable personnel. Never allow unsupervised children or pets near batteries.

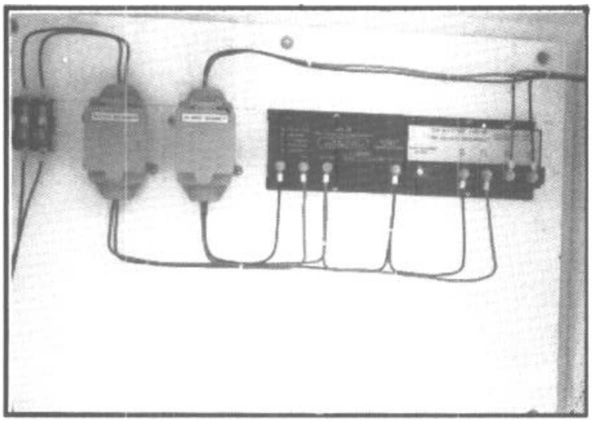
Do not set batteries on cold, damp surfaces.

Commercial battery enclosures may be available but are usually expensive. For small systems, a heavy-duty plastic tub may serve as an inexpensive alternative. Be sure it will withstand direct sunlight if the batteries are to be installed outdoors and above ground.

CONTROL CENTER

Electronic controllers, converters, or inverters are often installed in the control center along with switches, fuses, and other BOS. Electronic components must be able to withstand expected temperature extremes in both operating and non-operating states. Any printed circuit boards in these units should be coated or sealed to protect the electronics from humidity and dust. Certified electrical service boxes should be used. Consult any electrical supply company to get advice about the type of box needed for a specific application.

Install all switches, fuses, movistors and electronics in a protected J-box.



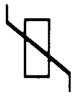
High temperatures will shorten the life of electronic equipment. Try to mount the boxes in a shaded area and/or provide air circulation, particularly for inverters. Dust can be a problem in a well-vented enclosure. Some boxes have filters at the air access points. Filters require regular cleaning. Screen the inlets of the electrical boxes to prevent spiders, wasps, and other insects from setting up residence. Finding wasps in the electrical box may not affect performance, but it will certainly make maintenance more exciting.

GROUNDING

A good ground will provide a well-defined, low-resistance path from the stand-alone PV system to earth ground. This path is expected to carry fault current if system malfunctions occur so the ground wire must be as large as the largest conductor in the system. Two types of grounding are needed in PV systems--system ground and equipment ground. For the system ground, one of the current carrying conductors, usually the negative, is grounded at a single point. This establishes the maximum voltage with respect to ground and also serves to discharge surge currents induced by lightning. Any exposed metal that might be touched by personnel should be grounded. This includes equipment boxes and array frames. This will limit the risk of electrical shock should a ground fault occur.

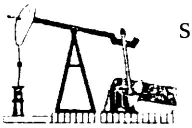
A low-resistance earth ground requires good contact between the ground rod and earth. Subterranean water lowers the resistivity of the contact. If the system is in an area with rocky soil, a good ground may be difficult to achieve. Consult a local electrician for suggestions.

A PV array can attract lightning, especially if located at a high elevation relative to the surrounding terrain. In particular, water pumping systems may draw lightning because of the excellent ground path provided by the well casing. Current surges can be caused by a direct lightning hit or by electromagnetic coupling of energy into the PV system's conductors.



Consider using lightning rods above arrays located on high ground.

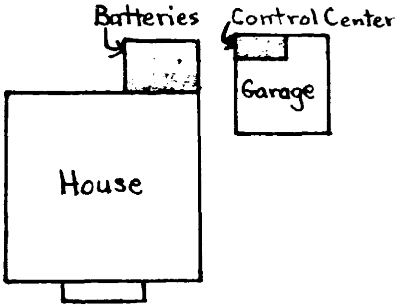
There is little that can be done to protect the PV system equipment from a direct lightning strike. Surges caused by near strikes occur more frequently and the severity of possible damage depends on the distance from the strike to the array. Commercially available surge protection devices (movistors and silicon oxide varistors) are reasonably priced and their use is recommended. They are normally installed in the array output and at the dc input to any electronic device. If an inverter is used, surge protection devices should be installed at the ac output as well as the dc input. Installing the wiring in grounded, buried metallic conduit will decrease susceptibility to lightning.



THE BROWN FAMILY PLAN THEIR SYSTEM INSTALLATION

Each family member was taught safe system operation and how to disconnect array power.

The Browns came to understand that a system is a collection of interactive components, and satisfactory operation is dependent on the reliability of each part. They were told that more system downtime is caused by failure of connections, switches, and fuses than failure of controllers, batteries or modules. These common failures can be avoided, to a large degree, with good installation practices. The Browns intended to supervise the installation of their system, so they studied the codes and regulation for electrical installations in their area. They contacted local authorities and asked what codes applied. They were particularly interested in safety issues, compliance with the NEC, convenience, and ease of maintenance. They carefully selected the location for their array, batteries, and control center. They planned to install the batteries, inverter, controller, and safety switches in a 100 square foot enclosure on the north side of their house. The wire run from batteries to inverter was less than 10 feet. The control/battery room would be attached to the house but could be accessed only from outside through double-wide, lockable doors. They made sure there would be good cross-flow ventilation in the insulated room. The PV array would be installed using the simple ground mounting technique described in this handbook. They would use lag screws to attach the panel frames to a treated wooden 4 x 4 carrier beam. They planned to buy the panel frames, and support hardware from the module manufacturer. By using this hardware, they would also be able to use the manufacturer designed wiring harness to electrically interconnect the PV modules. They would use conduit for all wire runs except the array to battery. For this, they would use No. 6 direct-burial cable. Number 6 wire was larger than required but would keep the voltage drop to just over 1 percent. With components on-hand and planning completed, the Browns started their installation project.



MAINTENANCE

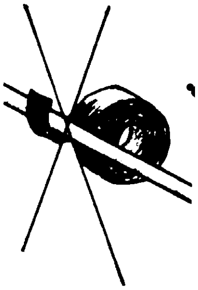
How much maintenance will be required?

Do I need special equipment or training?

PERIODIC CHECKS

Preventive maintenance is the best maintenance! Periodic checks are recommended for any stand-alone PV system so that little problems can be found and corrected before they affect system operation. The system should be checked soon after installation when it is presumably operating well. Much of the checking can be done with only a voltmeter, a clamp-on ammeter, and some common sense. Many failures can be avoided if periodic checking is done and corrective action taken before the problems cause system failure. Do these recommended checks regularly:

Preventive maintenance is the best maintenance.



Check systems at least once a year.

- Check the tightness of all connections in the system. Battery connections should be cleaned and sealed with a corrosion inhibitor.
- Check the electrolyte level and add clean (distilled) water as necessary. Do not overfill the batteries. Measure the specific gravity of each cell in the battery every year. The specific gravity is an indicator of the battery state-of-charge but the measurements may be misleading if the electrolyte has stratified. Check specific gravity from different levels in the cell to see if the electrolyte is stratified. If stratification is present, the battery should be charged vigorously to mix the electrolyte. If the specific gravity reading of any cell is different from the others by 0.050 it may indicate a weak cell. Monitor this cell's performance to see if replacement is required.
- With the battery under load, check the voltage of each battery cell and compare it to the average of all cell voltages. If the voltage of any cell differs by 0.05 volts from the others, it indicates a possible problem. Monitor this cell's performance to see if replacement is required.
- Check the system wiring. If any wires are exposed, look for cracking or checking of the insulation. Inspect the entry and exit points from all junction boxes and look for breaks or cracks in the insulation. Replace wires if necessary. Do not rely on common black electrical tape for long-term repair of damaged insulation.
- Check that all junction boxes are closed and sealed. Inspect for water damage or corrosion. If electronic components are mounted in junction boxes, check for ventilation in the box. Change or clean air filters.
- Inspect the array mounting frame or tracking mechanism. Maintain any tie-down anchors.

- Check the operation of switches. Make sure the switch movement is solid. Look for corrosion or charring around contacts. Check fuses with a voltmeter. A good fuse will have almost no voltage drop when current is flowing. Look for discoloration at the fuse ends.

The designer should provide specific instructions for maintaining the system. Following that advice, doing these simple checks, and correcting any visible problem as soon as they appear will increase the system availability and extend its life.

TROUBLESHOOTING

If a known or suspected problem has occurred, it can usually be located by following a logical progression of tests and analyzing the results. Basic tests can be completed with simple tools such as a voltmeter, clamp-on ammeter, hydrometer, pliers, screwdrivers, and crescent wrenches. Gloves, safety glasses, (for working around batteries), and rubber-soled shoes are recommended. Remove jewelry before testing any electrical circuits. Have two people working together to test the system. Before testing, make sure that both persons know where the power disconnect switches are and how to operate them. Safety first! Remember a PV array will produce power any time the sun is shining and any array that contains more than two modules can produce enough electricity to kill a human being under worst-case conditions. Always measure the voltage present before touching a wire or connector and never disconnect a wire before knowing what voltage and current are

Safety first

Check the simple things first.

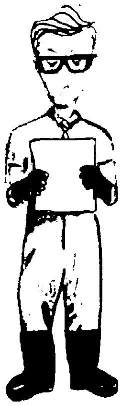


Figure 17 gives some general guidance for finding problems in stand-alone PV systems with batteries. Check the simple things first. Look for blown fuses, tripped breakers, or bad connections. Repair as necessary. Check the status lights, if any, on the controller. Next, check the loads. The appliances or pumps, etc. may have blown a fuse or failed. Check to see if the correct voltage and current are present at the load input. If you have another load that can be plugged into that circuit see if it will work. If it does, the original appliance is suspect. If the correct voltage is not present, check the battery voltage. If the correct voltage is present at the output, check the circuit between the battery and the load. Recharge the battery if the battery voltage is low. You can also check the voltage and specific gravity of each cell and look for weak cells. If the battery voltage is low (less than 11.0 volts on a 12 volt system) the problem may be with the controller. (Has the weather been cloudy for a long period--if so, there may be no system problem.) Check the input voltage at the controller, Is it equal to the battery voltage? If so, the controller has the array connected to the battery, Is a charging current flowing from the array? If yes, you may want to disconnect the load(s) and let the array charge the battery. If no current is flowing or if the voltage at the controller input equals the open-circuit voltage of the array, the controller may have failed. If the

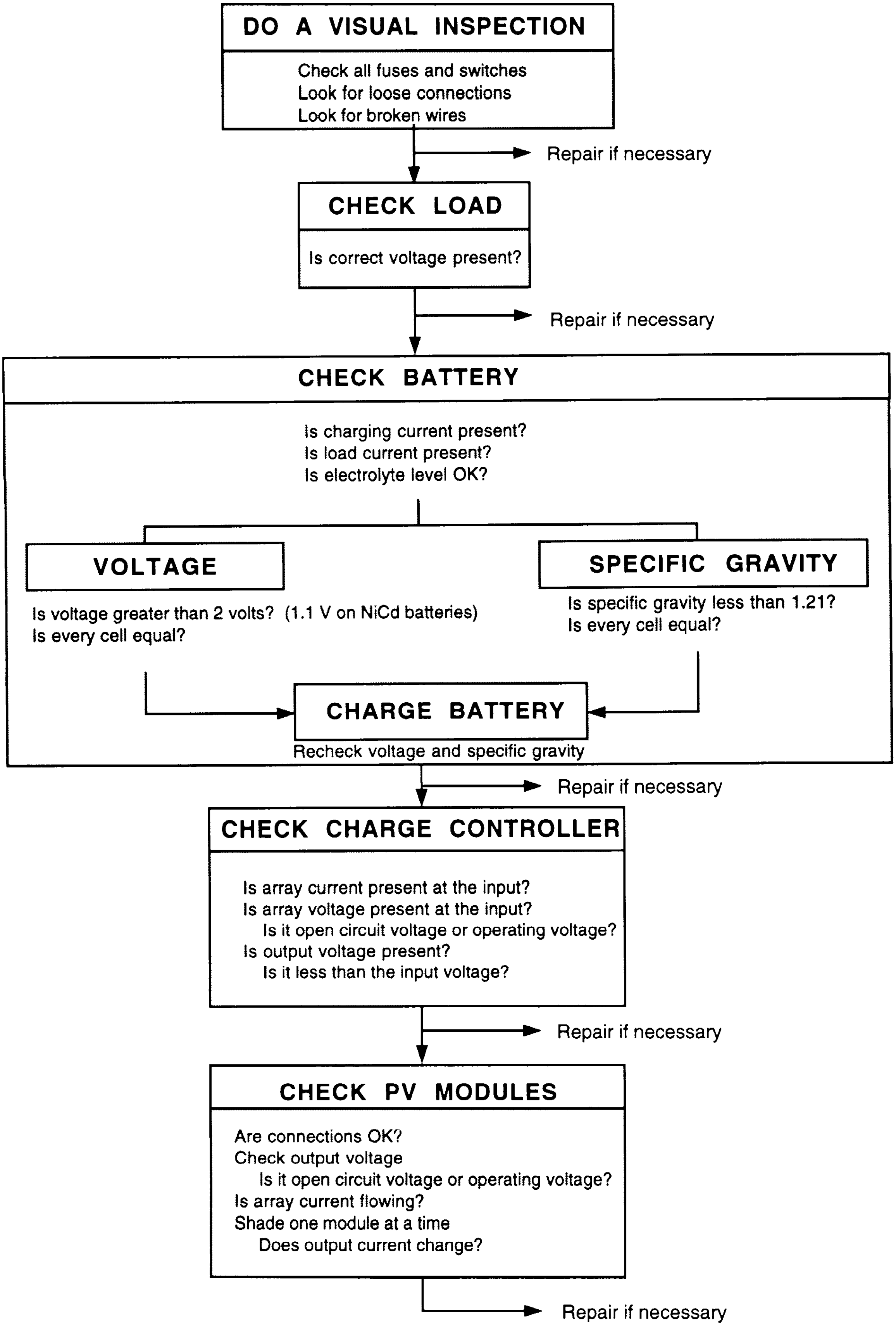


Figure 17. Troubleshooting Guide.

controller is okay, test the array. Measure the voltage at the output. You may want to bypass the controller and connect the array directly to the battery-check for current. Shade each module in turn and see if the current changes. Be sure to return the system to its original configuration when you have finished troubleshooting.

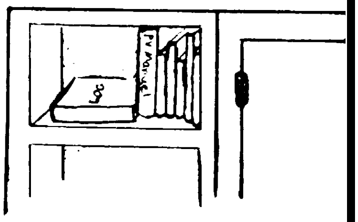
If the loads operate sometimes and you suspect the quantity of power being produced, the problem may be more difficult to locate. The power output of a stand-alone PV system varies with conditions, and checking the system performance requires simultaneous measurement of the existing solar conditions, the temperature, and the power output from the system. This may require specific test equipment and expertise that is not widely available. Contact your system designer or installer if you suspect a decrease in system performance but you can locate no problems.

THE BROWN FAMILY DEVELOP A MAINTENANCE PLAN

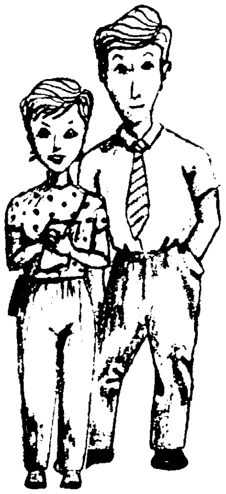
The Browns wanted their PV system to include sensors and meters so they could monitor system performance and be alert to potential trouble. They took photographs as their system was installed and included this photographic record in a log book they planned to keep as a record of all system events. They put this and all other system documentation on a shelf near the control center.

They ordered an operations manual complete with all system schematics, component specifications, warranties, preventive maintenance procedures, and a troubleshooting guide. They spent several hours studying the system documentation, and each family member was taught how to disconnect the array power and electrically isolate the battery bank. They put a sign over the array disconnect switch that reminded them that the dc side of the disconnect would have voltage present anytime the sun was shining.

They plan to inspect the system every month for the first year and every three months thereafter. They plan to tighten connections, clean equipment boxes, and look for corrosion. They will check the level on the battery electrolyte and correct the little things that may save them money over the long term. The system should serve them well--if they take care of it, it will take care of them.



The Browns bought a notebook and recorded all system data in it.



ECONOMICS: LIFE-CYCLE COST

How do I compare the cost of alternative systems?

DESCRIPTION

Doing a life-cycle cost analysis (LCC) gives you the total cost of your PV system--including all expenses incurred over the life of the system. There are two reasons to do an LCC analysis: 1) to compare different power options, and 2) to determine the most cost-effective system designs. For some applications there are no options to small PV systems so comparison of other power supplies is not an issue. The PV system produces power where there was no power before. For these applications the initial cost of the system is the main concern. However, even if PV power is the only option, a life-cycle cost (LCC) analysis can be helpful for comparing costs of different designs and/or determining whether a hybrid system would be a cost-effective option. An LCC analysis allows the designer to study the effect of using different components with different reliabilities and lifetimes. For instance, a less expensive battery might be expected to last 4 years while a more expensive battery might last 7 years. Which battery is the best buy? This type of question can be answered with an LCC analysis.

LCC analysis is a tool to compare the cost of alternative systems.

LCC analysis can be used to study the effect of changing economic variables.

Some agencies might want to compare the cost of different power supply options such as photovoltaics, fueled generators, or extending utility power lines. The initial costs of these options will be different as will the costs of operation, maintenance, and repair or replacement. A LCC analysis can help compare the power supply options. The LCC analysis consists of finding the present worth of any expense expected to occur over the reasonable life of the system. To be included in the LCC analysis, any item must be assigned a cost, even though there are considerations to which a monetary value is not easily attached. For instance, the cost of a gallon of diesel fuel may be known; the cost of storing the fuel at the site may be estimated with reasonable confidence; but, the cost of pollution caused by the generator may require an educated guess. Also, the competing power systems will differ in performance and reliability. To obtain a good comparison, the reliability and performance must be the same. This can be done by upgrading the design of the least reliable system to match the power availability of the best. In some cases, you may have to include the cost of redundant components to make the reliability of the two systems equal. For instance, if it takes one month to completely rebuild a diesel generator, you should include the cost of a replacement unit in the LCC calculation. A meaningful LCC comparison can only be made if each system can perform the same work with the same reliability.

LCC CALCULATION

The life-cycle cost of a project can be calculated using the formula:

$$LCC = C + M_{pw} + E_{pw} + R_{pw} - S_{pw}.$$

where the pw subscript indicates the present worth of each factor.

The capital cost (C) of a project includes the initial capital expense for equipment, the system design, engineering, and installation. This cost is always considered as a single payment occurring in the initial year of the project, regardless of how the project is financed.

Maintenance (M) is the sum of all yearly scheduled operation and maintenance (O&M) costs. Fuel or equipment replacement costs are not included. O&M costs include such items as an operator's salary, inspections, insurance, property tax, and all scheduled maintenance.

The energy cost (E) of a system is the sum of the yearly fuel cost. Energy cost is calculated separately from operation and maintenance costs, so that differential fuel inflation rates may be used.

Replacement cost (R) is the sum of all repair and equipment replacement cost anticipated over the life of the system. The replacement of a battery is a good example of such a cost that may occur once or twice during the life of a PV system. Normally, these costs occur in specific years and the entire cost is included in those years.

Convert all values to their present worth.

Salvage value is usually 10 to 20 percent of original cost.

The salvage value (S) of a system is its net worth in the final year of the life-cycle period. It is common practice to assign a salvage value of 20 percent of original cost for mechanical equipment that can be moved. This rate can be modified depending on other factors such as obsolescence and condition of equipment.

Future costs must be discounted because of the time value of money. One dollar received today is worth more than the promise of $1 next year, because the $1 today can be invested and earn interest. Future sums of money must also be discounted because of the inherent risk of future events not occurring as planned. Several factors should be considered when the period for an LCC analysis is chosen. First is the life span of the equipment. PV modules should operate for 20 years or more without failure. To analyze a PV system over a 5-year period would not give due credit to its durability and reliability. Twenty years is the normal period chosen to evaluate PV projects. However, most engine generators won't last 20 years so replacement costs for this option must be factored into the calculation if a comparison is to be made.

To discount future costs, the multipliers presented in Tables 3 and 4 can be used. Table 3 lists Single Present Worth factors. These are used to discount a cost expected to occur in a specific year, such as a battery replacement in year 10 of a project. Table 4 lists Uniform Present Worth factors. These are used to discount annually recurring costs, such as the annual fuel cost of a generator. To use the tables, simply select the column under the appropriate discount rate and read the multiplier opposite the correct year or span of years.

The discount rate used has a large effect on LCC results.

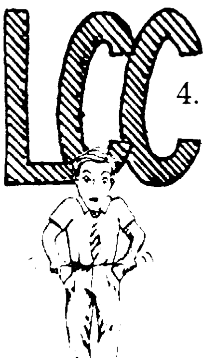
The discount rate selected for an LCC analysis has a large effect on the final results. It should reflect the potential earnings rate of the system owner. Whether the owner is a national government, small village, or an individual, money spent on a project could have been invested elsewhere and earned a certain rate of return. The nominal investment rate, however, is not an investor's real rate of return on money invested. Inflation, the tendency of prices to rise over time, will make future earnings worth less. Thus, inflation must be subtracted from an investor's nominal rate of return to get the net discount rate (or real opportunity cost of capital). For example, if the nominal investment rate was 7 percent, and general inflation was assumed to be 2 percent over the LCC period, the net discount rate that should be used would be 5 percent.

Use 20-30 years for a PV system evaluation.

A low discount rate increases future cost--a high discount rate emphasizes initial costs.

Different discount rates can be used for different commodities. For instance, fuel prices may be expected to rise faster than general inflation. In this case, a lower discount rate would be used when dealing with future fuel costs. In the example above the net discount rate was assumed to be 5 percent. If the cost of diesel fuel was expected to rise 1 percent faster than the general inflation rate, then a discount rate of 4 percent would be used for calculating the present worth of future fuel costs. Check with your local bank for their guess about future inflation rates for various goods and services. You have to make an estimate about future rates, realizing that an error in your guess can have a large affect on the LCC analysis results. If you use a discount rate that is too low, the future costs will be exaggerated; using a high discount rate does just the opposite, emphasizing initial costs over future costs. You may want to perform an LCC analysis with "high, low and medium" estimates on future rates to put bounds on the life-cycle cost of alternative systems.

LCC can be used to analyze investment decisions.



TECHNICAL NOTES

1. The formula for the single present worth (P) of a future sum of money (F) in a given year (N) at a given discount rate (I) is

$$P = F/(1 + I)^N.$$

2. The formula for the uniform present worth (P) of an annual sum (A) received over a period of years (N) at a given discount rate (I) is

$$P = A[1 - (1 + I)^{-N}]/I.$$

3. The formula for the modified uniform present worth of an annual sum (A) that escalates at a rate (E) over a period of years (N) at a given discount rate (I) is

4. The formula for the annual payment (A) on a loan whose principal is (P) at an interest rate (I) for a given period of years (N) is

$$A = P\{I/[1 - (1 + I)^{-N}]\}.$$

TABLE 3
Single Present Worth Factors

Net Discount Rate

Year	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12
1	0.990	0.980	0.971	0.962	0.952	0.943	0.935	0.926	0.917	0.909	0.901	0.893
2	0.980	0.961	0.943	0.925	0.907	0.890	0.873	0.857	0.842	0.826	0.812	0.797
3	0.971	0.942	0.915	0.889	0.864	0.840	0.816	0.794	0.772	0.751	0.731	0.712
4	0.961	0.924	0.888	0.855	0.823	0.792	0.763	0.735	0.708	0.683	0.659	0.636
5	0.951	0.906	0.863	0.822	0.784	0.747	0.713	0.681	0.650	0.621	0.593	0.567
6	0.942	0.888	0.837	0.790	0.746	0.705	0.666	0.630	0.596	0.564	0.535	0.507
7	0.933	0.871	0.813	0.760	0.711	0.665	0.623	0.583	0.547	0.513	0.482	0.452
8	0.923	0.853	0.789	0.731	0.677	0.627	0.582	0.540	0.502	0.467	0.434	0.404
9	0.914	0.837	0.766	0.703	0.645	0.592	0.544	0.500	0.460	0.424	0.391	0.361
10	0.905	0.820	0.744	0.676	0.614	0.558	0.508	0.463	0.422	0.386	0.352	0.322
11	0.896	0.804	0.722	0.650	0.585	0.527	0.475	0.429	0.388	0.350	0.317	0.287
12	0.887	0.788	0.701	0.625	0.557	0.497	0.444	0.397	0.356	0.319	0.286	0.257
13	0.879	0.773	0.681	0.601	0.530	0.469	0.415	0.368	0.326	0.290	0.258	0.229
14	0.870	0.758	0.661	0.577	0.505	0.442	0.388	0.340	0.299	0.263	0.232	0.205
15	0.861	0.743	0.642	0.555	0.481	0.417	0.362	0.315	0.275	0.239	0.209	0.183
16	0.853	0.728	0.623	0.534	0.458	0.394	0.339	0.292	0.252	0.218	0.188	0.163
17	0.844	0.714	0.605	0.513	0.436	0.371	0.317	0.270	0.231	0.198	0.170	0.146
18	0.836	0.700	0.587	0.494	0.416	0.350	0.296	0.250	0.212	0.180	0.153	0.130
19	0.828	0.686	0.570	0.475	0.396	0.331	0.277	0.232	0.194	0.164	0.138	0.116
20	0.820	0.673	0.554	0.456	0.377	0.312	0.258	0.215	0.178	0.149	0.124	0.104
21	0.811	0.660	0.538	0.439	0.359	0.294	0.242	0.199	0.164	0.135	0.112	0.093
22	0.803	0.647	0.522	0.422	0.342	0.278	0.226	0.184	0.150	0.123	0.101	0.083
23	0.795	0.634	0.507	0.406	0.326	0.262	0.211	0.170	0.138	0.112	0.091	0.074
24	0.788	0.622	0.492	0.390	0.310	0.247	0.197	0.158	0.126	0.102	0.082	0.066
25	0.780	0.610	0.478	0.375	0.295	0.233	0.184	0.146	0.116	0.092	0.074	0.059
26	0.772	0.598	0.464	0.361	0.281	0.220	0.172	0.135	0.106	0.084	0.066	0.053
27	0.764	0.586	0.450	0.347	0.268	0.207	0.161	0.125	0.098	0.076	0.060	0.047
28	0.757	0.574	0.437	0.333	0.255	0.196	0.150	0.116	0.090	0.069	0.054	0.042
29	0.749	0.563	0.424	0.321	0.243	0.185	0.141	0.107	0.082	0.063	0.048	0.037
30	0.742	0.552	0.412	0.308	0.231	0.174	0.131	0.099	0.075	0.057	0.044	0.033
35	0.706	0.500	0.355	0.253	0.181	0.130	0.094	0.068	0.049	0.036	0.026	0.019
40	0.672	0.453	0.307	0.208	0.142	0.097	0.067	0.046	0.032	0.022	0.015	0.011
45	0.639	0.410	0.264	0.171	0.111	0.073	0.048	0.031	0.021	0.014	0.009	0.006
50	0.608	0.372	0.228	0.141	0.087	0.054	0.034	0.021	0.013	0.009	0.005	0.003
55	0.579	0.337	0.197	0.116	0.068	0.041	0.024	0.015	0.009	0.005	0.003	0.002
60	0.550	0.305	0.170	0.095	0.054	0.030	0.017	0.010	0.006	0.003	0.002	0.001
65	0.524	0.276	0.146	0.078	0.042	0.023	0.012	0.007	0.004	0.002	0.001	0.001
70	0.498	0.250	0.126	0.064	0.033	0.017	0.009	0.005	0.002	0.001	0.001	0.000
75	0.474	0.226	0.109	0.053	0.026	0.013	0.006	0.003	0.002	0.001	0.000	0.000

TABLE 4
Uniform Present Worth Factors

Net Discount Rate

Year	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12
1	0.990	0.980	0.971	0.962	0.952	0.943	0.935	0.926	0.917	0.909	0.901	0.893
2	1.970	1.942	1.913	1.886	1.859	1.833	1.808	1.783	1.759	1.736	1.713	1.690
3	2.941	2.884	2.829	2.775	2.723	2.673	2.624	2.577	2.531	2.487	2.444	2.402
4	3.902	3.808	3.717	3.630	3.546	3.465	3.387	3.312	3.240	3.170	3.102	3.037
5	4.853	4.713	4.580	4.452	4.329	4.212	4.100	3.993	3.890	3.791	3.696	3.605
6	5.795	5.601	5.417	5.242	5.076	4.917	4.767	4.623	4.486	4.355	4.231	4.111
7	6.728	6.472	6.230	6.002	5.786	5.582	5.389	5.206	5.033	4.868	4.712	4.564
8	7.652	7.325	7.020	6.733	6.463	6.210	5.971	5.747	5.535	5.335	5.146	4.968
9	8.566	8.162	7.786	7.435	7.108	6.802	6.515	6.247	5.995	5.759	5.537	5.328
10	9.471	8.983	8.530	8.111	7.722	7.360	7.024	6.710	6.418	6.145	5.889	5.650
11	10.368	9.787	9.253	8.760	8.306	7.887	7.499	7.139	6.805	6.495	6.207	5.938
12	11.255	10.575	9.954	9.385	8.863	8.384	7.943	7.536	7.161	6.814	6.492	6.194
13	12.134	11.348	10.635	9.986	9.394	8.853	8.358	7.904	7.487	7.103	6.750	6.424
14	13.004	12.106	11.296	10.563	9.899	9.295	8.745	8.244	7.786	7.367	6.982	6.628
15	13.865	12.849	11.938	11.118	10.380	9.712	9.108	8.559	8.061	7.606	7.191	6.811
16	14.718	13.578	12.561	11.652	10.838	10.106	9.447	8.851	8.313	7.824	7.379	6.974
17	15.562	14.292	13.166	12.166	11.274	10.477	9.7.63	9.122	8.544	8.022	7.549	7.120
18	16.398	14.992	13.754	12.659	11.690	10.828	10.059	9.372	8.756	8.201	7.702	7.250
19	17.226	15.678	14.324	13.134	12.085	11.158	10.336	9.604	8.950	8.365	7.839	7.366
20	18.046	16.351	14.877	13.590	12.462	11.470	10.594	9.818	9.129	8.514	7.963	7.469
21	18.857	17.011	15.415	14.029	12.821	11.764	10.836	10.017	9.292	8.649	8.075	7.562
22	19.660	17.658	15.937	14.451	13.163	12.042	11.061	10.201	9.442	8.772	8.176	7.645
23	20.456	18.292	16.444	14.857	13.489	12.303	11.272	10.371	9.580	8.883	8.266	7.718
24	21.243	18.914	16.936	15.247	13.799	12.550	11.469	10.529	9.707	8.985	8.348	7.784
25	22.023	19.523	17.413	15.622	14.094	12.783	11.654	10.675	9.823	9.077	8.422	7.843
26	22.795	20.121	17.877	15.983	14.375	13.003	11.826	10.810	9.929	9.161	8.488	7.896
27	23.560	20.707	18.327	16.330	14.643	13.211	11.987	10.935	10.027	9.237	8.548	7.943
28	24.316	21.281	18.764	16.663	14.898	13.406	12.137	11.051	10.116	9.307	8.602	7.984
29	25.066	21.844	19.188	16.984	15.141	13.591	12.278	11.158	10.198	9.370	8.650	8.022
30	25.808	22.396	19.600	17.292	15.372	13.765	12.409	11.258	10.274	9.427	8.694	8.055
35	29.409	24.999	21.487	18.665	16.374	14.498	12.948	11.655	10.567	9.644	8.855	8.176
40	32.835	27.355	23.115	19.793	17.159	15.046	13.332	11.925	10.757	9.779	8.951	8.244
45	36.095	29.490	24.519	20.720	17.774	15.456	13.606	12.108	10.881	9.863	9.008	8.283
50	39.196	31.424	25.730	21.482	18.256	15.762	13.801	12.233	10.962	9.915	9.042	8.304
55	42.147	33.175	26.774	22.109	18.633	15.991	13.904	12.319	11.014	9.947	9.062	8.317
60	44.955	34.761	27.676	22.623	18.929	16.161	14.039	12.377	11.048	9.967	9.074	8.324
65	47.627	36.197	28.453	23.047	19.161	16.289	14.110	12.416	11.070	9.980	9.081	8.328
70	50.169	37.499	29.123	23.395	19.343	16.385	14.160	12.443	11.084	9.987	9.085	8.330
75	52.587	38.677	29.702	23.680	19.485	16.456	14.196	12.461	11.094	9.992	9.087	8.332

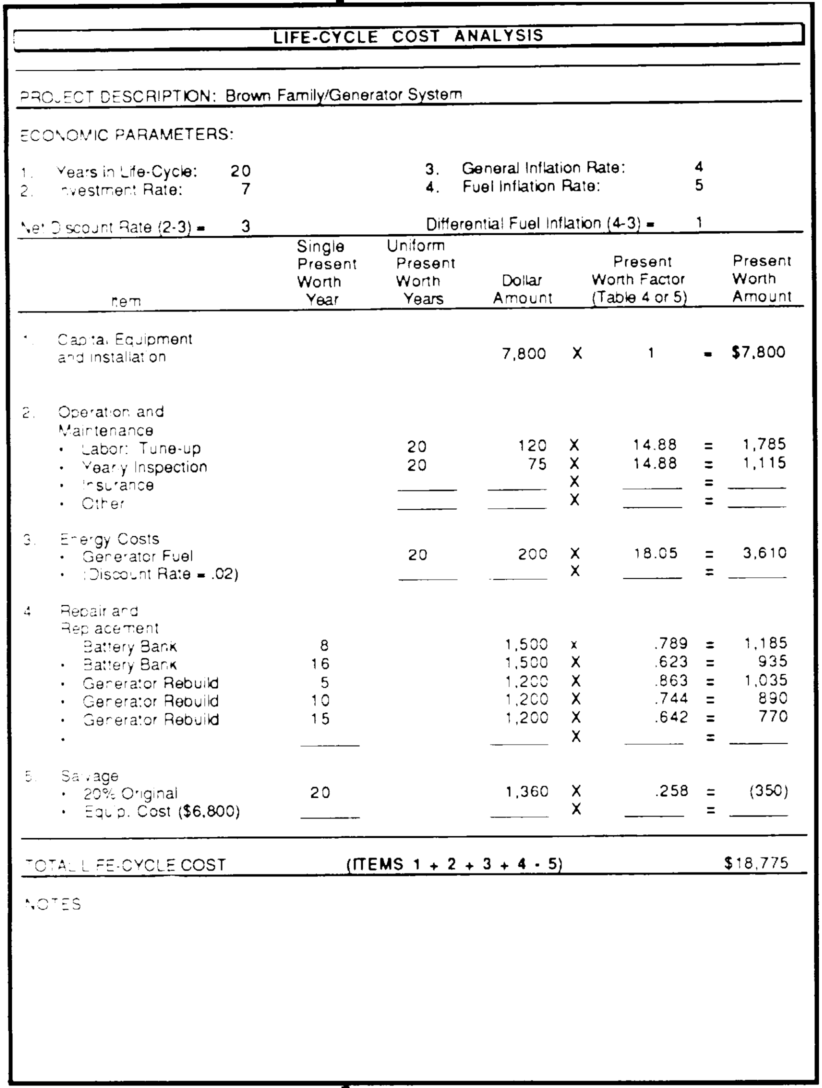
TABLE 5
Yearly Principal and Interest Per $1,000 Loan

Loan Rate		5-Year Loan	10-Year Loan	15-Year Loan	20-Year Loan	25-Year Loan
0.05		$230.97	$129.50	$96.34	$80.24	$70.95
0.0525		$232.57	$131.08	$97.98	$81.95	$72.74
0.055		$234.18	$132.67	$99.63	$83.68	$74.55
0.0575		$235.78	$134.26	$101.29	$85.42	$76.38
0.06		$237.40	$135.87	$102.96	$87.18	$78.23
0.0625		$239.01	$137.48	$104.65	$88.96	$80.09
0.065		$240.63	$139.10	$106.35	$90.76	$81.98
0.0675		$242.26	$140.74	$108.07	$92.57	$83.89
0.07		$243.89	$142.38	$109.79	$94.39	$85.81
0.0725		$245.53	$144.03	$111.53	$96.23	$87.75
0.075		$247.16	$145.69	$113.29	$98.09	$89.71
0.0775		$248.81	$147.35	$115.05	$99.96	$91.69
0.08		$250.46	$149.03	$116.83	$101.85	$93.68
0.0825		$252.11	$150.71	$118.62	$103.75	$95.69
0.085		$253.77	$152.41	$120.42	$105.67	$97.71
0.0875		$255.43	$154.11	$122.23	$107.60	$99.75
0.09		$257.09	$155.82	$124.06	$109.55	$101.81
0.0925		$258.76	$157.54	$125.90	$111.50	$103.88
0.095		$260.44	$159.27	$127.74	$113.48	$105.96
0.0975		$262.11	$161.00	$129.60	$115.46	$108.06
0.1		$263.80	$162.75	$131.47	$117.46	$110.17
0.1025		$265.48	$164.50	$133.36	$119.47	$112.29
0.105		$267.18	$166.26	$135.25	$121.49	$114.43
0.1075		$268.87	$168.03	$137.15	$123.53	$116.58
0.11		$270.57	$169.80	$139.07	$125.58	$118.74
0.1125		$272.27	$171.59	$140.99	$127.63	$120.91
0.115		$273.98	$173.38	$142.92	$129.70	$123.10
0.1175		$275.69	$175.18	$144.87	$131.79	$125.29
0.12		$277.41	$176.98	$146.82	$133.88	$127.50
0.1225		$279.13	$178.80	$148.79	$135.98	$129.72
0.125		$280.85	$180.62	$150.76	$138.10	$131.94
0.1275		$282.58	$182.45	$152.75	$140.22	$134.18
			MULTIPLY THE COST PER $1000 BY THE SIZE OF THE			
			LOAN (IN THOUSANDS OF DOLLARS)			

THE BROWN FAMILY DOES A LIFE-CYCLE COST ANALYSIS

The Browns used the life-cycle cost worksheet to compare PV and propane systems.

When the Brown Family was planning their home, they considered two options for providing electricity--the use of a diesel generator and the installation of a stand-alone PV system. They considered the reliability and power availability of these two options to be equal if both systems were maintained in good condition throughout their operational life spans. However, they expected to make three replacements (or rebuilds) of the generator over the 20-year period. They performed the following LCC analysis to help them determine the total cost the two options. They used the LCC Worksheet in Appendix B for eachexample.



LIFE-CYCLE COST ANALYSIS

PROJECT DESCRIPTION: Brown Family/Generator System

ECONOMIC PARAMETERS:

1. Years in Life-Cycle: 20
2. Investment Rate: 7
3. General Inflation Rate: 4
4. Fuel Inflation Rate: 5

Net Discount Rate (2-3) = 3

Differential Fuel Inflation (4-3) = 1

Item	Single Present Worth Year	Uniform Present Worth Years	Dollar Amount		Present Worth Factor (Table 4 or 5)		Present Worth Amount
1. Capital Equipment and installation			7,800	X	1	=	$7,800
2. Operation and Maintenance							
• Labor: Tune-up		20	120	X	14.88	=	1,785
• Yearly Inspection		20	75	X	14.88	=	1,115
• Insurance				X		=	
• Other				X		=	
3. Energy Costs							
• Generator Fuel		20	200	X	18.05	=	3,610
• (Discount Rate = .02)				X		=	
4. Repair and Replacement							
Battery Bank	8		1,500	x	.789	=	1,185
• Battery Bank	16		1,500	X	.623	=	935
• Generator Rebuild	5		1,200	X	.863	=	1,035
• Generator Rebuild	10		1,200	X	.744	=	890
• Generator Rebuild	15		1,200	X	.642	=	770
•				X		=	
5. Salvage							
• 20% Original	20		1,360	X	.258	=	(350)
• Equip. Cost ($6,800)				X		=	
TOTAL LIFE-CYCLE COST	(ITEMS 1 + 2 + 3 + 4 - 5)						$18,775

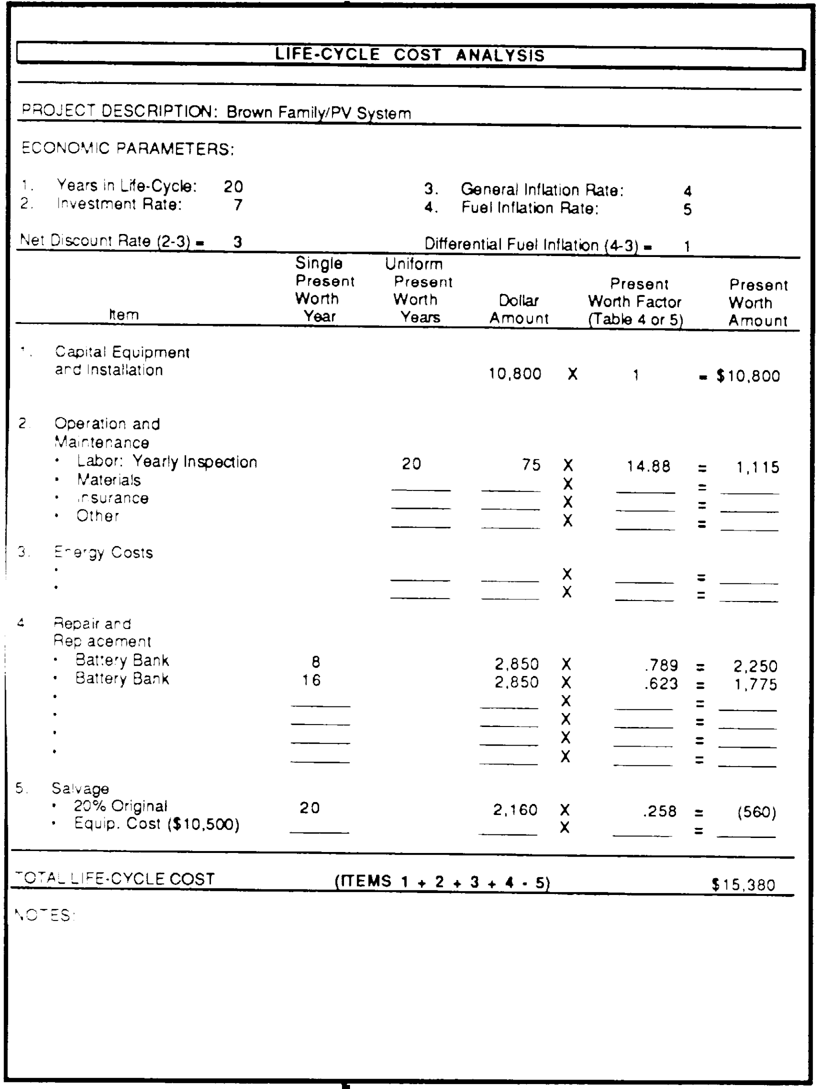
NOTES

LCC for Generator System

The proposed generator system consisted of a 4-kilowatt generator, a 500 ampere-hour battery bank, and a 2.5-kilowatt inverter. The initial installation cost of this system was calculated to be $7,800 U.S. dollars, including design and engineering. The generator would consume $200 a year in fuel, require annual inspections ($75/year) and tune-ups ($120/year), and have to be rebuilt every 5 years at an estimated cost of $1,200. In addition, the battery bank would have to be replaced every 8 years.

The PV system consisted of a 600-watt array, a 950-ampere-hour battery, and a 2.5-kilowatt inverter. The cost of designing and installing this system was estimated to be $10,800. The only future cost for this system was replacing the batter) bank every 8 years and a yearly inspection at $75 per year.

The life-cycle period was set at 20 years to coincide with the expected life of the PV power system. Mrs. Brown thought the family could earn a 7 percent rate of return on a 20 year fixed investment, and general inflation was assumed to be 4 percent a year. Thus, their net discount rate was set at 3 percent. Fuel inflation was estimated to be 5 percent a year so the differential fuel inflation was set at 1 percent (5 percent fuel inflation minus 4 percent general inflation). Having made the basic assumptions for each system the family filled out the LCC sheet in Appendix B for both alternatives.



LIFE-CYCLE COST ANALYSIS

PROJECT DESCRIPTION: Brown Family/PV System

ECONOMIC PARAMETERS:

1. Years in Life-Cycle: 20
2. Investment Rate: 7
3. General Inflation Rate: 4
4. Fuel Inflation Rate: 5

Net Discount Rate (2-3) = 3

Differential Fuel Inflation (4-3) = 1

Item	Single Present Worth Year	Uniform Present Worth Years	Dollar Amount		Present Worth Factor (Table 4 or 5)		Present Worth Amount
1. Capital Equipment and Installation			10,800	X	1	=	$10,800
2. Operation and Maintenance							
• Labor: Yearly Inspection		20	75	X	14.88	=	1,115
• Materials				X		=	
• Insurance				X		=	
• Other				X		=	
3. Energy Costs							
•				X		=	
•				X		=	
4. Repair and Replacement							
• Battery Bank	8		2,850	X	.789	=	2,250
• Battery Bank	16		2,850	X	.623	=	1,775
•				X		=	
•				X		=	
•				X		=	
•				X		=	
5. Salvage							
• 20% Original	20		2,160	X	.258	=	(560)
• Equip. Cost ($10,500)				X		=	
TOTAL LIFE-CYCLE COST	(ITEMS 1 + 2 + 3 + 4 - 5)						$15,380

NOTES:

LCC for PV System

The initial capital cost of each system is treated as a payment that occurs in Year 0 of the life-cycle. Even if the money is borrowed, the initial cost is not discounted because financing costs should not be included in any life-cycle cost analysis.

The yearly tune-up cost is calculated under the maintenance heading. This is an annually recurring cost and is discounted using Table 4 at a 3 percent net discount rate. (For the 20 years the factor is 14.877. The annual inspection cost is multiplied by this factor to obtain the present worth estimate.) Energy cost is also an annual cost and is handled the same way, except the discount rate used is differential fuel inflation rate of 1 percent.

Repair costs are discounted using the 3 percent net discount rate and Table 3. At a 3 percent discount rate, the factor for year 8 is 0.789. The repair cost is multiplied by this factor and entered into the presentworth column. This is done for each individual repair, in this case, two battery replacements and three generator rebuilds.

The final cost factor is salvage. Here, 20 percent of the original value of each system's hardware is entered and discounted in year 20. A 7 percent discount rate is used because inflation is not a factor in the salvage value computation.

The present worth figures can now be added, subtracting the salvage value, to give the life-cycle cost of each system. The generator system cost was $18,775 while the LCC of the PV system was $15,380. Since the PV system costs less and provides silent power reliably, the Brown Family confirmed the economic feasibility of their desire to invest in a PV system.

After deciding on the PV system, the Browns wanted to check the annual financing cost of their PV system so they could estimate their cash flow requirements. Using the loan payment chart given in Table 5, they calculated the principal and interest on the $10,500 initial system cost. The result was $991.09 per year or about $83 per month for 20 years assuming a 7 percent interest rate. The Browns felt the independence provided by their PV system was a big bargain.

LIFE-CYCLE COST COMPARISON

Item	Present Worth Generator System	Present Worth PV System
1. Capital Equipment and Installation	$7,800	$10,800
2 Operation and Maintenance		
• Labor: Tune-up	1,785	1,115
• Yearly Inspection	1,115	
• Insurance		
• Other		
3 Energy Costs		
• Generator Fuel	3,610	–
• (Discount Rate = .02)		
4. Repair and Replacement		
• Battery Bank, yr. 8	1,185	2,250
• Battery Bank, yr. 16	935	1,775
• Generator Rebuild, yr. 5	1,035	
• Generator Rebuild, yr. 10	890	
• Generator Rebuild, yr. 15	770	
5. Salvage		
• 20% Original	(350)	(560)
TOTAL LIFE-CYCLE COST	$18,775	$15,380

NOTES:

Go PV

SPECIFIC APPLICATIONS

There are some applications that deserve extra attention because of their importance or uniqueness. This section includes a discussion on four such areas--water pumping, hybrid systems, direct-drive systems, and cathodic protection systems. Specific examples of these systems are included in the yellow pages of this handbook.

WATER PUMPING SYSTEMS

What pump should I use?

What about water storage?

Do I use batteries?

Should I use a tracking array?

USE

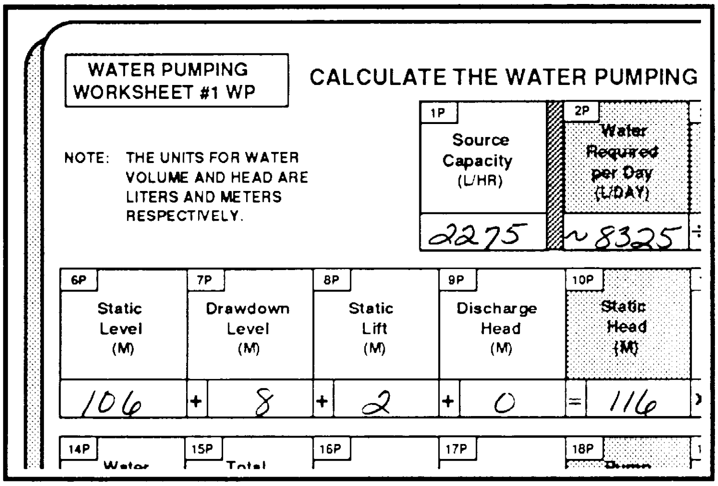
Water pumping is an application common around the world. Stand-alone PV systems are being used increasingly for intermediate sized pumping applications--those between hand pumps and large generator powered systems. The advantages of PV powered pumps are

- Low maintenance,
- No pollution,
- Easy installation,
- Reliability,
- Possibility of unattended operation,
- Capability to be matched to demand.

The disadvantages are the high initial cost and the variable water production.

To accurately size a PV pump, the characteristics of the source must be known.

If a reliable pump system is to be realized, the system designer must be familiar with the well, the storage system, the terrain surrounding the well, and manufacturers' data on available pumps. Using water pumping worksheet, WP 1, a portion of which is shown in the inset, will allow an accurate calculation of the energy needed to pump the water required. Four example water pumping systems are included in this handbook.



WATER PUMPING WORKSHEET #1 WP

CALCULATE THE WATER PUMPING

NOTE: THE UNITS FOR WATER VOLUME AND HEAD ARE LITERS AND METERS RESPECTIVELY.

1P Source Capacity (L/HR)	2P Water Required per Day (L/DAY)
2275	~ 8325

6P Static Level (M)		7P Drawdown Level (M)		8P Static Lift (M)		9P Discharge Head (M)		10P Static Head (M)
106	+	8	+	2	+	0	=	116

14P Water

15P Total

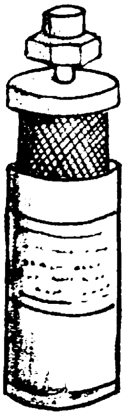
16P

17P

18P

The first requirement is an estimate of the water needed and the amount of water that can be supplied by the source (flowrate). If the water needs vary throughout the year, a monthly profile should be drawn and matched to a monthly profile of the production capability of the water source. It is important to know the worst case conditions, so data on production and demand for the driest months of the year should be available or estimated. If the capability of the water source is limited, the designer must take action. One thing that can be done is to improve the water source or develop other sources. Using a smaller pump is another option but the availability of different size pumps is limited. Another method is to incorporate batteries into the system and distribute the pumping time over a longer period. This is one of two reasons to use batteries in a water pumping system. The other is if the pumping time needs to be controlled--usually to pump at a high flowrate for a short time. An example might be a residential system with storage tanks when you want to pump all the water for the household during times when other loads are not operating. Although using batteries in a system will maximize the pump efficiency--because of the steady operating conditions presented to the pump and motor--most water pumping systems do not contain batteries. It is usually less expensive to store water than to store electricity. If a tank is available, the system can pump all day and the water stored for later use. Gravity-feed or a small pressure pump can then be used to deliver the water to the user.

Talk to several pump manufacturers. Investigate several pumps.


DC Pump

Another variable that must be specified is the pumping time factor. For the design method presented in this handbook, this time factor is referenced to the number of daily peak sun hours. If a direct-drive centrifugal pump is used, the pumping time factor will equal 1.0. In other words, the pump will operate with varying efficiency through all daylight hours but that is equivalent to operating at the rated efficiency during the peak sun hours. If batteries are used, the pumping time factor would be equal to the hours of scheduled operation divided by the number of peak sun hours. If a linear current booster or peak power tracking controller is used between the array and the pump in a direct drive system, the pumping time factor should be 1.2. This takes into account the improvement in pump performance that these devices achieve.

The pump size, operating time, and total power demand can be calculated if the efficiency of the pump and the depth of the water are known. The efficiency of specific pumps depends on pump type and operating conditions. For centrifugal pumps the efficiency is a function of head, flow, and solar insolation, all of which will vary throughout the day. Under some conditions the average daily efficiency, called wire-to-water efficiency, can be as little as one-third the peak pump efficiency. In contrast, the efficiency of a displacement pump changes little with changing solar conditions. Some typical wire-to-water efficiencies are given in Table 6.

TABLE 6
Measurements of Wire-to-Water Efficiency

Head (m)	Type Pump	Wire-to-Water Efficiency (%)
0-5	Centrifugal	15-25
6-20	Centrifugal with Jet	10-20
	Submersible	20-30
21-100	Submersible	30-40
	Jack pump	30-45
>100	Jack pump	35-50

Many pumping systems use PV arrays mounted on one-axis trackers. Tracking the array not only increases the hours of operation (peak sun hours) but also provides a more consistent operating point (voltage and current) for the pump motor. Therefore, tracking is recommended for latitudes less than 40°.

Batteries can be used to control pumping time.

SIZING

Worksheet WP 1 can be used to calculate the energy needed by the water pumping load. The system design can then be completed using Worksheets 2 through 5 that are common to any other PV system sizing. Finally, Worksheet WP 2 can be filled in to summarize the key factors of the pump system. Copies of WP 1 and WP 2 are provided in Appendix B. The key factors required are

- water source capacity,
- water volume required per day,
- solar insolation availability,
- pumping time,
- static water level,
- drawdown level,
- discharge head,
- pipe size friction,
- pumping subsystem efficiency.

Some of the terms are defined in Figure 18. The most important is total dynamic head (TDH) which is the sum of the static head, the drawdown, and the equivalent head caused by friction losses in the pipe. TDH is expressed in feet or meters and is dependent on the flow rate. It must be specified at a certain flow rate such as a TDH of 10 meters at 250 liters per hour. The result of the calculations is the corrected ampere-hour load, the same value determined using Worksheet 1 for a non-water pumping loads.

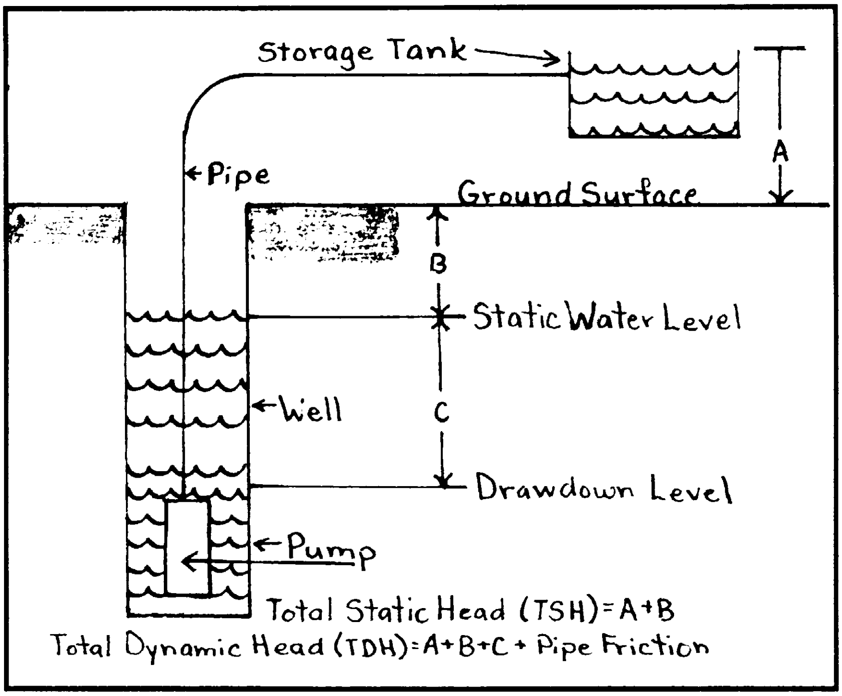
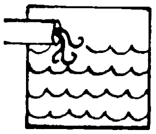


Figure 18. Water Pumping System Terms.

Worksheet WP 2 provides a method of calculating the daily total water pumped and the pumping rate.

CHARACTERISTICS

There are two broad categories of pumps being used in stand-alone PV systems around the world--rotating and positive displacement--and there are many variations on the designs of these two basic types. Examples of the rotating pump type are centrifugal, rotating vane, or screw drive. These pumps move water continuously when power is presented to the pump. The output of these pumps is dependent on head, solar radiation (current produced), and operating voltage. They are well suited for pumping from shallow reservoirs or cisterns. They can be tied directly to the PV array output but their performance will be improved by using an electronic controller such as a linear current booster to improve the match between the pump and PV array.



Water storage is usually the lower cost option for deeper wells.

Positive displacement pumps move "packets of water." Examples are diaphram pumps and piston pumps (jack pumps). These are typically used for pumping water from deep wells. Their output is nearly independent of head and proportional to solar radiation. Jack pumps should not be connected directly to a PV array output because of the large load current changes during each pump cycle. Peak power controllers are recommended. The controllers adjust the operating point of the PV array to provide maximum current for motor starting and then keep the array operating at the maximum power conditions Some system designers use batteries between the jack pump and the array to provide a stable voltage source to start and operate the pump. Usually they are not sized to provide nighttime pumping, but only to give stable system operation.

Batteries can provide a steady operating voltage to the dc motor of a pump.

Pumps are also categorized as surface or submersible. Surface pumps have the obvious advantage of being more accessible for maintenance. When specifying a surface pump you must distinguish between suction and lift. A pump may be installed a few feet above the water level, with a pipe from the pump to the water. The maximum length of the pipe is determined by the suction capability of the pump. The pump may then "lift" the water to a storage tank above the pump. The elevation of the storage tank is determined by the lift capability of the pump. Most submersible pumps have high lift capability. They are sensitive to dirt/ sand in the water and should not be run if the water level drops below the pump. The type of pump will depend on the water required, the total dynamic head, and the capability of the water source. Most dealers will help you specify the best pump for your application.

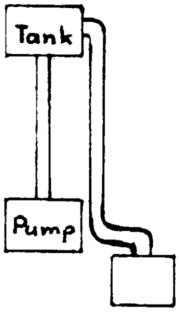
Both rotating and displacement pumps can be driven by ac or dc motors. The choice of motor depends on water volume needed, efficiency, price, reliability, and availability of support. DC motors are an attractive option because of their compatibility with the power source and because their efficiency is usually higher than that of ac motors. However, their initial cost is higher, the selection may be limited in some countries, and the brush type motor requires periodic maintenance. Some brushless dc motors are available and promise improved reliability and decreased maintenance. AC motors require a dc to ac inverter, but their lower price and wider availability are advantages.

In water pumping systems, storage can be achieved by using batteries or by storing the water in tanks. Adding batteries to a system increases cost and decreases reliability. Water storage is better for most applications. However, considerable evaporation losses can occur if the water is stored in open tanks or reservoirs. Closed tanks large enough to store several days water supply can be expensive. In some countries, these tanks are not available or the equipment necessary to handle, move, and install the tanks may not be available. Also, any water storage is susceptible to vandalism and pollution.

INSTALLATION

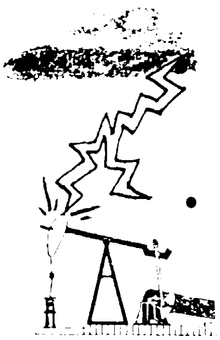
Many failures of PV pumping systems are caused by pump problems. The PV power supply has much higher reliability than the pump/motor subsystem. A good installation of the pumping hardware will increase reliability. Some things to watch for are described below.

- **Varying Water Levels** - The water level in a well may vary seasonally, daily, or even hourly. The water level in some wells in rocky areas has been reported to drop as much as 75 feet during pumping. The pump must be mounted to keep the water inlet below the water level at all times. If the replenishment rate of a well is lower than the maximum possible pumping rate, a level switch or mechanical valve should be included to protect the pump from operating dry. Float switches should be used on storage tanks if the volume of the tank is smaller than the daily pump rate. This will prevent wasted water or worse, pump damage due to overheating.



Long pipe runs and bends in the pipe increase friction losses and reduce flow rates.

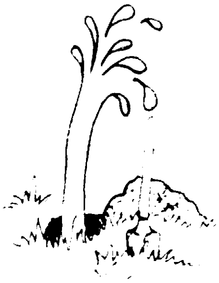
- **Protect the Pump Input** - Sand is a primary cause of pump failure. If the well is located where dirt and sand may be pulled into the pump, a sand screen should be used. Most pump manufacturers offer this option or they can recommend methods for limiting the risk.
- **Ground the Equipment** - Water pumps attract lightning because of the excellent ground they provide. If possible, do not locate the pump system on high ground. Consider erecting lightning rods on higher terrain around the pump. Ground the pump motor, the array frame, all equipment boxes, and one system conductor to the well casing (if metal) or to a bare conductor running down to the water level. Never use the pipe string to the pump as a ground, because the ground would be interrupted when maintenance was being performed. Use of movistors to protect electronics is recommended in areas prone to lightning.



Water pumps draw lightning because of the excellent ground they provide.

- **Avoid Long Pipe Runs** - Friction losses can significantly increase the head and thus the size of the PV array. Friction losses depend on the size of the pipe, the length, the flow rate, and the number of bends in the pipe. Because the output of a stand-alone PV system is power-limited and varies throughout the day, it is particularly important to keep friction losses low. Pump system efficiency can drop to near zero if a large friction loss must be overcome. Try to limit the friction loss to less than 10 percent of the head. This can be done by oversizing the pipe, eliminating bends and junctions, and reducing flow rate. Data on pipe size and friction rates are available from pump manufacturers.

- **Use Steel Pipe** - Steel pipe is recommended for use in the well, particularly if submersible pumps are used. Plastic pipe may break. However, plastic pipe provides an inexpensive way to run water from the well to the storage tank or end user. Fiberglass sucker rods may be used in a well with a jack pump. They are lighter than metal, buoyant, and much easier to pull for pump maintenance. The pipe diameter should be larger than the pump cylinder. This will allow the pump leathers to be changed by pulling the sucker rod without pulling the pipe.



Mark pipe location for future reference.

- Protect the Control Equipment - All electronic control equipment should be housed in weather-resistant boxes. All wires should be approved for outdoor use or installed in conduit. Any cables used for submersible pumps should be appropriate for that application. Pump manufacturers will give recommended wire types for their equipment.

- **Protect the Well** - Use sanitary well seals for all wells. Bury pipes from wellhead to tank at a depth that will insure the pipe will not be broken by traffic or during future trenching or excavation. Mark pipe runs for future reference.

HYBRID SYSTEMS

What advantages do hybrid systems offer?

How do I design a hybrid system?

USE

A hybrid power system has more than one type of generator-usually a gasoline or diesel-powered engine generator and a renewable energy source such as PV, wind, or hydropower system. A W-engine hybrid is the only type considered in this handbook. A hybrid system is most often used for larger applications such as village power; residential systems where generators already exist; and in applications like telecommunications where availability requirements are near 100 percent. Almost all PV-generator hybrid systems include batteries for storage.

The most common configuration for a W-generator system is one in which the PV array and the generator each charge the batteries. A block diagram is shown in Figure 19. This configuration is intended to optimize the use of both power sources during normal operation. In many systems, the photovoltaic array is sized to supply power to the load during normal conditions. The generator is used only if solar radiation is low for several days in a row, or if load demand is unusually high. The generator is run for a short period of time near its optimum operating point, typically at 80 to 90 percent of rated power. This kind of operation reduces generator maintenance and fuel costs and prolongs the useful life of the generator.

For some applications, a PV-generator may be a good option.

Other advantages of using a hybrid system are

- **Improved Economics** - A large part of the cost of PV stand-alone systems results from the need to size the array and batteries to support the load under worst-case weather conditions. In many applications, this marginal power may be less expensive if provided by a generator. In regions with

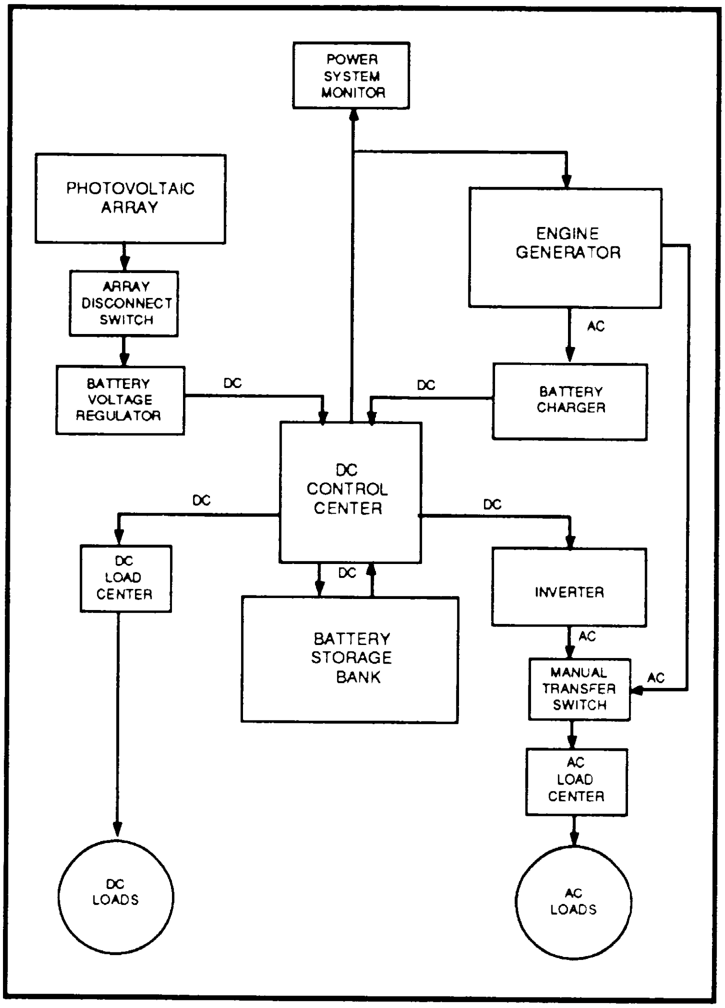
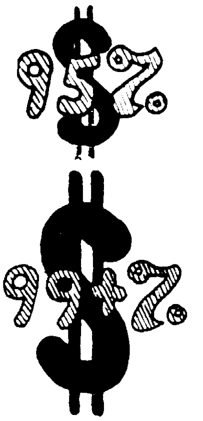


Figure 19. PV-Hybrid System Block Diagram.

variable climate, where average daily insolation in winter is two or three times less than in summer, the use of a hybrid system may be a good option. Figure 20 demonstrates how the marginal cost of photovoltaic systems changes relative to power availability. This plot indicates that a PV system providing 90 percent of the load will cost about $3,600 but the cost rapidly goes past $8,000 before an availability of 98 percent is reached. It may be more economical to provide some of this power with a generator. However, maintenance, logistics, and fuel costs can be quite expensive for generators operating in remote areas. These factors must be considered in any cost estimate of the hybrid system.



It is expensive to get the last 5 percent of system availability with PV.

- **Lower Initial Cost** - An engine generator costs less than a PV system of equal size.

Increasing the size of the PV array will increase the reliability of a hybrid system.

- **Increased Reliability** - The two independent power systems provide redundancy and possibly greater overall reliability if the hybrid system is properly maintained and controlled.

Design Flexibility - The design of a hybrid system depends on the load mix between the engine generator and the PV system. As the size of the PV array increases the operating time of the generator goes down. This saves fuel, lowers maintenance, and prolongs generator life but theinitial cost will be higher than a power system with a smaller PV array. For a hybrid system the size of the battery bank is usually smaller than for a stand-alone PV system designed for the same application. This is because the fueled generator will be available to keep the battery state-of-charge above the recommended limit. When sizing the batteries, be sure the generator charging current does not exceed the recommended charge rate for the battery (usually less than C/3).

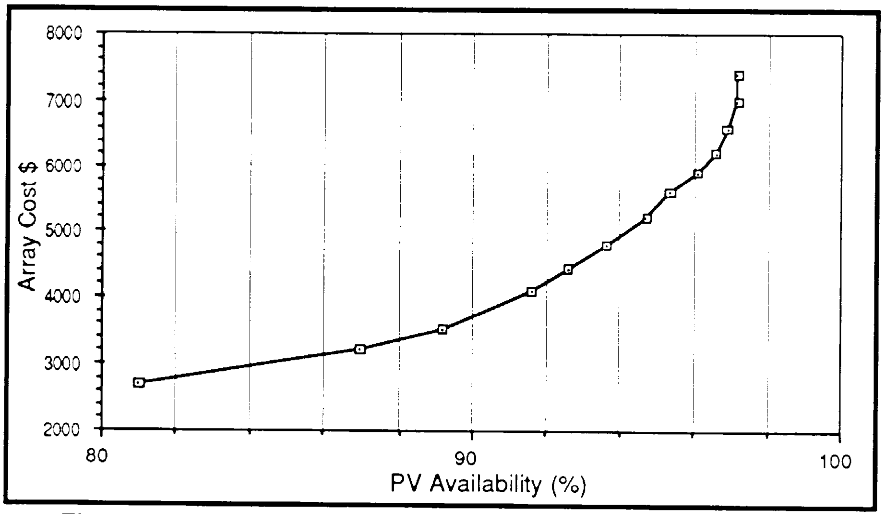
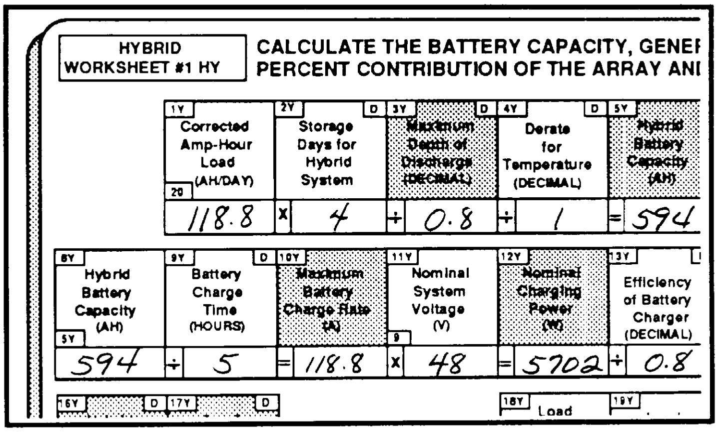


Figure 20. Cost v. Availability for a PV-Only System in the Northeastern United States.

SIZING

Two hybrid worksheets, HY 1 shown in the inset, and HY 2 are provided in Appendix B. The key factors to be determined are

- the load mix between PV and generator,
- the size and type of generator, and
- the battery size.



HYBRID
WORKSHEET #1 HY

CALCULATE THE BATTERY CAPACITY, GENE
PERCENT CONTRIBUTION OF THE ARRAY AN

1Y Corrected Amp-Hour Load (AH/DAY) 20		2Y D Storage Days for Hybrid System		3Y D Maximum Depth of Discharge (DECIMAL)		4Y D Derate for Temperature (DECIMAL)		5Y Hybrid Battery Capacity (AH)
118.8	x	4	÷	0.8	÷	1	=	594

8Y Hybrid Battery Capacity (AH) 5Y		9Y D Battery Charge Time (HOURS)		10Y Maximum Battery Charge Rate (A)		11Y Nominal System Voltage (V) 9		12Y Nominal Charging Power (W)		13Y Efficiency of Battery Charger (DECIMAL)
594	÷	5	=	118.8	x	48	=	5702	÷	0.8

16Y D 17Y D

18Y Load 19Y

The sizing method assumes that a stand-alone PV system has already been considered--the load has been estimated and the solar radiation at the site is known. The primary decision is the load mix between generators. Selecting the mix is simplified by using the graph given in Figure 21.

The designer selects a hybrid array to load ratio for the system realizing that the higher up the curve, the higher the percentage of load supplied by the PV array. The load mix will be a key determinant in the type and size of the generator and the battery. The most cost-effective system is obtained by selecting a point on or slightly below the knee of the curve. For example, a hybrid array/load ratio of 0.25 should give a hybrid system design where the PV array supplied 90 percent of the annual load demand. An array/load ratio of 0.15 would give a system with lower initial cost because the amount of load provided by the PV array would be about 57 percent. The generator would operate more in this latter design with corresponding increases in fuel cost and maintenance. If the generator is in a remote location the cost of this maintenance may be exorbitant. These are the design tradeoffs that must be made.

PV is a slow-rate battery charger--a generator is a high-rate charger.

Desired operating time for the generator dictates PV/generator mix.

If high reliability is required, the system should be designed for 90 to 95 percent PV contribution. The generator is used only for back-up during worst-case conditions, typically in the winter months when it is most difficult to get a generator started. Therefore, having two power sources at an unattended site does not, in itself, guarantee 100 percent reliability. The control system must be properly designed for fail-safe operation

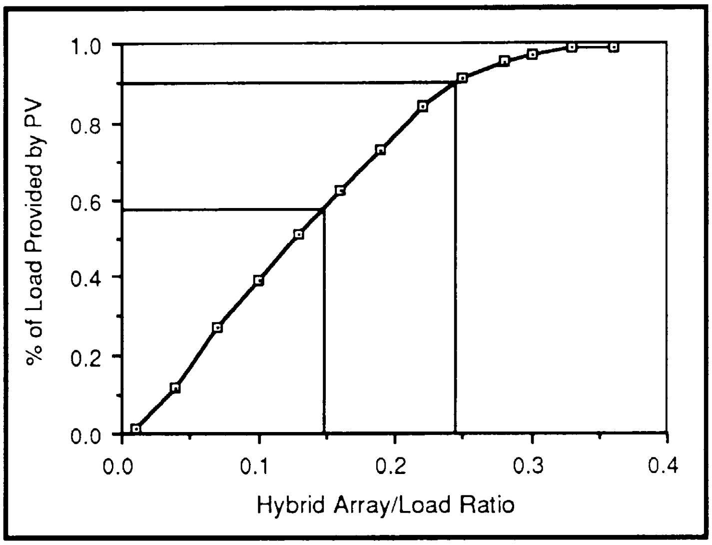


Figure 21. PV-Generator Mix Plot for Omaha.

and regular maintenance performed, particularly on the generator. Also, the control system for a hybrid system is more complex because the regulation of the batteries and load must be maintained under all operating conditions.

All generators require periodic routine maintenance (i.e., oil change, engine tuneup, and eventually engine rebuilding). The designer should always look carefully at the generator service requirements, see Table 7, which depend on the run time and thus the generator's electrical power contribution to the hybrid system. At a remote unmanned microwave relay site, the desired generator maintenance interval for oil change and engine tuneup may be only once a year. In contrast, the owner of a hybrid home power system is often willing to perform this routine maintenance monthly. The type of generator and the percentage of load demand met by the generator depend on these issues.

With a generator available for back-up power, the battery size in the hybrid system may be decreased without lowering system availability. However, the battery must be carefully matched to the loads and power sources. To extend battery life, the designer must use a reliable controller to protect the smaller battery and prevent frequent cycling or excessive depth of discharge. The batteries must have sufficient capacity to provide the maximum peak power required by the load and to accept the maximum charge current provided by the generator.

The battery size can be decreased if a generator is available.

The discharge capability of the battery is a function of the battery size and state of charge. Batteries that are discharged quickly will drop in voltage, and may shut down the inverters and/or loads. A discharge factor of 5 or greater is recommended. Like the charge factor, this number is given relative to the rated capacity, C, of the

TABLE 7
Generator Information

Type	Size Range (kW)	Applications	Cost (&/W)	Maintenance Intervals		Engine Rebuild (Hours)
				Oil Change (Hours)	Clean, Tune-up (Hours)	
Gas* (3600 rpm)	1 - 20	Cabin, RV Light Use	0.50	25	300	2,000 - 5000
Gas (1800 rpm)	5 - 20	Residence Heavy Use	0.75	50	300	2,000 - 5,000
Diesel	3 - 100	Industrial	1.00	125-750	500 - 1,500	6,000

*Gasoline, propane, or natural gas

battery, i.e., and a 100-ampere-hour battery should not be discharged at more than a 20 ampere rate for a long period.

Conversely, the batteries must have sufficient capacity to accept the maximum charge current from the generator/charger and the PV system. If not, the battery may be damaged by the high current. Few batteries can withstand a charge rate greater than C/3 amperes.

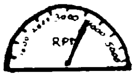
GENERATOR SELECTION

The choice of the size and type of generator is critical to successful hybrid design. Several types of generators, their size range, applications, and approximate cost/watt are given in Table 8. The portable, light-duty generator is the least expensive option for a small intermittent load where reliability is not a major factor. For industrial systems with high reliability requirements, a stationary heavy-duty generator is recommended. Important considerations in choosing the type of generator are

- **Size and Nature of the Load** - Consider the size of the load, the starting requirements, and running time.

- **Fuel Type** - Consider fuel availability, handling and storage requirements, and environmental factors, such as temperature and likelihood of contamination. Propane or LPG fuel is an excellent choice for many remote homes because it is readily available in most parts of the U.S., requires no handling on the part of the homeowner, is easily stored, and is excellent for cold weather starting. Although diesel fuel is widely available, contamination can occur and lead to difficulties in cold weather starting.

Efficiency falls rapidly if the generator is operated at low load.



- **Generator Running Speed** - Choose a generator running speed suitable for the expected run time. If the generator is only used occasionally to charge a battery bank, a 3,600 rpm unit may suffice. If the generator will be used over 400 hours per year, a unit with a lower running speed, 1,800 rpm, is recommended.

- **Compatibility with Controls** - Check the generator specifications for details on operational control and whether the generator can be integrated into a central control system. Larger generators often have built-in control systems to prevent the generator from starting or operating when engine failure might occur; i.e., when oil pressure is low.

When the generator size is calculated, the main consideration is operating efficiency. Generators operate most efficiently when running near their rated output power. Efficiency can drop by 50 percent or more when operating at low loads. This will result in greater maintenance costs and shorter generator lifetime. Size the generator to provide the current needed to operate the loads and charge the battery efficiently. Power losses in the battery charger and those losses due to environmental conditions and fuel type must be accounted for. The generator's capacity to supply power under the system's actual operating conditions depends on the current required to start the load, the duration of generator run time, fuel consumption at the desired running efficiency, and maintenance requirements under real conditions (i.e., considering temperature, altitude, dust, moisture, and contamination). This information is provided in the generator and battery charger specifications.

CONTROL

Integration of a generator into a PV system requires a more sophisticated control strategy. Most controllers are custom designed by an experienced electronic engineer / technician. Controls for PV-generator systems perform two main functions--battery regulation and subsystem management. Battery regulation is the same as the control process in a stand-alone PV system where batteries must be protected against excessive charging and discharging. Subsystem management of the generator, photovoltaic array, and load requires starting or stopping the generator, and connecting or disconnecting the loads or portions of the PV array. Finally, it may be desired to actuate alarms, either on-site or via telephone link, in the event of system malfunction or to automatically provide an equalization charge to the batteries. Remember, the more one requires of the control system, the higher the price and the higher the chance of failure.

Most control subsystems are custom built for hybrid systems.

DIRECT-DRIVE SYSTEMS

What happens if I wire a module directly to a small load?

USE

Some loads may be powered directly from a PV array. Many of the loads are small and require only a few watts of power. Since no batteries are used, the load will operate only when the sun is shining, There must be a good match between the daytime operating hours and the load demand profile. A good example is an attic fan. A PV powered direct-drive attic fan moves more air on sunny days than on cloudy ones, thus matching the need for attic cooling. Direct-drive systems seldom operate at their optimum operating point because of the varying solar conditions and load power requirements. Because the characteristics of the load determine the operating point of the PV module, the primary design requirement for these applications is the match of the load impedance with the PV module's optimum output.

Many companies are selling 'kits' that include the PV source and the load.

Match load and solar availability profiles.

To evaluate an application for a direct-drive power source consider the following

- Does the daily load demand profile match the solar profile?
- Are the needs of the load compatible with the seasonal variation of solar insolation at the application site? Will the load be damaged by operating at or near open circuit voltage or by high currents caused by high solar radiation?
- Does the direct-drive system need to be transportable?

Finally, check with local solar system dealers to see if a complete system (like an attic fan) is available. A packaged system will likely be less expensive than a custom designed system.

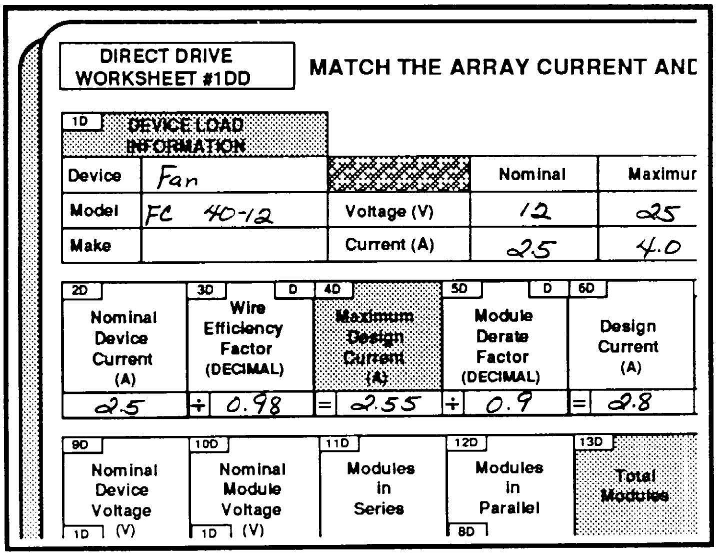
SIZING

As with all stand-alone PV systems, the determination of the load is the first requirement for a direct-drive system. Since the load will seldom operate at its optimum point, try to determine how it will perform over a range of input voltage and current. The main thing to prevent is any damage to the load. Two worksheets are provided in Appendix B and a portion of Worksheet DD 1 is shown in the inset. They are meant for small systems such as attic fans, blowers, toys, etc., and not for direct-drive water pumps. Worksheet DD 1 can be used to describe the load, the expected losses, and the number of modules required. Worksheet DD 2 is for listing the wiring and protection components. The calculations are straight-forward. The keys are to:

- Make sure the voltage of the load and module are compatible. The load must be able to withstand the module's maximum open-circuit voltage which will occur on the coldest day.

- Select a module that provides the necessary current for rated load operation at the average insolation. For instance, if the solar insolation is typically 900 w/m² on a clear day, select a module that produces the desired current at that level of insolation. However, check that the load will not be damaged by a current produced at 1,200 w/m².

Make sure flexible sunlight resistant wire is specified and used. A manual disconnect switch is recommended for fixed installations to give the user daytime control over the load. If the system is portable, the module can be covered or turned away from the sun to turn off the load.



DIRECT DRIVE WORKSHEET #1DD

MATCH THE ARRAY CURRENT AN

1D DEVICE LOAD INFORMATION

Device	Fan		Nominal	Maximu
Model	FC 40-12	Voltage (V)	12	25
Make		Current (A)	25	4.0

2D Nominal Device Current (A)	3D D Wire Efficiency Factor (DECIMAL)	4D Maximum Design Current (A)	5D D Module Derate Factor (DECIMAL)	6D Design Current (A)
2.5	÷ 0.98	= 2.55	÷ 0.9	= 2.8

9D Nominal Device Voltage 1D (V)	10D Nominal Module Voltage 1D (V)	11D Modules in Series	12D Modules in Parallel 8D	13D Total Modules

CATHODIC PROTECTION

Why do we need it? ***How does It work?*** ***When should PV be used?***

BACKGROUND

Methods for preventing corrosion on underground metal structures (cathodic protection) have been known for over 150 years. However, cathodic protection was not widely practiced in the United States until the 1940's. Since that time protection systems have become standard for many pipelines, railroads, bridges, wharves, towers, etc. The U.S. Environmental Protection Agency now requires cathodic protection for all buried storage tanks containing petrochemicals. Corrosion is caused by an oxidation process that occurs when electrons leave a metal that is immersed in an electrolyte. In practical situations, the electrolyte consists of water or the water in the ground. This water will have impurities and may be acidic or salty. Furthermore, the consistency of the electrolyte will vary from season to season and even day to day. This makes the design of a cathodic protection system a job for experienced experts. However, the basic concept is simple. If the loss of electrons from the buried metal can be prevented, there will be no corrosion. Cathodic protection systems are used to reverse the current flow caused by the electrons leaving the metal and going into the electrolyte. In most cases this requires a low voltage dc power system--an ideal application for PV systems.

Corrosion control for buried storage tanks is mandated by the federal government.

Burying sacrificial anodes is a common practice to protect selected metal

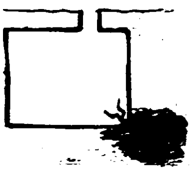
Almost all metals corrode to some extent when they are located in a damp environment. Some materials like metallic sodium will react violently when it comes into contact with water. At the other end of the oxidation potential scale are the noble metals such as gold which will not react unless it is placed in a strong acid solution. Most of the metals that are of interest to the cathodic protection engineer contain some iron. When iron or an iron alloy are buried, a chemical reaction will occur where electrons will leave the metal and enter the surrounding electrolyte. This causes corrosion and the method of slowing or stopping these electrons from leaving the metal is called cathodic protection. Stopping the electrons can be accomplished if a voltage that is slightly larger than the oxidation potential is set up between the metal to be protected and the electrolyte. Setting up this voltage can be done in two ways; with an external power supply, and by burying a metal with more tendency to corrode than the protected metal. In this latter case, the so-called sacrificial anode, usually made of magnesium or zinc, will corrode first and setup a potential that will "protect" the other metal in the electrolyte. The sacrificial anode method does not require an external voltage source and will not be considered in this handbook except to say that the material of the sacrificial anode must corrode easily; this reduces the potential between the metal to be protected and the surrounding electrolyte. However, the sacrificial anode loses effectiveness as it corrodes and has a finite lifetime.

The other method of corrosion control is to use an external voltage source to overcome the galvanic potential between the buried metal and the anode. For this type of protection system, the anode is made of an inert material such as graphite, high-silicon iron, or one of the noble metals, (The latter are seldom used because of their high cost.) The impressed voltage, which can be provided with a PV system, causes the current to flow from the anode to the metal to be protected. The amount of current required depends on many factors such as the type of metal, the area to be protected, the ever changing composition of the electrolyte and the type of anode used. The voltage depends on the amount of current required and the total resistance in the cathodic protection circuit. Although only a few volts are required for many small applications, the customary way to obtain power has been to rectify ac utility grid power to low voltage dc power and in almost all cases, the current is supplied continuously. Because dc voltage is applied to the metal to be protected, some corrosion control engineers have started to use PV power supplies for some of their applications. While most include batteries to provide the required current continuously, there is some research being considered to determine how much protection can be given by a PV only system that reverses the current only when the sun shines. If this type of protection can be shown to lengthen the life of the buried metal by some significant amount of time, we may see PV modules connected to a pipeline every mile or so–a breakthrough for economical cathodic protection. In any case, using PV power systems eliminates the need for utility power and the losses inherent in rectifying high voltage ac power to low voltage dc power.

Corrosion is increased if the soil is damp.

Impressing a current with an external power supply is a more controllable technique than the sacrificed anode method and is almost always used if a power supply is available in the area. One or more anodes are buried in the vicinity and the external voltage source connected between these anodes and the metal to be protected. The amount of current required depends on the amount of metal in contact with the electrolyte, the effectiveness of the metal's coating, and the characteristics of the soil where the metal is buried. If the resistivity of the soil around the buried metal is less than 1,000 ohms per cubic centimeter (Ω /cc), the number of electrons leaving the metal will be high enough to cause severe corrosion. A resistivity of 10,000 to 50,000 Ω /cc will cause mild corrosion and corrosion may not be a problem at resistivities higher than 100,000 Ω /cc. Estimating the soil resistivity is not easy but in general, a sandy, dry soil will have a resistivity greater than 20,000 Ω /cc whereas a salt water marsh may be below 1,000 Ω /cc. Locating the metal in the highest resistivity soil available will lower the current required for cathodic protection. When the current requirement is known, the PV power source can be sized using techniques presented in this handbook.

USE



Corrosion begins at the surface of bare metal and usually causes pitting that will eventually penetrate the metal. The current required to protect a bare metal surface can be greatly reduced by using protective coating on the metal prior to installation; a coating efficiency of 99 percent or better is commonly achieved by wrapping a pipe that is to be buried. Soil resistivity is the single, greatest, rapidly changing variable in cathodic protection systems. Although metals, surface area, anode type and polarization will change relatively little over the life of the particular system, soil resistivity changes significantly with soil texture, organic matter, solute content, location, depth, etc. A mile-long pipeline can easily transsect three or more soil types having a range in soil properties and can experience continuous gradients in moisture content. Therefore, accurately specifying a cathodic protection system requires much data on the conditions at the site. It is common to do a series of tests using a temporary anode. A low voltage dc generator is used to impress a current on system and the voltage is measured near the temporary anode. Even with these test data, it is known that the soil resistivity will change with weather conditions. For this reason many cathodic protection systems include a variable resistor to allow periodic adjustments of the load current to compensate for changing soil moisture, corroding anode surface area, and polarization effects. More recently, electronic controllers have been designed and used to compensate for changes in soil resistivity.

SIZING

As with all PV systems, load determination is central to system sizing. A load current greater than or equal to the corrosion current is necessary to protect the metal structure. However, overcurrent is wasted current, and can be detrimental because it may cause blistering of protective coatings. The required current depends upon the following:

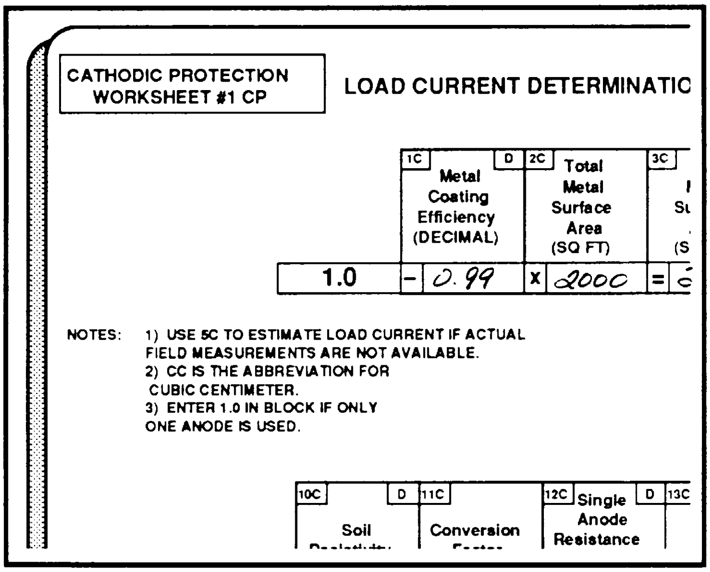
- The exposed metal surface area and metal type,
- The metal's coating effectiveness,
- The polarization effect of applied current on the metal surface,
- The soil resistivity,
- The shape of the metal surface (cylinder, I-beam, flat plate, etc.),
- The isolation from another cathodic protection system (stray current elimination),
- The type and size of anode used.

The systems must provide enough current to meet the worst-case demand but not enough to damage a structure when conditions are favorable. Two special cathodic protection worksheets (a portion of Worksheet CP is shown below) can be used to estimate the load current if better information is not available. These, plus the normal worksheets, all of which are provided in Appendix B, can be used to complete the cathodic protection system sizing.

INSTALLATION

The installation of the anodes is critical to the performance of the cathodic protection system. The number used, their orientation to one another and with the metal to be protected, and their depth are decisions that require expert advice, particularly for larger systems. Anodes can be installed several hundred meters from the structure to be protected to take advantage of optimum soil conditions and to spread the effect over a larger area such as a pipeline. Alternatively, anodes may be placed around or on either side of a tank, for instance, and be located only a few meters from the protected structure. In either case, a thick bed of prepared petroleum coke or coal coke is usually used to surround the anode. This reduces the resistivity of the soil surrounding the anode and provides a measure of consistency to the soil conditions. Multiple anodes may be required to provide the protection current to all the uncoated areas of the metal structure to be protected. Also, most designers try to limit the current from a single anode to less than 2 amperes because the cost of rectifiers goes up for higher power units. (This will not be a limitation with PV power systems and may offer another reason to use this renewable power source.) If multiple anodes are used, their interaction must be considered. The resistance of two parallel anodes placed close to one another will be more than one-half the resistance of the single anode. For instance, a pair of anodes 100 feet apart will have resistance equal to 51 percent of a single anode; if they are 10 feet apart the combined resistance will be 57 percent. The interaction increases and becomes more complex with more than two anodes, particularly if they are located in a non-uniform geometry. A correction table is given with the instructions for the cathodic protection worksheets in Appendix B.

Anode installation is expensive.



CATHODIC PROTECTION WORKSHEET #1 CP

LOAD CURRENT DETERMINATI

		1C Metal Coating Efficiency (DECIMAL) D		2C Total Metal Surface Area (SQ FT)		3C
1.0	–	0.99	x	2000	=	

NOTES: 1) USE 5C TO ESTIMATE LOAD CURRENT IF ACTUAL FIELD MEASUREMENTS ARE NOT AVAILABLE.
2) CC IS THE ABBREVIATION FOR CUBIC CENTIMETER.
3) ENTER 1.0 IN BLOCK IF ONLY ONE ANODE IS USED.

10C Soil D	11C Conversion	12C Single Anode Resistance D	13C

RECOMMENDED READING

Home Power Magazine, P.O. Box 520, Ashland, OR 97520.

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Risser, V. Vernon, Hybrid Power Systems: Issues & Answers, PV Design Assistance Center, Sandia National Laboratories, October 1992.

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Thomas, M. G., Water Pumping: The Solar Alternative, PV Design Assistance Center, Sandia National Laboratories, SAND87-0804, April 1987.

Thomas, M. G., Post, H. N., and Van Ansdall, A. Photovoltaics Now--Photovoltaic Systems for Government Agencies, PV Design Assistance Center, Sandia National Laboratories, SAND88-3149, March 1994.

Wiles, J. C., Photovoltaic Power Systems and the National Electrical Code--Suggested Practices, PV Design Assistance Center, Sandia National Laboratories, August 1994.

GLOSSARY

A

Activated Shelf Life • The period of time, at a specified temperature, that a charged battery can be stored before its capacity falls to an unusable level.

AIC • Amperage interrupt capability. DC fuses should be rated with a sufficient AIC to interrupt the highest possible current.

Air Mass • Equal to the cosine of the zenith angle-that angle from directly overhead to a line intersecting the sun. The air mass is an indication of the length of the path solar radiation travels through the atmosphere. An air mass of 1.0 means the sun is directly overhead and the radiation travels through one atmosphere (thickness).

Alternating Current (ac) • An electric current that reverses direction periodically.

Ambient Temperature • The temperature of the surrounding area.

Amorphous Silicon • A thin-film PV silicon cell having no crystalline structure. Manufactured by depositing layers of doped silicon on a substrate. See also Single-crystal Silicon & Polycrystalline Silicon.

Ampere (A) • Unit of electric current. The rate of flow of electrons in a conductor equal to one coulomb per second.

Ampere-Hour (Ah) • The quantity of electrical energy equal to the flow of current of one ampere for one hour. The term is used to quantify the energy stored in a battery.

Angle of Incidence • The angle that a light ray striking a surface makes with a line perpendicular to the surface.

Anode • The positive electrode in an electrochemical cell (battery). Also, the earth ground in a cathodic protection system. Also, the positive terminal of a diode.

Array • A collection of electrically connected photovoltaic (PV) modules.

Array Current • The electrical current produced by a PV array when it is exposed to sunlight.

Array Operating Voltage • The voltage produced by a PV array when exposed to sunlight and connected to a load.

Availability • The quality or condition of a PV system being available to provide power to a load. Usually measured in hours per year. One minus availability equals downtime.

Azimuth • Horizontal angle measured clockwise from true north; 180° is true south.

B

Base Load • The averageamount of electric power that a utility must supply in any period.

Battery • A device that converts the chemical energy contained in its active materials directly into electrical energy by means of an electrochemical oxidation-reduction (redox) reaction.

Battery Capacity • The total number of ampere-hours that can be withdrawn from a fully charged battery. See Ampere-Hour & Rated Battery Capacity.

Battery Cell • The smallest unit or section of a battery that can store electrical energy and is capable of furnishing a current to an external load. For lead-acid batteries the voltage of a cell (fully charged) is about 2.2 volts dc.

Battery Cycle Life • The number of times a battery can be discharged and recharged before failing. Battery manufacturers specify Cycle Life as a function of discharge rate and temperature.

Battery Self-Discharge • Loss of energy by a battery that is not under load.

Battery State of Charge (SOC) **•** Percentage of full charge or 100 percent minus the depth of discharge. See Depth of Discharge.

Battery Terminology

Captive Electrolyte Battery • A battery having an immobilized electrolyte (gelled or absorbed in a material).

Deep-Cycle Battery • A battery with large plates that can withstand many discharges to a low SOC.

Lead-Acid Battery • A general category that includes batteries with plates made of pure lead, lead-antimony, or lead-calcium immersed in an acid electrolyte.

Liquid Electrolyte Battery • A battery containing a liquid solution of acid and water. Distilled water may be added to these batteries to replenish the electrolyte as necessary. Also called a flooded battery because the plates are covered with the electrolyte.

Nickel Cadmium Battery • A battery containing nickel and cadmium plates and an alkaline electrolyte.

Sealed Battery • A battery with a captive electrolyte and a resealing vent cap, also called a valve-regulated battery. Electrolyte cannot be added.

Shallow-Cycle Battery • A battery with small plates that cannot withstand many discharges to a low SOC.

Blocking Diode • A diode used to prevent undesired current flow. In a PV array the diode is used to prevent current flow towards a failed module or from the battery to the PV array during periods of darkness or low current production.

British Thermal Unit (Btu) • The quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit. $1\ \text{kw/m}^2 = 317\ \text{BT/ft}^2$ hour

Bypass Diode • **A** diode connected in parallel with a PV module to provide an alternate current path in case of module shading or failure.

C

Capacity (C) • The total number of ampere-hours that can be withdrawn from a fully charged battery at a specified discharge rate and temperature. See Battery Capacity.

Cathode • The negative electrode in an electrochemical cell. Also, the negative terminal of a diode.

Charge • The process of adding electrical energy to a battery.

Charge Controller • A device that controls the charging rate and/or state of charge for batteries.

Charge Controller Terminology

Activation Voltage(s) • The voltage(s) at which the controller will take action to protect the batteries.

Adjustable Set Point • A feature allowing the user to adjust the voltage levels at which the controller will become active.

High Voltage Disconnect • The voltage at which the charge controller will disconnect the array from the batteries to prevent overcharging.

High Voltage Disconnect Hysteresis • The voltage difference between the high voltage disconnect setpoint and the voltage at which the full PV array current will be reapplied.

Low Voltage Disconnect • The voltage at which the charge controller will disconnect the load from the batteries to prevent over-discharging.

Low Voltage Disconnect Hysteresis • The voltage difference between the low voltage disconnect setpoint and the voltage at which the load will be reconnected.

Low Voltage Warning • A warning buzzer or light that indicates the low battery voltage setpoint has been reached.

Maximum Power Tracking or Peak Power Tracking • Operating the array at peak power point of the array’s I-V curve where maximum power is obtained.

Multi-stage Controller • Unit that allows different charging currents as the battery nears full SOC.

Reverse **Current Protection** • Any method of preventing unwanted current flow from the battery to the PV array (usually at night). See Blocking Diode.

Series Controller • A controller that interrupts the charging current by open-circuiting the PV array. The control element is in series with the PV array and battery.

Shunt Controller • A controller that redirects or shunts the charging current away from the battery. The controller requires a large heat sink to dissipate the current from the short-circuited PV array. Most shunt controllers are for smaller systems producing 30 amperes or less.

Single-Stage Controller • A unit that redirects all charging current as the battery nears full SOC.

Tare Loss • Loss caused by the controller. One minus tare loss, expressed as a percentage, is equal to the controller efficiency.

Temperature Compensation • A circuit that adjusts the charge controller activation points depending **on** battery temperature. This feature is recommended if the battery temperature is expected to vary more than ±5°C from ambient temperature. The temperature coefficient for lead acid batteries is typically -3 to -5 millivolts/°C per cell.

Charge Factor • A number representing the time in hours during which a battery can be charged at a constant current without damage to the battery. Usually expressed in relation to the total battery capacity, i.e., C/5 indicates a charge factor of 5 hours. Related to Charge Rate.

Charge Rate • The current used to recharge a battery. Normally expressed as a percentage of total battery capacity. For instance, C/5 indicates a charging current equal to one-fifth of the battery's capacity.

Cloud Enhancement • The increase in solar intensity caused by reflected ix-radiance from nearby clouds.

Concentrator • A photovoltaic module that uses optical elements to increase the amount of sunlight incident on a PV cell.

Conversion Efficiency • The ratio of the electrical energy produced by a photovoltaic cell to the solar energy impinging on the cell.

Converter • A unit that converts a dc voltage to another dc voltage.

Crystalline Silicon • A type of PV cell made from a single crystal or polycrystalline slice of silicon.

Current (Amperes, Amps, A) • The flow of electric charge in a conductor between two points having a difference in potential (voltage).

Cutoff Voltage • The voltage levels (activation) at which the charge controller disconnects the array from the battery or the load from the battery.

Cycle • The discharge and subsequent charge of a battery.

D

Days of Storage • The number of consecutive days the stand-alone system will meet a defined load without solar energy input. This term is related to system availability.

Deep Cycle • Type of battery that can be discharged to a large fraction of capacity many times without damaging the battery.

Design Month • The month having the combination of insolation and load that requires the maximum energy from the array.

Depth of Discharge (DOD) • The percent of the rated battery capacity that has been withdrawn. See Battery State of Discharge.

Diffuse Radiation • Radiation received from the sun after reflection and scattering by the atmosphere and ground.

Diode • Electronic component that allows current flow in one direction only. See Blocking Diode & Bypass Diode.

Direct Beam Radiation • Radiation received by direct solar rays. Measured by a pyrheliometer with a solar aperature of 5.7° to transcribe the solar disc.

Direct Current (dc) • Electric current flowing in only one direction.

Discharge • The withdrawal of electrical energy from a battery.

Discharge Factor • A number equivalent to the time in hours during which a battery is discharged at constant current usually expressed as a percentage of the total battery capacity, i.e., C/5 indicates a discharge factor of 5 hours. Related to Discharge Rate.

Discharge Rate • The current that is withdrawn from a battery over time. Expressed as a percentage of battery capacity. For instance, a C/5 discharge rate indicates a current equal to one-fifth of the rated capacity of the battery.

Disconnect • Switch gear used to connect or disconnect components in a PV system.

Downtime • Time when the PV system cannot provide power for the load. Usually expressed in hours per year or that percentage.

Dry Cell • A cell (battery) with a captive electrolyte. A primary battery that cannot be recharged.

Duty Cycle • The ratio of active time to total time. Used to describe the operating regime of appliances or loads in PV systems.

Duty Rating • The amount of time an inverter (power conditioning unit) can produce at full rated power.

E

Efficiency • The ratio of output power (or energy) to input power (or energy). Expressed in percent.

Electrolyte • The medium that provides the ion transport mechanism between the positive and negative electrodes of a battery.

Energy Density • The ratio of the energy available from a battery to its volume (wh/m^3) or weight (wh/kg).

Equalization Charge • The process of mixing the electrolyte in batteries by periodically overcharging the batteries for a short time.

F

Fill Factor • For an I-V curve, the ratio of the maximum power to the product of the open-circuit voltage and the short-circuit current. Fill factor is a measure of the "squareness" of the I-V curve.

Fixed Tilt Array • A PV array set in at a fixed angle with respect to horizontal.

Flat-Plate Array • A PV array that consists of non-concentrating PV modules.

Float Charge • A charge current to a battery that is equal to or slightly greater than the self discharge rate.

Frequency • The number of repetitions per unit time of a complete waveform, expressed in Hertz (Hz).

G

Gassing • Gas by-products, primarily hydrogen, produced when charging a battery. Also, termed out-gassing.

Grid • Term used to describe an electrical utility distribution network.

I

Insolation • The solar radiation incident on an area over time. Equivalent to energy and usually expressed in kilowatt-hours per square meter. See also Solar Resource.

Inverter (Power Conditioning Unit, PCU, or Power Conditioning System, PCS) • In a PV system, an inverter converts dc power from the PV array/battery to ac power compatible with the utility and ac loads.

Inverter Terminology

> **Duty Rating** • This rating is the amount of time the inverter can supply its rated power. Some inverters can operate at their rated power for only a short time without overheating.
>
> **Frequency** • Most loads in the United States require 60 Hz. High-quality equipment requires precise frequency regulation--variations can cause poor performance of clocks and electronic timers.
>
> **Frequency Regulation** • This indicates the variability in the output frequency. Some loads will switch off or not operate properly if frequency variations exceed 1 percent.
>
> **Harmonic Content** • The number of frequencies in the output waveform in addition to the primary frequency. (50 or 60 Hz.) Energy in these harmonic frequencies is lost and may cause excessive heating of the load.

Input Voltage • This is determined by the total power required by the ac loads and the voltage of any dc loads. Generally, the larger the load, the higher the inverter input voltage. This keeps the current at levels where switches and other components are readily available.

Modified Sine Wave • A waveform that has at least threestates (i.e., positive, off, and negative). Has less harmonic content than a square wave.

Modularity • The use of multiple inverters connected in parallel to service different loads.

Power Factor • The cosine of the angle between the current and voltage waveforms produced by the inverter. For resistive loads, the power factor will be 1.0.

Power Conversion Efficiency • The ratio of output power to input power of the inverter.

Rated Power • Rated power of the inverter. However, some units can not produce rated power continuously. See duty rating.

Root Mean Square (RMS) • The square root of the average square of the instantaneous values of an ac output. For a sine wave the RMS value is 0.707 times the peak value. The equivalent value of ac current, I, that will produce the same heating in a conductor with resistance, R, as a dc current of value I.

Sine Wave • A waveform corresponding to a single-frequency periodic oscillation that can be mathematically represented as a function of amplitude versus angle in which the value of the curve at any point is equal to the sine of that angle.

Square Wave • A wave form that has only two states, (i.e., positive or negative). A square wave contains a large number of harmonics.

Surge Capacity • The maximum power, usually 3-5 times the rated power, that can be provided over a short time.

Standby Current • This is the amount of current (power) used by the inverter when no load is active (lost power). The efficiency of the inverter is lowest when the load demand is low.

Voltage Regulation • This indicates the variability in the output voltage. Some loads will not tolerate voltage variations greater than a few percent.

Voltage Protection • Many inverters have sensing circuits that will disconnect the unit from the battery if input voltage limits are exceeded.

Irradiance • The solar power incident on a surface. Usually expressed in kilowatts per square meter. Irradiance multiplied by time equals Insolation.

I-V Curve • The plot of the current versus voltage characteristics of a photovoltaic cell, module, or array. Three important points on the I-V curve are the open-circuit voltage, short-circuit current, and peak power operating point.

K

Kilowatt (kw) • One thousand watts. A unit of power.

Kilowatt Hour (kwh) • One thousand watt-hours. A unit of energy. Power multiplied by time equals energy.

L

Life • The period during which a system is capable of operating above a specified performance level.

Life-Cycle Cost • The estimated cost of owning and operating a system for the period of its useful life. See Economics section for definition of terms.

Load • The amount of electric power used by any electrical unit or appliance at any given time.

Load Circuit • The wire, switches, fuses, etc. that connect the load to the power source.

Load Current (A) • The current required by the electrical device.

Load Resistance • The resistance presented by the load. See Resistance.

Langley (L) • Unit of solar irradiance. One gram calorie per square centimeter. 1 L = 85.93 kwh/m^2.

Low Voltage Cutoff (LVC) • The voltage level at which a controller will disconnect the load from the battery.

M

Maintenance-Free Battery • A sealed battery to which water cannot be added to maintain electrolyte level.

Maximum Power Point or Peak Power Point • That point on an I-V curve that represents the largest area rectangle that can be drawn under the curve. Operating a PV array at that voltage will produce maximum power.

Module • The smallest replaceable unit in a PV array. An integral, encapsulated unit containing a number of PV cells.

Modularity • The concept of using identical complete units to produce a large system.

Module Derate Factor • A factor that lowers the module current to account for field operating conditions such as dirt accumulation on the module.

Movistor • Metal Oxide Varistor. Used to protect electronic circuits from surge currents such as produced by lightning.

N

NEC • An abbreviation for the National Electrical Code which contains guidelines for all types of electrical installations. The 1984 and later editions of the NEC contain Article 690, “Solar Photovoltaic Systems” which should be followed when installing a PV system.

NEMA • National Electrical Manufacturers Association. This organization sets standards for some non-electronic products like junction boxes.

Normal Operating Cell Temperature (NOCT) • The estimated temperature of a PV module when operating under 800 w/m^2 irradiance, 20°C ambient temperatureand wind speed of 1 meter persecond. NOCT is used to estimate the nominal operating temperature of a module in its working environment.

Nominal Voltage • A reference voltage used to describe batteries, modules, or systems (i.e., a 12-volt or 24-volt battery, module, or system).

N-Type Silicon • Silicon material that has been doped with a material that has more electrons in its atomic structure than does silicon.

O

Ohm • The unit of electrical resistance in which an electromotive force of one volt maintains a current of one ampere.

Open Circuit Voltage • The maximum voltage produced by an illuminated photovoltaic cell, module, or array with no load connected. This value will increase as the temperature of the PV material decreases.

Operating Point • The current and voltage that a module or array produces when connected to a load. The operating point is dependent on the load or the batteries connected to the output terminals of the array.

Orientation • Placement with respect to the cardinal directions, N, S, E, W; azimuth is the measure of orientation from north.

Outgas • See Gassing.

Overcharge • Forcing current into a fully charged battery. The battery will be damaged if overcharged for a long period.

P

Panel • A designation for a number of PV modules assembled in a single mechanical frame.

Parallel Connection • Term used to describe the interconnecting of PV modules or batteries in which like terminals are connected together. Increases the current at the same voltage.

Peak Load • The maximum load demand on a system.

Peak Power Current • Amperes produced by a module or array operating at the voltage of the I-V curve that will produce maximum power from the module. See I-V Curve.

Peak Sun Hours • The equivalent number of hours per day when solar irradiance averages 1,000 w/m^2. For example, six peak sun hours means that the energy received during total daylight hours equals the energy that would have been received had the irradiance for six hours been 1,000 w/m^2.

Peak Watt • The amount of power a photovoltaic module will produce at standard test conditions (normally 1,000 w/m^2 and 25° cell temperature).

Photovoltaic Cell • The treated semiconductor material that converts solar irradiance to electricity.

Photovoltaic System • An installation of PV modules and other components designed to produce power from sunlight and meet the power demand for a designated load.

Plates • A metal plate, usually lead or lead compound, immersed in the electrolyte in a battery.

Pocket Plate • A plate for a battery in which active materials are held in a perforated metal pocket.

Polycrystalline Silicon • A material used to make PV cells which consist of many crystals as contrasted with single crystal silicon.

Power (Watts) • A basic unit of electricity equal (in dc circuits) to the product of current and voltage.

Power Conditioning System (PCS) • See Inverter.

Power Density • The ratio of the rated power available from a battery to its volume (watts per liter) or weight (watts per kilogram).

Power Factor • The cosine of the phase angle between the voltage and the current waveforms in an ac circuit. Used as a designator for inverter performance. A power factor of 1 indicates current and voltage are in phase and power is equal to the product of volt-amperes. (no reactive power).

Primary Battery • A battery whose initial capacity cannot be restored by charging.

Pyranometer • An instrument used for measuring global solar irradiance.

Pyrheliometer • An instrument used for measuring direct beam solar irradiance. Uses an aperature of 5.7° to transcribe the solar disc.

R

Rated Battery Capacity • The term used by battery manufacturers to indicate the maximum amount of energy that can be withdrawn from a battery under specified discharge rate and temperature. See Battery Capacity.

Rated Module Current (A) • The current output of a PV module measured at standard test conditions of 1,000 w/m^2 and 25°C cell temperature.

Reactive Power • The sine of the phase angle between the current and voltage waveforms in an ac system. See power factor.

Remote Site • A site not serviced by an electrical utility grid.

Resistance (R) • The property of a conductor which opposes the flow of an electric current resulting in the generation of heat in the conducting material. The measure of the resistance of a given conductor is the electromotive force needed for a unit current flow. The unit of resistance is ohms.

Sacrificial Anode • A piece of metal buried near a structure that is to be protected from corrosion. The metal of the sacrificial anode is intended to corrode and reduce the corrosion of the protected structure.

Seasonal Depth of Discharge • An adjustment factor used in some system sizing procedures which “allows” the battery to be gradually discharged over a 30-90 day period of poor solar insolation. This factor results in a slightly smaller PV array.

Secondary Battery • A battery that can be recharged.

Self-Discharge • The loss of useful capacity of a battery due to internal chemical action.

Semiconductor • A material that has a limited capacity for conducting electricity. The silicon used to make PV cells is a semiconductor.

Series Connection • Connecting the positive of one module to the negative of the next module. This connection of PV modules or batteries increases the voltage while the current remains the same.

Shallow Cycle Battery • A type of battery that should not be discharged more than 25 percent.

Shelf Life • The period of time that a device can be stored and still retain a specified performance.

Short Circuit Current (Isc) • The current produced by an illuminated PV cell, module, or array when its output terminals are shorted.

Silicon • A semiconductor material used to make photovoltaic cells.

Single-Crystal Silicon • Material with a single crystalline formation, Many PV cells are made from single crystal silicon.

Solar Cell • See Photovoltaic Cell.

Solar Insolation • See Insolation.

Solar Irradiance • See Irradiance.

Solar Noon • The midpoint of time between sunup and sunset. The point when the sun reaches its highest point in its daily traversal of the sky.

Solar Resource • The amount of solar insolation a site receives, usually measured in kwh/m^2/day which is equivalent to the number of peak sun hours. See Insolation and Peak Sun Hours.

Specific Gravity • The ratio of the weight of the solution to the weight of an equal volume of water at a specified temperature. Used as an indicator of battery state of charge.

Stand-Alone PV System • A photovoltaic system that operates independent of the utility grid.

Starved Electrolyte Cell • A battery containing little or no free fluid electrolyte.

State of Charge (SOC) • The instantaneouscapacity of a battery expressed at a percentage of rated capacity.

Stratification • A condition that occurs when the acid concentration varies from top to bottom in the battery electrolyte. Periodic, controlled charging at voltages that produce gassing will mix the electrolyte. See Equalization.

String • A number of modules or panels interconnected electrically in series to produce the operating voltage required by the load.

Subsystem • Any one of several components in a PV system (i.e., array, controller, batteries, inverter, load).

Sulfating • The formation of lead-sulfate crystals on the plates of a lead-acid battery. If the crystals get large enough shorting of the cell may occur.

Surge Capacity • The ability of an inverter or generator to deliver high currents momentarily required when starting motors.

System Availability • The percentage of time (usually expressed in hours per year) when a PV system will be able to fully meet the load demand.

System Operating Voltage • The array output voltage under load. Thesystem operating voltage is dependent on the load or batteries connected to the output terminals.

System Storage • See Battery Capacity.

T

TC, TW, THHN • See Wire Types

Temperature Compensation • An allowance made in charge controllers set points for battery temperatures. Feature recommended when battery temperatures are expected to exceed ±5°C from ambient.

Temperature Factors • It is common for three elements in PV system sizing to have distinct temperature corrections. A factor used to decrease battery capacity at cold temperatures. A factor used to decrease PV module voltage at high temperatures. A factor used to decrease the current carrying capability of wire at high temperatures.

Thin Film PV Module • A PV module constructed with sequential layers of thin film semiconductor materials. See Amorphous Silicon.

Tilt Angle • The angle of inclination of a solar collector measured from the horizontal.

Total ac Load Demand • The sum of the ac loads. This value is important when selecting an inverter.

Tracking Array • A PV array that follows the path of the sun. This can mean one-axis, east to west daily tracking, or two-axis tracking where the array follows the sun in azimuth and elevation.

Trickle Charge • A small charge current intended to maintain a battery in a fully charged condition.

U

UP, USE • See Wire Types

Uninterruptible Power Supply (UPS) • The designation of a power supply providing continuous uninterruptible service. The UPS will contain batteries.

V

Varistor • A voltage-dependent variable resistor. Normally used to protect sensitive equipment from power spikes or lightning strikes by shunting the energy to ground.

Vented Cell • A battery designed with a vent mechanism to expel gases generated during charging.

Volt (V) • The unit of electromotive force that will force a current of one ampere through a resistance of one ohm.

W

Watt (W) • The unit of electrical power. The power developed when a current of one ampere flows through a potential difference of one volt; 1/746 of a horsepower.

Watt Hour (Wh) • A unit of energy equal to one watt of power connected for one hour.

Waveform • The characteristic shape of an ac current or voltage output.

Water Pumping Terminology

Centrifugal Pump • See rotating pump

Displacement or Volumetric Pump • A type of water pump that utilizes a piston, cylinder and stop valves to move packets of water.

Dynamic Head • The vertical distance from the center of the pump to the point of free discharge of the water. Pipe friction is included. See Friction Head.

Friction Head • The energy that must be overcome by the pump to offset the friction losses of the water moving through a pipe.

Rotating Pump • A water pump using a rotating element or screw to move water. The faster the rotation, the greater the flow.

Static Head • The vertical distance from the water level to the point of free discharge of the water. It is measured when the pump is not operating.

Storage • This term has dual meaning for water pumping systems. Storage can be achieved by pumping water to a storage tank, or storing energy in a battery subsystem.

Suction Head • The vertical distance from the surface of the water source to the center of the pump (when the pump is located above the water level).

Wet Shelf Life • The period of time that a charged battery, when filled with electrolyte, can remain unused before dropping below a specified level of performance.

Wire Types • See Article 300 of National Electric Code for more information
Tray Cable (TC) - may be used for interconnecting balance-of-systems (BOS).

Underground Feeder (UF) - may be used for array wiring if sunlight resistant coating is specified; can be used for interconnecting BOS components but not recommended for use within battery enclosures.

Underground Service Entrance (USE) - may be used within battery enclosuresand for interconnecting BOS.

TW/THHN - may be used for interconnecting BOS but must be installed in conduit--either buried or above ground. It is resistant to moisture.

Z

Zenith Angle • The angle between directly overhead and the line intersecting the sun. (90°- zenith) is the elevation angle of the sun above the horizon.

POINT DESIGNS

Sixteen specific design examples, called point designs, are described in this section. These point designs cover a wide range of applications, geography, and system size. Each example is based on an actual installation, but some of the details have been altered to make the design more illustrative. The components described were available and commonly used in 1994. However, their inclusion does not represent an endorsement as in all cases comparable products were available.

The sixteen point designs are summarized in the table below.

	Location	Peak Array Size (W)	Storage Size (AH) or Type	System Control
Navigation Beacon (DC)	Texas	39	Batteries 315	Photocell
Security Lighting (DC)	Arizona	157	Batteries 540	Controller/ Timer
Vaccine Refrigeration Freezer (DC)	Roatan Honduras (World.Maps)	261	Batteries 612	Controller
Microwave Repeater (Hybrid)	Idaho	1,683	Batteries 1,800	Hybrid System Control Unit
Radio Repeater (DC)	Oregon	612	Batteries 1,860	Controller
Travelers Radio (DC)	New Mexico	180	Batteries 300	Controller
DC Cabin (DC)	Vermont	180	Batteries 220	Controller
Residential (AC/DC)	Colorado	572	Batteries 700	Controller
Residential (Hybrid)	South Carolina	1,014	Batteries 555	Hybrid System Controller
Direct Pump (DC)	Nebraska	144	Water	Linear Current Booster
Deep Well Jack Pump (DC)	New Mexico	809	Water	Peak Power Tracker
Submersible Pump (AC)	Antigua	1,323	Water	Inverter / Controller
Shallow Well Pump (DC)	Bolivia	300	Batteries 240	Linear Current Booster
Pipeline Monitor (DC)	Kansas	11	Batteries 10	None
Direct Fan (DC)	Colorado	22	None	None
Cathodic Protection (DC)	Louisiana	30	Batteries 55	Controller

A cost analysis for each example is included. The prices used are approximately what a person installing a PV system in the United States would pay in 1994. They are

Crystalline PV Modules	$6.50/watt
Deep-Cycle Lead-Acid Batteries	$2.00/ampere-hour
Solid state controllers	$6.00/ampere
Inverters	$0.75/watt
BOS	System Dependent
Installation	Site Dependent

The life-cycle cost (LCC) analyses were performed using the simplified methodology presented in Economics: Life-Cycle Costing beginning on page 59. The period and rates used are shown in the box.

Life-Cycle Period = 20 years
Investment Rate = 7 percent
Net Discount Rate = 3 percent

General Inflation = 4 percent
Fuel Inflation = 5 percent
Differential Fuel Inflation= 2 percent

Installation labor is priced at $250 per day per person, and does not include travel except as noted. Loads are not included as a capital cost except where noted.

All operation and maintenance items are calculated as an annually recurring cost. Replacement costs are estimated for array, battery, and BOS components over the life cycle period. Load replacement is not considered part of the life cycle cost of the power system. Salvage is estimated at 20 percent of the original equipment cost (excluding installation). No inflation adjustment is used in the discount rate when calculating salvage value.

The installed cost per peak watt is calculated by dividing the initial cost of the hardware and installation by the peak array power. The peak array power is the number of modules times the peak module power as stated by the manufacturer even though the array may not operate at that peak power point.

The reader is cautioned not to use these cost figures to compare the different systems or attempt to identify less expensive components. Many site-specific factors affect the cost of an installed system. Often these factors outweigh the cost difference between different models. However, the system costs stated here are typical for the generic type of application and they can be used for comparison with other power options such as generators or primary batteries. For those readers in countries other than the United States, the relative costs may be useful in determining driving factors in the life cycle cost of the sample system.

WARNING SIGNALS

Warning signals are used for public safety and their operational performance is often mandated by law. The warning signal must be located where the need is and using a photovoltaic power system offers the advantage of being able to place the system at the optimum location. System availability requirements are near 100 percent for those systems that safeguard human life. Check with local authorities for applicable regulations.

APPLICATIONS

- Navigation Beacons
- Audible Fog Signals
- Highway Warning Signs
- Aircraft Warning Lights
- Railroad Crossing Signals

USERS

Maritime shipping, U.S. Navy, U.S. Coast Guard, oil industry, highway departments, railroads, and private owners of communication towers, tall buildings on flight paths, wharves, or structures requiring warning or identification.

LOAD

Lamps, sirens, and foghorns are common 12 volt dc loads. The power requirements for lamps are usually predictable but may vary seasonally if warning system operation is dependent on thenumber of nighttime hours. Power demand for highway and railroad signals may vary with traffic. Warning signals for dust or icy roads will vary with ambient conditions.

ARRAY

Many systems are located in harsh environments. For marine applications, modules that have passed stringent salt water testing conducted by the U.S. Coast Guard should be used. Non-corroding metal such as stainless steel is often used. Wiring connections should be enclosed and protected against corrosion. Solder connections are recommended. All switches should be enclosed in NEMA boxes rated for the type of environment. Enclose wire in conduit where practical.

BATTERIES

Batteries must be protected from the environment. Vented, non-metallic, sunlight resistant battery enclosures are available but expensive. Vinyl tubs are an inexpensive alternative but require inspection and possible replacement. Batteries are often buried for added protection in cold climates. Select a well drained location and provide a moisture drain hole in the bottom of the battery enclosure. Adequate venting must be provided if batteries are to be stored inside a building. Sealed batteries are often used because of lower maintenance requirements and to prevent leakage or contamination of the electrolyte. Regulations dictate minimum number of days of battery storage and possibly minimum state of charge levels for navigation aids in some locations.

CONTROL

Many warning systems use no controller because the battery storage is large relative to the array size and the probability of overcharging the batteries is low. A low-voltage disconnect should be used to prevent excessive battery discharge. A blocking diode should be used to protect against battery discharge through the array at night. Be sure that module has sufficient voltage to charge the battery fully with the diode in the circuit.

MOUNTING

PV arrays should be mounted in an area clear from shading. In colder climates, snow shedding from the array must be considered. In such areas, modules are sometimes mounted vertically. Seaborne arrays may be subject to hurricane force winds up to 125 mph (60 meters per second) and salt spray environments. Horizontal mounts are common on floating buoys. Bird spikes or other roosting inhibitors are often used for arrays. In marine conditions, all mounting structures should be constructed from non-corrosive materials such as stainless steel, aluminum, brass, or plastic. Protect wire and connections and keep wire runs short. A good ground must be provided, particularly for pole or tower mounted systems.

POINT DESIGN NO. 1

NAVIGATION BEACON

This point design example is a flashing beacon mounted on a navigation buoy in the shipping channel near Port Arthur, Texas. The load consists of a single lamp operating 1.0 second on and 3.6 seconds off during hours of darkness. The lamp draws 2 amperes when lighted. The flasher controls the lamp and draws 0.22 amperes when the lamp is lighted. There is a surge current of 0.39 amperes each time the flasher turns on. This current flows approximately 1/10 of the time the flasher is on. A photocell controls the hours of operation. The design has 14 days of battery capacity (required by regulation) and does not include a charge controller. Provision is made to disconnect the load if the battery voltage drops below 11 volts.

KEY DESIGN INFORMATION

APPLICATION:	Maritime Navigation
SITE:	Near Port Arthur, Texas
LOCATION/ELEVATION:	31°3’ N 110°2’W 5m
ENVIRONMENT:	Salt Spray
TEMPERATURE RANGE (°C):	-15 to 42
MAXIMUM WIND SPEED (m/s):	40
AVAILABILITY REQUIRED:	Critical (>99.9% by regulation)
LOAD PROFILES:	Hours of darkness vary from 9.8 hours in July to 13.0 hours in December

INSTALLATION

The photovoltaic array is mounted horizontally above the beacon using an anodized aluminum framework mechanically and electrically attached to the metal body of the buoy. The module is wired to the battery using a thermoplastic jacketed TW cable designed to be both sunlight resistant and weatherproof in a marine environment. No fuses are used but a blocking diode is installed in the positive lead between the battery and the module. The diode is located inside the battery compartment for protection from the environment. The conductors for the beacon are of the same type as the array conductors. Both array and load conductors are run in conduit attached to the buoy structure to prevent them from becoming abraded or damaged. The batteries are installed inside a vault on the buoy with wire access through grommet-protected holes. All battery terminals are coated with a corrosion inhibitor. A light sensing photodiode switchused to control the hours of operation is installed inside the standard beacon fixture. The fixture is sealed to protect both lamp and photodiode from the salt-spray environment. All wiring connections are made with crimped and soldered connectors. Strain relief is provided.

WORKSHEET #1 CALCULATE THE LOADS (FOR EACH MONTH OR SEASON AS REQUIRED)

1 Load Description	2 QTY	3 Load Current (A)	4 Load Voltage (V)	5A DC Load Power (W)	5B AC Load Power (W)	6 Daily Duty Cycle (HRS/DAY)	7 Weekly Duty Cycle (DAYS/WK)	8 Power Conversion Efficiency (DECIMAL) D	9 Nominal System Voltage (V)	10 Amp-Hour Load (AH/DAY)
Lamp DC	1	x 2.0	x 12	= 24	N/A	x 2.9	x 7 ÷7	÷ 1	÷ 12	= 5.8
Flasher DC	1	x 0.2	x 12	= 2.4	N/A	x 2.9	x 7 ÷7	÷ 1	÷ 12	= 0.58
Surge Current DC	1	x 0.4	x 12	= 4.8	N/A	x 0.29	x 7 ÷7	÷ 1	÷ 12	= 0.12
DC		x	x	=	N/A	x	x ÷7	÷	÷	=
AC		x	x	N/A	=	x	x ÷7	÷	÷	=
AC		x	x	N/A	=	x	x ÷7	÷	÷	=
AC		x	x	N/A	=	x	x ÷7	÷	÷	=
AC		x	x	N/A	=	x	x ÷7	÷	÷	=
11 Total Load Power (W)		DC 11A	31.2		AC 11B			12 Total Amp-Hour Load (AH/DAY)		6.5

13 Total DC Load Power (W) 11A	14 Total AC Load Power (W) 11B	15 Nominal System Voltage (V) 9	16 Peak Current Draw (A)	17 Total Amp-Hour Load (AH/DAY) 12	18 Wire Efficiency Factor (DECIMAL) D	19 Battery Efficiency Factor (DECIMAL) D	20 Corrected Amp-Hour Load (AH/DAY)
31.2	+	÷ 12	= 2.6	6.5	÷ 0.98	÷ 0.9	= 7.4

DESIGN NOTES:

Daily Duty Cycle
1.0 seconds on
3.6 seconds off

1/4.6 = 22% Duty Cycle

Maximum demand
on longest night
of 13 hours.
13 X 0.22 = 2.9 hr/day

Surge current flows
1/10 of on time or
0.29 hr/day.

WORKSHEET #2 DESIGN CURRENT AND ARRAY TILT

21					
System Location	Gulf of Mexico	Latitude	31° 3' N	Longitude	110° 2' W
Insolation Location	New Orleans	Latitude	29° 6' N	Longitude	90° 2' W

	Tilt at Latitude -15°			Horizontal Tilt ~~at Latitude~~			Tilt at Latitude +15°		
MONTH	22A Corrected Load (AH/DAY) 20	23A Peak Sun (HRS/DAY)	24A Design Current (A)	22B Corrected Load (AH/DAY) 20	23B Peak Sun (HRS/DAY)	24B Design Current (A)	22C Corrected Load (AH/DAY) 20	23C Peak Sun (HRS/DAY)	24C Design Current (A)
J		÷	=	7.4	÷ 2.9	= 2.6		÷	=
F		÷	=		÷	=		÷	=
M		÷	=		÷	=		÷	=
A		÷	=		÷	=		÷	=
M		÷	=		÷	=		÷	=
J		÷	=		÷	=		÷	=
J		÷	=		÷	=		÷	=
A		÷	=		÷	=		÷	=
S		÷	=		÷	=		÷	=
O		÷	=		÷	=		÷	=
N		÷	=		÷	=		÷	=
D		÷	=	7.4	÷ 2.8	= 2.6		÷	=

Select the largest design current and corresponding peak sun from each latitude and enter below

Latitude -15°	
25A Peak Sun (HRS/DAY)	26A Design Current (A)

Latitude	
25B Peak Sun (HRS/DAY)	26B Design Current (A)
2.8	2.6

Latitude +15°	
25C Peak Sun (HRS/DAY)	26C Design Current (A)

Now select the smallest design current and corresponding peak sun

NOTE: DO NOT MIX TRACKING AND FIXED ARRAY DATA ON THE SAME SHEET.

27 Peak Sun (HRS/DAY	28 Design Current (A)
2.8	2.6
Tilt Angle =	0°

DESIGN NOTES:

Floating buoy-modules mounted in horizontal plane on top of buoy.

Insolation estimate from local source.

Maximum load in December and January with 13 hours of darkness.

WORKSHEET #3 CALCULATE SYSTEM BATTERY SIZE

29 Corrected Amp-Hour Load (AH/DAY) 20		30 Storage Days D		31 Maximum Depth of Discharge (DECIMAL) D		32 Derate for Temperature (DECIMAL) D		33 Required Battery Capacity (AH)		34 Capacity of Selected Battery (AH)		35 Batteries in Parallel
7.4	x	14	÷	0.3	÷	0.95	=	364	÷	105	=	3

NOTE: BLOCK 35. ROUND UP
FOR CONSERVATIVE DESIGN.

36 Nominal System Voltage (V) 9		37 Nominal Battery Voltage (V)		38 Batteries in Series		39 Batteries in Parallel 35		40 Total Batteries
12	÷	12	=	1	x	3	=	3

BATTERY INFORMATION	
Make	Delco
Model	2000
Type	Lead Calcium
Nominal Voltage (V)	12
Rated Capacity (AH)	105

41 Batteries in Parallel 35		42 Capacity of Selected Battery (AH) 34		43 System Battery Capacity (AH)		44 Maximum Depth of Discharge (DECIMAL) 31		45 Usable Battery Capacity (AH)
3	x	105	=	315	x	0.3	=	95

NOTE: USE MANUFACTURER'S DATA TO FILL
IN BATTERY INFORMATION BLOCK

DESIGN NOTES:

>30% discharge may damage this sealed shallow cycle battery.

Coldest temperature expected is -15°C.

WORKSHEET #4 CALCULATE SYSTEM ARRAY SIZE

46 Design Current (A) 28		47 Module Derate Factor (DECIMAL) D		48 Derated Design Current (A)		49 Rated Module Current (A) D		50 Modules in Parallel
2.6	÷	0.95	=	2.7	÷	2.3	=	1

		51 Nominal Battery Voltage 37		52 Batteries in Series 38		53 Voltage Required for Load (V)		54 Highest Temperature Module Voltage (V)		55 Modules in Series		56 Modules in Parallel 50		57 Total Modules
1.20	x	12	x	1		14.4	÷	15	=	1	x	1	=	1

NOTE: USE MANUFACTURER'S SPECIFICATIONS TO FILL IN PV MODULE INFORMATION BLOCK.

58 Modules in Parallel 50		59 Rated Module Current (A)		60 Rated Array Current (A)
	x	2.3	=	2.3
		61 Module Short Circuit Current (A)		62 Array Short Circuit Current (A)
	x	2.5	=	2.5

PV MODULE INFORMATION

Make/Model	Solarex MSX-38MM		Nominal Volts	12	
Length	28	Width 28	Thickness	2	
Weight	21 lbs.		Bypass Diode	Y [✓ N]	
Voltage (V)	At STC	Open Circuit	At Highest Expected Temperature		
	16.8	21.6	15		
Current (A)	At STC	Short Circuit			
	2.3	2.5			

63 Modules in Series 55		64 Rated Module Voltage (V)		65 Array Rated Voltage (V)
	x	16.8	=	16.8
		66 Open Circuit Module Voltage (V)		67 Array Open Circuit Voltage (V)
	x	21.6	=	21.6

NOTES: BLOCK 50 - ROUND UP FOR CONSERVATIVE DESIGN.

BLOCK 55 - ROUND UP OR SELECT ANOTHER MODULE WITH SUFFICIENT VOLTAGE TO CHARGE THE BATTERIES WHEN OPERATING AT THE HIGHEST EXPECTED TEMPERATURE.[2]

DESIGN NOTES:

Module is rated for use in a marine environment.

Rated voltage of 17.2 V@ 25°C gives a voltage of 15 V@55°C.

Hybrid system not feasible for this application.

PROTECTION COMPONENTS SPECIFICATION

Protected Circuit	Protection Device				Rated Current	Rated Voltage	Description
	Switch	Diode	Fuse	Movistor			
D1 Array output		✓			5amp	100 V	Blocking diode
D2 Array output				✓			Surge protector
D3 Load circuit	✓				4amp	20 V	Photodiode controlled switch
D4							
D5							
D6							
D7							
D8							
D9							
D10							
D11							
D12							
D13							
D14							

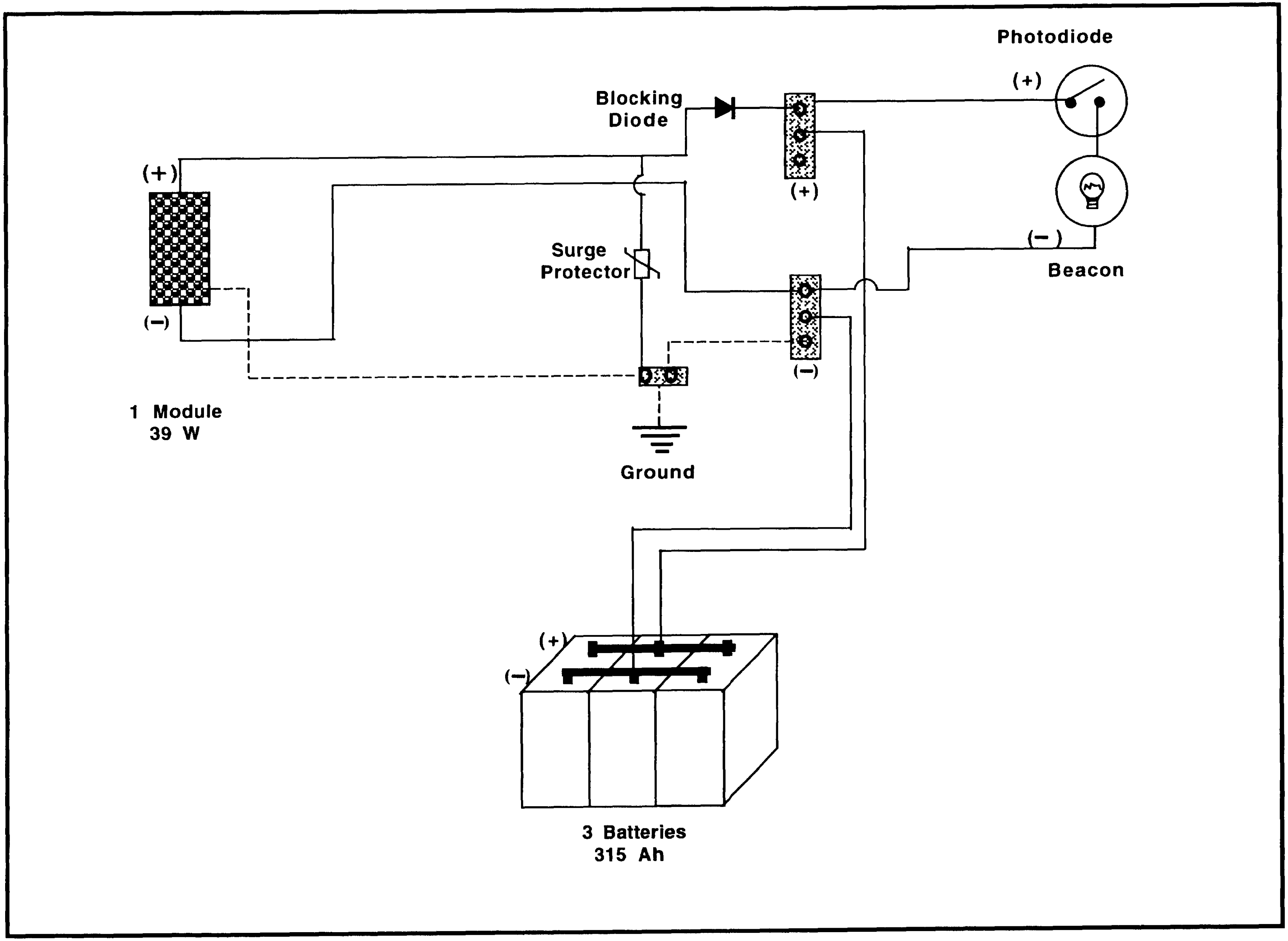
DC WIRE SIZING SPECIFICATION

E1 Wire Runs	E2 System Voltage (V)	E3 Maximum Current (A)	E4 One Way Length (FT)	E5 Allowed Voltage Drop (%)	E6 Allowance for Temperature Derate	E7 AWG Number	E8 Wire Type
Array Circuit							
Module to Module							
Array to Controller or Battery	12	4.6	10	2	18%	TW/#12	
DC Circuits							
Battery to Battery	12		1	0.1	—	#6	
Battery or Controller to DC Loads	12	3.2	4	1	—	TW/#12	
Branch Circuits							
A							
B							
C							
D							
E							
Battery Charger to Batteries							
Battery to Inverter Or Converter							

System Grounding	Wire Type	AWG Number	Type of Earth Ground
E9 Equipment Ground	Bare Copper	#8	To buoy body
E10 System Ground	Bare Copper	#8	To buoy body

DESIGN NOTES:

All wire installed in conduit or within the buoy.


Photodiode
(+)
Blocking
Diode
(+)
(+)
(−)
Beacon
Surge
Protector
(−)
(−)
1 Module
39 W
Ground
(+)
(−)
3 Batteries
315 Ah

ECONOMICS ANALYSIS

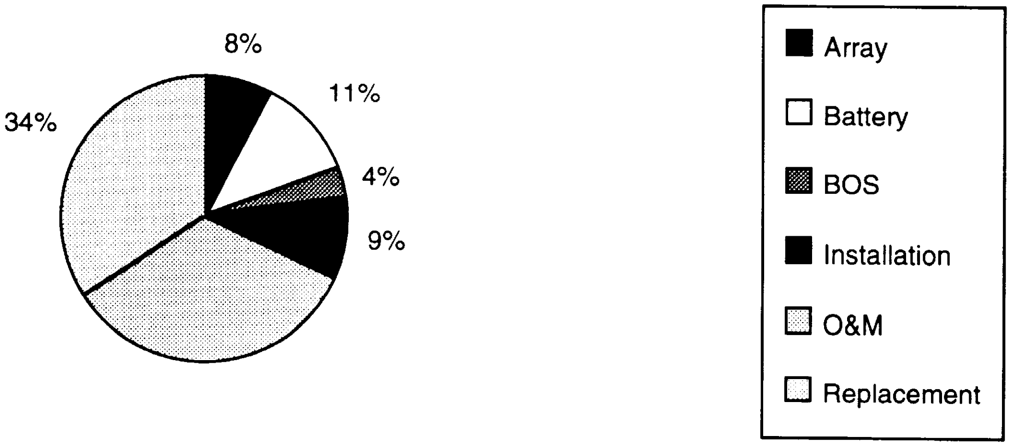
LIFE-CYCLE COST ANALYSIS
POINT DESIGN: NAVIGATION BEACON

Item		Dollar Amount ($)	Present Worth ($)	Percent Total LCC cost (%)
1. CAPITAL COSTS:				
Array		$450	$450	8.2
Battery		630	630	11.5
BOS and Mounting Hardware		205	205	3.7
Installation		500	500	9.2
A - SUBTOTAL (Equipment & Installation)		**1,785**	**1,785**	**32.6**
2. OPERATION & MAINTENANCE				
B - Annual Inspection		**125**	**1,860**	**34.0**
3. REPLACEMENT:	(YEAR)			
Battery	4	630	560	10.2
Battery	8	630	497	9.1
Battery	12	630	440	8.0
Battery	16	630	392	7.2
C - SUBTOTAL (Replacement Cost)		**2,520**	**1,889**	**34.6**
4. SALVAGE:	(YEAR)			
D - 20% of Original	20	**(257)**	**(66)**	**(1-2)**
TOTAL LIFE-CYCLE COST (A + B + C - D)			**$5,468**	**100.0**

ECONOMIC NOTES:

1) For this application, a module rated for a marine environment is specified. The cost is $1150/peak watt.
2) Installation cost assumes two person/days at $250 per day. However, the cost of $1,100 for boat & fuel is not included as this cost would have to be borne regardless of the type of system installed.
3) Capital cost does not include beacon, flasher, or photocell.
4) Maintenance is based on average 4-hour annual inspection visit by U.S.C.G. personnel.

COST ELEMENTS AS A PERCENT OF LCC (%)



LIGHTING

PV powered lighting systems are installed and operating in many locations. They have proved reliable and are the low cost alternative for many users. Recent improvements in lamp efficiency have allowed system costs to decrease. Security lighting, such as required for military applications, can be powered by PV systems at a fraction of the cost of extending utility lines to remote areas. Lamp control can be implemented with photocells, timers, switches, or sensors such as motion or infrared. The increasing demand for dc lamps has caused an improvement in reliability of lamp fixtures and ballasts. Outdoor lamps are packaged and sealed to prevent build up of dust and dirt on or in the fixture and inside reflectors. Starting gas lamps in cold weather can be a problem. The mounting position affects the performance and lifetime of gas bulbs; check specifications. Lamp efficiency generally increases with wattage so it is better to use fewer bulbs of higher wattage. Extended service lamps are generally less efficient than standard lamps but may prove to be the least cost option. Prepackaged systems with PV power supply, battery, ballast, lamp, and control are now available. Check with local PV system supply companies.

APPLICATIONS

- Billboards
- Security Lighting
- Emergency Warning
- Area Lighting
- Domestic Use

LOAD

Most stand-alone PV lighting systems operate at 12 or 24 volts dc. Incandescent and halogen bulbs that operate at 12 volts have been used in automobiles for years but the bulbs are not energy efficient and must be incorporated into a lamp fixture that is suitable for the application. Their use is not recommended. Fluorescent lamps are recommended for their efficiency-up to four times the lumens per watt of incandescent lamps. The fluorescent bulb and any other gas bulb, such as mercury vapor or sodium, may be difficult to start in extreme cold weather. The latter types, examples of high intensity discharge lamps, may require several minutes to light fully and must cool completely prior to relighting. A well-designed reflector and/or diffuser can be used to focus the available light and lower the total PV power required.

ARRAY

All connections should be made in water-tight junction boxes with strain relief connectors. See Article 310 of the NEC for wire types and approved usage. Conduit is often used to protect the wire from the lamp to the batteries. If conduit is not used, all wiring should be laced and attached to the support structure with sun resistant nylon or plastic wire ties. The array frame should be grounded. The array azimuth should be true south (north in southern hemisphere) with tilt angle as determined in sizing calculations. A switch is normally installed so the array can be disconnected. Use of a fuse in the battery lead is recommended to prevent damage in case of a short in the load. Use movistors or silicon oxide varistors for lightning and surge protection. Consider the possibility of vandalism when deciding how to install the system.

BATTERIES

Batteries are required for all PV lighting systems. Deep cycle lead acid and nickel cadmium batteries specifically designed for photovoltaic applications are recommended. Using sealed batteries minimizes the problem of ventilation and corrosion and lowers maintenance cost but the sealed battery may not last as long as an industrial grade deep-cycle battery. Batteries should be located in a weather resistant enclosure. Nonmetallic enclosures are recommended to prevent corrosion. Follow battery manufacturer’s installation and maintenance requirements.

CONTROL

For systems installed in remote areas, the reliability of the charge controller is critical and directly affects life-cycle cost. Buy a high quality controller with plenty of safety factor on the current that can be handled. The operation of the lamp may be controlled by sensing the PV array current and activating the lamp when the current drops near zero. Other methods of control are timers, photocells, or motion sensors.

MOUNTING

PV arrays may be ground mounted, pole mounted, or mounted to the structure that is being illuminated. Elevating the array above the structure may decrease the possibility of vandalism. Array frames should be anodized aluminum, galvanized, or stainless steel and the installation designed for maximum anticipated wind velocities. Stainless steel fasteners with lockwashers are recommended. Keep the wire length to a minimum. Fencing may be required to protect the array from animals. A steep array tilt angle increases snow shedding if there are no restrictions near the bottom of the array.

POINT DESIGN NO. 2

SECURITY LIGHTING

An officer at a military base near Yuma, Arizona, was required to install security lighting on a one acre area. Overhead lines were prohibited and underground service was expensive. Her options were PV or a diesel generator and after she investigated pole mounted PV lights the choice was obvious. She could provide enough light to guard against intrusion with three 18-watt pole lamps. They were independent, no interconnect wires to run, and they could be located at any convenient place within the designated area. She decided to put one pole light near the guard shack, double the power system size on that unit, and provide an 18-watt lamp inside the shack. All lights were to operate all night every night so she decided to use a current sensing relay in the PV array circuit to control the lamps. Any time current was flowing from the array the lamps would remain off. With this control method, all three independent lights would turn on and off at approximately the same time.

KEY DESIGN INFORMATION

APPLICATION:	Security Lighting
SITE:	Yuma, Arizona
LOCATION/ELEVATION:	32°42’ N 114°36' W 300 m
ENVIRONMENT:	Desert
TEMPERATURE RANGE (°C):	-5 to 45
MAXIMUM WIND SPEED (m/s):	40
AVAILABILITY REQUIRED:	Noncritical
LOAD PROFILES:	Every hour of darkness

INSTALLATION

The base engineers designed the system and hired a local contractor to build a pole kit with PV modules mounted above the lamp and the battery enclosure mounted to the pole near ground level. The modules were prewired and assembled in an aluminum frame that was attached to the pole at the proper tilt angle. The array conductors were run down the inside of the metal pole to the control box mounted to the pole behind the battery enclosure. The battery box was shaded with a metal overhang to maintain temperatures near ambient. The metal pole was used as the ground and the negative conductor was bonded to it in the controller box. A lightning rod was bonded to the pole and extended above and on the north side of the modules. A design and operations manual was generated and a maintenance logbook was placed in the guardshack. Personnel were instructed to keep a record of all maintenance items.

WORKSHEET #1 CALCULATE THE LOADS (FOR EACH MONTH OR SEASON AS REQUIRED)

1 Load Description	2 QTY	3 Load Current (A)	4 Load Voltage (V)	5A DC Load Power (W)	5B AC Load Power (W)	6 Daily Duty Cycle (HRS/DAY)	7 Weekly Duty Cycle (DAYS/WK)	8 Power Conversion Efficiency (DECIMAL) D	9 Nominal System Voltage (V)	10 Amp-Hour Load (AH/DAY)
18 Watt Pole Lamp DC	1	x 1.8	x 12	= 21.6	N/A	x 13	x 7 ÷7	÷ 1	÷ 12	= 23.4
18 Watt Guard Shack Light DC	1	x 1.8	x 12	= 21.6	N/A	x 13	x 7 ÷7	÷ 1	÷ 12	= 23.4
DC		x	x	=	N/A	x	x ÷7	÷	÷	=
DC		x	x	=	N/A	x	x ÷7	÷	÷	=
AC		x	x	N/A	=	x	x ÷7	÷	÷	=
AC		x	x	N/A	=	x	x ÷7	÷	÷	=
AC		x	x	N/A	=	x	x ÷7	÷	÷	=
AC		x	x	N/A	=	x	x ÷7	÷	÷	=
11 Total Load Power (W)			DC 11A	43.2	AC 11B		12 Total Amp-Hour Load (AH/DAY)			46.8

13 Total DC Load Power (W) 11A	14 Total AC Load Power (W) 11B	15 Nominal System Voltage (V) 9	16 Peak Current Draw (A)	17 Total Amp-Hour Load (AH/DAY) 12	18 Wire Efficiency Factor (DECIMAL) D	19 Battery Efficiency Factor (DECIMAL) D	20 Corrected Amp-Hour Load (AH/DAY)
43.2	+	÷ 12	= 3.6	46.8	÷ 0.98	÷ 0.9	= 53.1

DESIGN NOTES:

This design is unique to the pole lamp-plus-guard shack light system. The other pole light systems will be half as large.

13hrs/day is worst case winter time load.

12 volt DC ballast draws 1.8A.

WORKSHEET #2 DESIGN CURRENT AND ARRAY TILT

21	System Location	near Yuma, Az	Latitude	32°42′ N	Longitude	114° 36′ W
	Insolation Location	Phoenix, Az	Latitude	33° 16′ N	Longitude	112° W

DESIGN NOTES:

Wintertime will be maximum load. Use latitude +15°.

MONTH	Tilt at Latitude -15°			Tilt at Latitude			Tilt at Latitude +15°		
	22A Corrected Load (AH/DAY) 20	23A Peak Sun (HRS/DAY)	24A Design Current (A)	22B Corrected Load (AH/DAY) 20	23B Peak Sun (HRS/DAY)	24B Design Current (A)	22C Corrected Load (AH/DAY) 20	23C Peak Sun (HRS/DAY)	24C Design Current (A)
J		÷	=		÷	=	53.1	÷ 5.79	= 9.2
F		÷	=		÷	=		÷	=
M		÷	=		÷	=		÷	=
A		÷	=		÷	=		÷	=
M		÷	=		÷	=		÷	=
J		÷	=		÷	=		÷	=
J		÷	=		÷	=		÷	=
A		÷	=		÷	=		÷	=
S		÷	=		÷	=		÷	=
O		÷	=		÷	=		÷	=
N		÷	=		÷	=		÷	=
D		÷	=		÷	=	53.1	÷ 5.43	= 9.8

Select the largest design current and corresponding peak sun from each latitude and enter below

Latitude -15°	
25A Peak Sun (HRS/DAY)	26A Design Current (A)

Latitude	
25B Peak Sun (HRS/DAY)	26B Design Current (A)

Latitude +15°	
25C Peak Sun (HRS/DAY)	26C Design Current (A)
5.4	9.8

Now select the smallest design current and corresponding peak sun

27 Peak Sun (HRS/DAY)	28 Design Current (A)
5.4	9.8
Tilt Angle =	~50°

NOTE: DO NOT MIX TRACKING AND FIXED ARRAY DATA ON THE SAME SHEET.

WORKSHEET #3

CALCULATE SYSTEM BATTERY SIZE

DESIGN NOTES:

29 Corrected Amp-Hour Load (AH/DAY) 20		30 Storage Days D		31 Maximum Depth of Discharge (DECIMAL) D		32 Derate for Temperature (DECIMAL) D		33 Required Battery Capacity (AH)		34 Capacity of Selected Battery (AH)		35 Batteries in Parallel
53.1	X	5	÷	0.5	÷	1	=	531	÷	90	=	6

NOTE: BLOCK 35. ROUND UP FOR CONSERVATIVE DESIGN.

36 Nominal System Voltage (V) 9		37 Nominal Battery Voltage (V)		38 Batteries in Series		39 Batteries in Parallel 35		40 Total Batteries
12	÷	12	=	1	X	6	=	6

BATTERY INFORMATION	
Make	Johnson Controls
Model	GC 12100B
Type	Gel Sealed Lead Acid
Nominal Voltage (V)	12
Rated Capacity (AH)	90

41 Batteries in Parallel 35		42 Capacity of Selected Battery (AH) 34		43 System Battery Capacity (AH)		44 Maximum Depth of Discharge (DECIMAL) 31		45 Usable Battery Capacity (AH)
6	X	90	=	540	X	0.5	=	270

NOTE: USE MANUFACTURER'S DATA TO FILL IN BATTERY INFORMATION BLOCK

WORKSHEET #4 CALCULATE SYSTEM ARRAY SIZE

46 Design Current (A) 28		47 Module Derate Factor (DECIMAL) D		48 Derated Design Current (A)		49 Rated Module Current (A) D		50 Modules in Parallel
9.8	÷	0.9	=	10.9	÷	2.3	=	4

		51 Nominal Battery Voltage 37		52 Batteries in Series 38		53 Voltage Required for Load (V)		54 Highest Temperature Module Voltage (V)		55 Modules in Series		56 Modules in Parallel 50		57 Total Modules
1.20	x	12	x	1		14.4	÷	14.9	=	1	x	4	=	4

58 Modules in Parallel 50		59 Rated Module Current (A)		60 Rated Array Current (A)
	x	2.3	=	9.2
		61 Module Short Circuit Current (A)		62 Array Short Circuit Current (A)
	x	2.6	=	10.4

NOTE: USE MANUFACTURER'S SPECIFICATIONS TO FILL IN PV MODULE INFORMATION BLOCK.

63 Modules in Series 55		64 Rated Module Voltage (V)		65 Array Rated Voltage (V)
	x	17.1	=	17.1
		66 Open Circuit Module Voltage (V)		67 Array Open Circuit Voltage (V)
	x	21.6	=	21.6

PV MODULE INFORMATION

Make/Model	Solarex MSX-40			**Nominal Volts**	12
Length	30	**Width**	20	**Thickness**	2.1
Weight	12 lbs.			**Bypass Diode**	Y [✓ N]

Voltage (V)	**At STC**	**Open Circuit**	**At Highest Expected Temperature**
	17.1	21.6	14.9
Current (A)	**At STC**	**Short Circuit**	
	2.3	2.6	

NOTES: BLOCK 50 - ROUND UP FOR CONSERVATIVE DESIGN.
BLOCK 55 - ROUND UP OR SELECT ANOTHER MODULE WITH SUFFICIENT VOLTAGE TO CHARGE THE BATTERIES WHEN OPERATING AT THE HIGHEST EXPECTED TEMPERATURE.

DESIGN NOTES:

This module will produce 14.9 V @ 75°C.

Hybrid system not reasonable for this application.

CONTROLLER SPECIFICATION

		A1 Array Short Circuit Current (A) 62		A2 Minimum Controller Current (A)		A3 Rated Controller Current) (A)		A4 Controllers in Parallel
1.25	X	10.4	=	13	÷	20	=	1

A5

(CONTROLLER)

Make/Model Heliotrope CC20

Rated Voltage 12

Rated Current 20

Features

Temperature Compensation ✓

Reverse Current Protection ✓

Adjustable Set Points)

High Voltage Disconnect 15.0

High Voltage Re-connect 14.1

Low Voltage Disconnect 12.2

Low Voltage Re-connect 13.0

Meters

Battery Voltage _____

Array Current _____

Load Current _____

DESIGN NOTES:

Protected Circuit	Protection Device				Rated Current	Rated Voltage	Description
	Switch	Diode	Fuse	Movistor			
D1 Array output	✓				15 amps	200 V	DC switch installed in junction box
D2 Array output	relay				15 amps	24 V	
D3 Array output			✓		15 amps	125 V	DC fuse installed in junction box
D4 Controller to load	✓				15 amps	200 V	DC switch installed in junction box
D5							that is mounted on the light pole
D6 Controller to load			✓		15 amps	125 V	DC Fuse installed in junction box mounted
D7							on light pole
D8 Battery			✓		20 amps	125 V	DC Fuse installed in battery box
D9 Controller input				✓			
D10							
D11							
D12							
D13							
D14							

DC WIRE SIZING SPECIFICATION

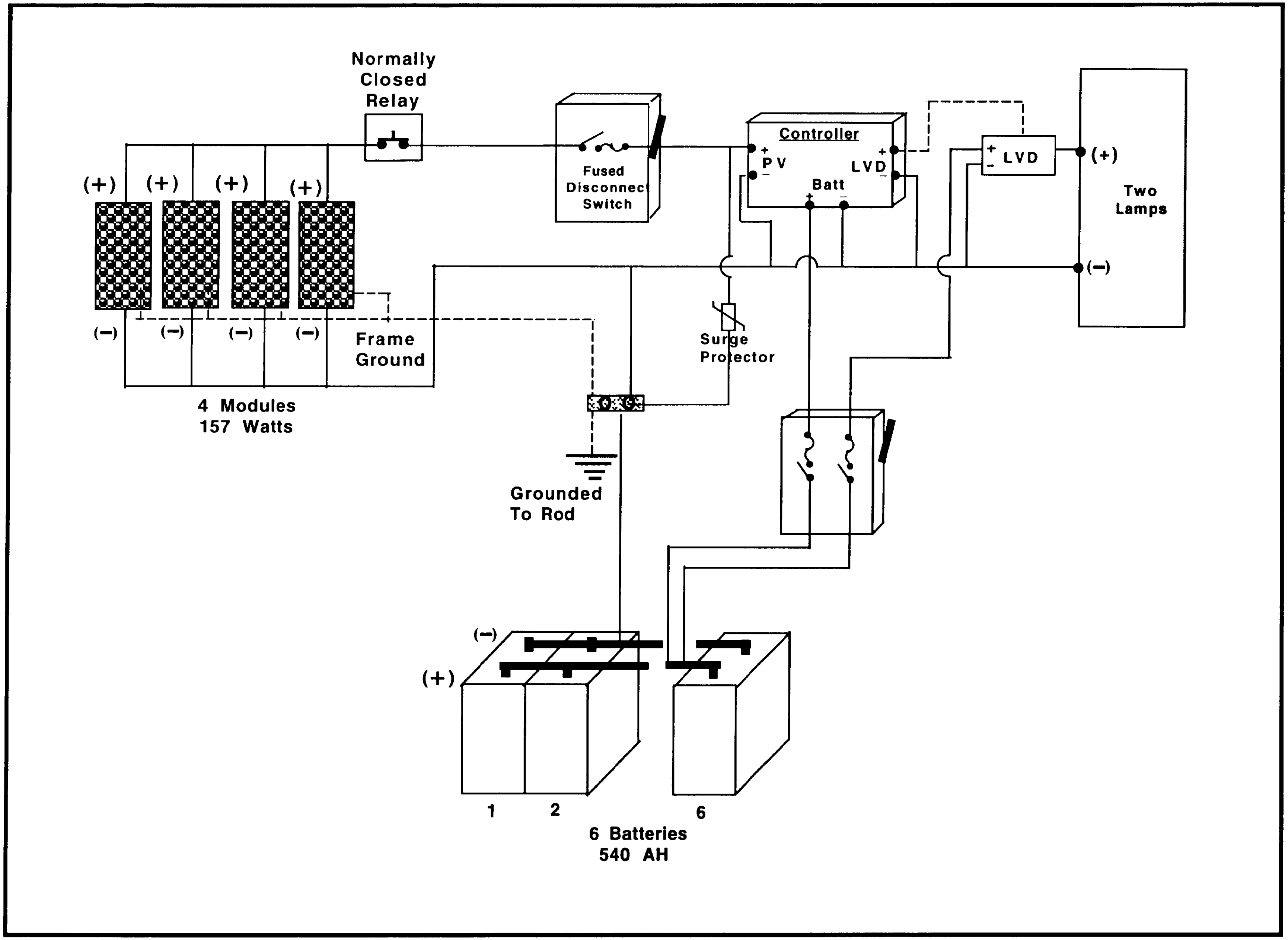
E1 Wire Runs	E2 System Voltage (V)	E3 Maximum Current (A)	E4 One Way Length (FT)	E5 Allowed Voltage Drop (%)	E6 Allowance for Temperature Derate	E7 AWG Number	E8 Wire Type
Array Circuit							
Module to Module	12	2.3	2	1%	18%	#12uF	
Array to Controller or Battery	12	10	25	3%	18%	#6 uF	
DC Circuits							
Battery to Battery	12	—	1	1%	—	#6	
Battery to DC Loads	12	3.6	40	3%	18%	#8uF	
Branch Circuits							
A ________							
B ________							
C ________							
D ________							
E ________							
Battery Charger to Batteries							
Battery to Inverter Or Converter							

System Grounding	Wire Type	AWG Number	Type of Earth Ground
E9 Equipment Ground	Bare Copper	#8	Copper Rod
E10 System Ground	Bare Copper	#8	Copper Rod

DESIGN NOTES:

All exposed wire is to be marked sunlight resistant.

Battery cables supplied by battery dealer.


Normally Closed Relay
Fused Disconnect Switch
Controller
+ P V –
+ LVD –
Batt
+ –
+ LVD –
(+)
(–)
Two Lamps
(+) (+) (+) (+)
(–) (–) (–) (–)
Frame Ground
4 Modules 157 Watts
Surge Protector
Grounded To Rod
(–)
(+)
1
2
6
6 Batteries 540 AH

ECONOMICS ANALYSIS

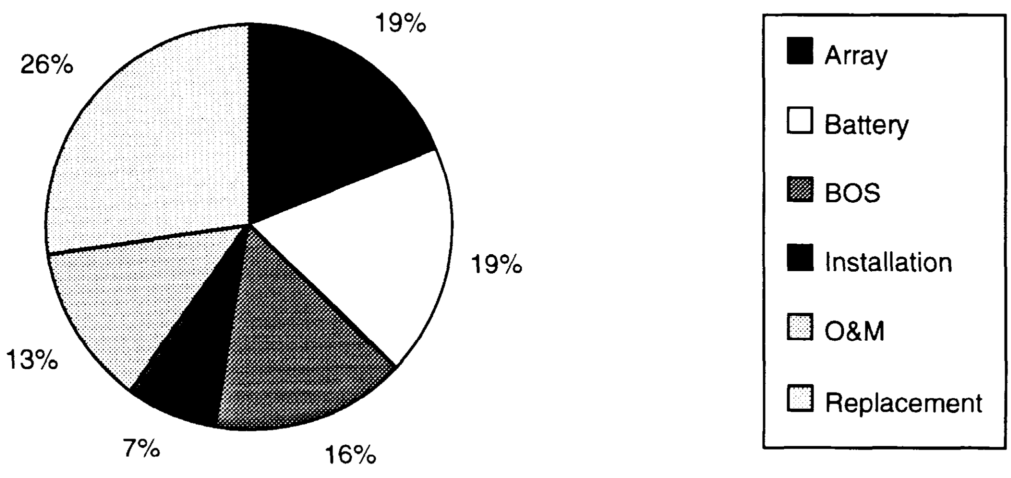
LIFE-CYCLE COST ANALYSIS
POINT DESIGN: SECURITY LIGHTING

Item		Dollar Amount ($)	Present Worth ($)	Percent Total LCC cost (%)
1. CAPITAL COSTS:				
Array		$1,040	$1,040	18.6
Battery		1,080	1,080	19.3
BOS + Mounting Hardware		900	900	16.1
Installation		400	400	7.1
A - SUBTOTAL (Equipment & Installation)		**3,420**	**3,420**	**61.1**
2. OPERATION & MAINTENANCE				
B - Annual Inspection		**50**	**743**	**13.3**
3. REPLACEMENT:	(YEAR)			
Battery	8	1,080	1278	15.2
Battery	16	1,080	1010	12.0
Controller	10	104	64	1.1
C - SUBTOTAL (Replacement Cost)		**2,264**	**1,598**	**28.5**
4. SALVAGE:	(YEAR)			
D - 20% of Original	20	**(604)**	**(156)**	**(2.9)**
TOTAL LIFE-CYCLE COST (A + B + C - D)			**$5,605**	**100.0**

ECONOMIC NOTES:

1) Cost is calculated for the two lamp system. The other pole lamps would cost about 70 percent of this amount when installation costs are included.
2) Capital cost does not include the fluorescent light fixtures or lamps.

COST ELEMENTS AS A PERCENT OF LCC (%)



REFRIGERATION

The use of PV powered refrigerator/freezers (R/F) is increasing because of the high reliability they provide. The World Health Organization has specified PV power be used for medical vaccine refrigerators in numerous countries around the world. Many dollars worth of vaccine can be ruined if not maintained at the recommended temperature. This requires a reliable power source for the refrigerator. Also, the high-efficiency dc refrigerators are being used more in residential applications because their cost is decreasing as larger numbers are manufactured. In most instances, the efficiency of the dc refrigerator is higher than an equivalent size ac unit. This reduces the power requirements accordingly. For PV powered refrigerators, the mode of operation directly affects the total system cost. Factors such as number of users, door opening habits, seasonal use variations, time of loading, temperature of incoming material, and physical location of the unit will significantly affect the amount of power required. User training in proper operation and maintenance should be a part of any project to install R/F systems in remote areas.

APPLICATIONS

- Medical
- Recreational
- Commercial
- Residential

LOAD

Most stand-alone PV refrigerator/freezer systems operate at 12 volt or 24 volt dc. The design features that contribute to efficient operation and lower power demand include shape, increased insulation, tight door seals, compartmentalization, efficient compressors with effective heat removal (with or without fans), manual defrosting, and top-loading design. However, all these advantages can be outweighed by careless and improper use. User training is mandatory. Ice making requires a large amount of power. If regular ice making is required, consider an R/F unit with two separate compressors or use an inverter and ac freezer.

ARRAY

All connections should be in water-tight junction boxes with strain relief connectors. All wiring should be in conduit or laced and attached to support structure with wire ties. The array should be grounded with the ground conductor securely attached to each support structure and the earth rod. Array azimuth should be true south (north in southern hemisphere) with tilt angle as determined in sizing calculations. If vandalism is a possibility, consider elevating the array or restricting access with fencing.

BATTERIES

Batteries provide the high availability of PV refrigeration systems. Deep cycle lead acid or nickel cadmium types specifically designed for photovoltaic applications are recommended. Sealed batteries may be used to minimize the problem of ventilation and corrosion and lower maintenance cost. Check battery availability in the local area. Batteries should be located in a weather-resistant enclosure close to the R/F. Nonmetallic enclosures are recommended to prevent corrosion particularly if flooded electrolyte batteries are used. An in-line fuse should be installed at the battery output terminal. Follow battery manufacturer's installation and maintenance requirements. For systems installed in remote areas, the battery charge regulation is critical and directly affects life-cycle cost.

CONTROL

Battery state of charge control is required to prevent deep discharge or overcharge of the battery particularly for systems installed in remote areas. Using a controller with temperature compensation is recommended if the batteries are not in a controlled environment. Controllers with meters or warning lights allow the system performance to be monitored easily. The operation of the R/F can be controlled by a thermostat. Manually controlled mechanical thermostats are recommended over electronic thermostats because of their simplicity and reliability. Select an R/F unit with separate thermostat controls for each compartment.

MOUNTING

PV arrays may be ground mounted or mounted to the building that houses the refrigerator. Installing the array on the roof of the structure may decrease the possibility of vandalism, but precautions should be taken to minimize the possibility of roof leaks. Do not put the array directly on the roof--leave at least 3 inches for air circulation under the array. Array frames should be anodized aluminum, galvanized or stainless steel, and designed for maximum anticipated wind velocities. Stainless steel fasteners with lockwashers, nylock or pel nuts are recommended. Locating all subsystems close to the load will keep wire length to a minimum. Fencing may be required to protect the array from animals if the array is ground mounted. Use solid foundations and/or ground anchors to secure the array. Put the junction box and controller in the building with the R/F if possible.

POINT DESIGN NO. 3

VACCINE REFRIGERATION/FREEZER

A PV powered refrigerator/freezer was needed for medical vaccine storage on the remote tropical island of Roatan, Honduras. A dual compressor R/F unit was chosen. Each compressor operates independently and draws 5 amperes when operating. The sealed lead-acid battery bank is enclosed beneath the R/F unit. This arrangement reduces the chance of accidental contact with the battery terminals and the room is well ventilated so no danger of gas build up exists. The R/F is used every day with the active compressor time estimated at 9 hours per day for the refrigerator and 5 hours for the freezer in the summer time with corresponding wintertime numbers of 7 hours and 4 hours. The operators of the clinic were briefed on the operation and maintenance of the installed R/F and told how to conserve energy by keeping the R/F closed as much as possible.

KEY DESIGN INFORMATION

APPLICATION:	Vaccine Refrigerator/Freezer Storage
SITE:	Roatan, Honduras
LOCATION/ELEVATION:	16° N 86° W 30 m
ENVIRONMENT:	Island
TEMPERATURE RANGE (°C):	15 to 35
MAXIMUM WIND SPEED (m/s):	40
AVAILABILITY REQUIRED:	Critical

INSTALLATION

This refrigeration system uses a roof-mounted array that supplies power to the internal batteries in the R/F. The array was placed on a portion of the building roof that was free from shadows caused by vent stacks, chimneys, trees, and overhead wires. The array conductors were routed in conduit around the base of the building and entered the building at the back of the R/F. The system switches were mounted on the wall adjacent to the refrigerator/freezer unit. After the batteries were installed in the R/F, it was carefully leveled to provide optimum operation. The location chosen for the refrigerator/freezer was in a room that provided good ventilation for the compressor while keeping the unit out of direct sunlight.

WORKSHEET #1 **CALCULATE THE LOADS** (FOR EACH MONTH OR SEASON AS REQUIRED)

For Winter Use

DESIGN NOTES:

1 Load Description	2 QTY		3 Load Current (A)		4 Load Voltage (V)		5A DC Load Power (W)		5B AC Load Power (W)		6 Daily Duty Cycle (HRS/DAY)		7 Weekly Duty Cycle (DAYS/WK)		8 Power Conversion Efficiency (DECIMAL) D		9 Nominal System Voltage (V)		10 Amp-Hour Load (AH/DAY)
Refrigerator DC	1	X	5	X	12	=	60		N/A	X	7	X	7 ÷7	÷	1	÷	12	=	35
Freezer DC	1	X	5	X	12	=	60		N/A	X	4	X	7 ÷7	÷	1	÷	12	=	20
DC		X		X		=			N/A	X		X	÷7	÷		÷		=	
DC		X		X		=			N/A	X		X	÷7	÷		÷		=	
AC		X		X			N/A	=		X		X	÷7	÷		÷		=	
AC		X		X			N/A	=		X		X	÷7	÷		÷		=	
AC		X		X			N/A	=		X		X	÷7	÷		÷		=	
AC		X		X			N/A	=		X		X	÷7	÷		÷		=	

11 Total Load Power (W)	DC 11A	AC 11B	12 Total Amp-Hour Load (AH/DAY)
			55

13 Total DC Load Power (W) 11A		14 Total AC Load Power (W) 11B		15 Nominal System Voltage (V) 9		16 Peak Current Draw (A)	17 Total Amp-Hour Load (AH/DAY) 12		18 Wire Efficiency Factor (DECIMAL) D		19 Battery Efficiency Factor (DECIMAL) D		20 Corrected Amp-Hour Load (AH/DAY)
120	+	—	÷	12	=	10	55	÷	.98	÷	.9	=	62.4

WORKSHEET #1 **CALCULATE THE LOADS** (FOR EACH MONTH OR SEASON AS REQUIRED)

For Summer Use

1 Load Description	2 QTY	3 Load Current (A)	4 Load Voltage (V)	5A DC Load Power (W)	5B AC Load Power (W)	6 Daily Duty Cycle (HRS/DAY)	7 Weekly Duty Cycle (DAYS/WK)	8 Power Conversion Efficiency (DECIMAL) D	9 Nominal System Voltage (V)	10 Amp-Hour Load (AH/DAY)
Refrigerator DC	1	X 5	X 12	= 60	N/A	X 9	X 7 ÷7	÷ 1	÷ 12	= 45
Freezer DC	1	X 5	X 12	= 60	N/A	X 5	X 7 ÷7	÷ 1	÷ 12	= 25
DC		X	X	=	N/A	X	X ÷7	÷	÷	=
DC		X	X	=	N/A	X	X ÷7	÷	÷	=
AC		X	X	N/A	=	X	X ÷7	÷	÷	=
AC		X	X	N/A	=	X	X ÷7	÷	÷	=
AC		X	X	N/A	=	X	X ÷7	÷	÷	=
AC		X	X	N/A	=	X	X ÷7	÷	÷	=
11 Total Load Power (W)				DC 11A	AC 11B			12 Total Amp-Hour Load (AH/DAY)		70

13 Total DC Load Power (W) 11A	14 Total AC Load Power (W) 11B	15 Nominal System Voltage (V) 9	16 Peak Current Draw (A)	17 Total Amp-Hour Load (AH/DAY) 12	18 Wire Efficiency Factor (DECIMAL) D	19 Battery Efficiency Factor (DECIMAL) D	20 Corrected Amp-Hour Load (AH/DAY)
120	+ —	÷ 12	= 10	70	÷ .98	÷ .9	= 79.4

DESIGN NOTES:

Summer use is higher than winter. The worst case load is reflected in the operating hours per day.

Separate access to refrigerator and freezer is possible.

More access to refrigerator is required.

WORKSHEET #2 DESIGN CURRENT AND ARRAY TILT

21						
	System Location	Roatan Island	Latitude	16° N	Longitude	86° W
	Insolation Location	World Maps	Latitude		Longitude	

	Tilt at Latitude -15°			Tilt at Latitude			Tilt at Latitude +15°		
MONTH	22A Corrected Load (AH/DAY) 20	23A Peak Sun (HRS/DAY)	24A Design Current (A)	22B Corrected Load (AH/DAY) 20	23B Peak Sun (HRS/DAY)	24B Design Current (A)	22C Corrected Load (AH/DAY) 20	23C Peak Sun (HRS/DAY)	24C Design Current (A)
J	62.4	÷ 5.0	= 12.5		÷	=	62.4	÷ 6.0	= 10.4
F		÷	=		÷	=		÷	=
M		÷	=		÷	=		÷	=
A		÷	=		÷	=		÷	=
M		÷	=		÷	=		÷	=
J	79.4	÷ 5.5	= 14.4		÷	=	79.4	÷ 4.5	= 17.6
J	79.4	÷ 5.5	= 14.4		÷	=	79.4	÷ 4.5	= 17.6
A		÷	=		÷	=		÷	=
S		÷	=		÷	=		÷	=
O		÷	=		÷	=		÷	=
N		÷	=		÷	=		÷	=
D	62.4	÷ 5.0	= 12.5		÷	=	62.4	÷ 6.0	= 10.4

Select the largest design current and corresponding peak sun from each latitude and enter below

Latitude -15°		Latitude		Latitude +15°	
25A Peak Sun (HRS/DAY)	26A Design Current (A)	25B Peak Sun (HRS/DAY)	26B Design Current (A)	25C Peak Sun (HRS/DAY)	26C Design Current (A)
5.5	14.4			4.5	17.6

Now select the smallest design current and corresponding peak sun

27 Peak Sun (HRS/DAY	28 Design Current (A)
5.5	14.4
Tilt Angle =	0°

NOTE: DO NOT MIX TRACKING AND FIXED ARRAY DATA ON THE SAME SHEET.

DESIGN NOTES:

Peak sun hours taken from world data maps for winter (latitude +15°) and summer (latitude -15°).

WORKSHEET #3 CALCULATE SYSTEM BATTERY SIZE

29 Corrected Amp-Hour Load (AH/DAY) 20		30 Storage Days D		31 Maximum Depth of Discharge (DECIMAL) D		32 Derate for Temperature (DECIMAL) D		33 Required Battery Capacity (AH)		34 Capacity of Selected Battery (AH)		35 Batteries In Parallel
79.4	X	5	÷	0.8	÷	1.0	=	496	÷	204	=	3

NOTE: BLOCK 35. ROUND UP FOR CONSERVATIVE DESIGN.

36 Nominal System Voltage (V) 9		37 Nominal Battery Voltage (V)		38 Batteries In Series		39 Batteries In Parallel 35		40 Total Batteries
12	÷	12	=	1	X	3	=	3

BATTERY INFORMATION	
Make	Exide
Model	DE 30
Type	Flooded Lead Acid
Nominal Voltage (V)	12
Rated Capacity (AH)	204

41 Batteries In Parallel 35		42 Capacity of Selected Battery (AH) 34		43 System Battery Capacity (AH)		44 Maximum Depth of Discharge (DECIMAL) 31		45 Usable Battery Capacity (AH)
3	X	204	=	612	X	0.8	=	490

NOTE: USE MANUFACTURER'S DATA TO FILL IN BATTERY INFORMATION BLOCK

DESIGN NOTES:

Rounded up for consevative design.

WORKSHEET #4 CALCULATE SYSTEM ARRAY SIZE

46 Design Current (A) 28		47 Module Derate Factor (DECIMAL) D		48 Derated Design Current (A)		49 Rated Module Current (A) D		50 Modules in Parallel
14.4	÷	0.95	=	15.2	÷	3.0	=	5

		51 Nominal Battery Voltage 37		52 Batteries in Series 38		53 Voltage Required for Load (V)		54 Highest Temperature Module Voltage (V)		55 Modules in Series		56 Modules in Parallel 50		57 Total Modules
1.20	x	12	x	1		14.4	÷	14.5	=	1	x	5	=	5

NOTE: USE MANUFACTURER'S SPECIFICATIONS TO FILL IN PV MODULE INFORMATION BLOCK.

PV MODULE INFORMATION

Make/Model	Siemens M55			**Nominal Volts**	12
Length	51	**Width**	13	**Thickness**	1.4
Weight	12.6 lb			**Bypass Diode**	Y [✓ N]
Voltage (V)	**At STC**	**Open Circuit**		**At Highest Expected Temperature**	
	17.4	21.7		14.5	
Current (A)	**At STC**	**Short Circuit**			
	3.0	3.4			

58 Modules in Parallel 50		59 Rated Module Current (A)		60 Rated Array Current (A)
	x	3.0	=	15
		61 Module Short Circuit Current (A)		62 Array Short Circuit Current (A)
	x	3.4	=	17

63 Modules in Series 55		64 Rated Module Voltage (V)		65 Array Rated Voltage (V)
	x	17.4	=	17.4
		66 Open Circuit Module Voltage (V)		67 Array Open Circuit Voltage (V)
	x	21.7	=	21.7

NOTES: BLOCK 50 - ROUND UP FOR CONSERVATIVE DESIGN.
BLOCK 55 - ROUND UP OR SELECT ANOTHER MODULE WITH SUFFICIENT VOLTAGE TO CHARGE THE BATTERIES WHEN OPERATING AT THE HIGHEST EXPECTED TEMPERATURE.

DESIGN NOTES:

Module derate of 5% because clinic operators will clean modules periodically.

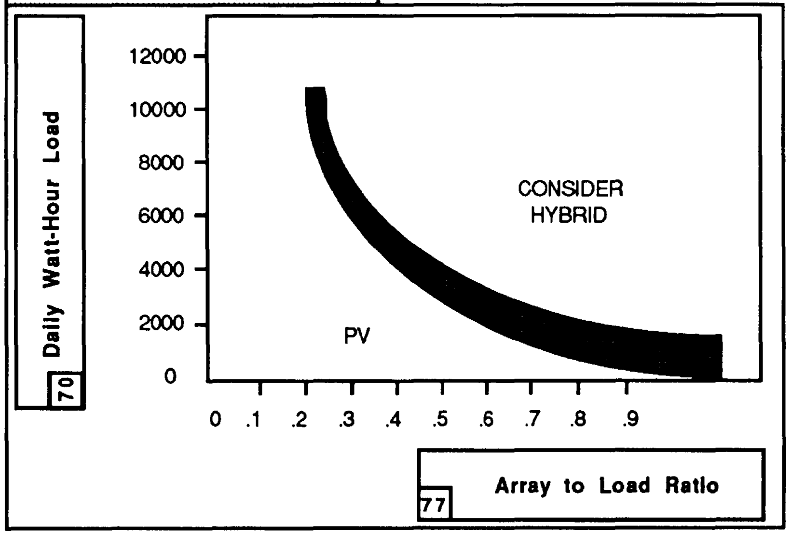
WORKSHEET #5 HYBRID DESIGN DETERMINATION

DESIGN NOTES:

68 Corrected Amp-Hour Load (AH/DAY) 20		69 Nominal System Voltage (V) 9		70 Watt-Hour Load (WH/DAY)		71 Conversion Factor		72 Annual Kilowatt-Hr Load (KWH/YEAR)
79.4	X	12	=	953	X	.365	=	348

73 Derated Design Current (A) 48		74 Nominal System Voltage (V) 9		75 Design Array Power (W)		76 Watt-Hour Load (WH/DAY) 70		77 Array to Load Ratio (DECIMAL)
15.2	X	12	=	182	÷	950	=	0.19

78 **Hybrid Indicator**



Hybrid Design Flag

Yes	No
☐	☒

IF YES, USE HYBRID WORKSHEETS TO COMPLETE SIZING OF A HYBRID SYSTEM. IF NO, PROCEED TO FUNCTIONAL SPECIFICATION SHEETS.

CONTROLLER SPECIFICATION

	A1 62	Array Short Circuit Current (A)	A2	Minimum Controller Current (A)	A3	Rated Controller Current) (A)	A4	Controllers in Parallel
1.25	x	17	=	21	÷	30	=	1

A5

(CONTROLLER)

Make/Model Polar Products PCC 12V30

Rated Voltage 12

Rated Current ____

Features

Temperature Compensation ____

Reverse Current Protection ____

Adjustable Set Points)

High Voltage Disconnect ____

High Voltage Re-connect ____

Low Voltage Disconnect ____

Low Voltage Re-connect ____

Meters

Battery Voltage *

Array Current *

Load Current *

See note

DESIGN NOTES:

Controller has 3 indicator lights:

Green - battery charged
Yellow - warning
Red - low voltage

Ice making function disconnected when red light is on.

Medical personnel instructed to make ice only when a green light condition exists.

PROTECTION COMPONENTS SPECIFICATION

Protected Circuit	Protection Device				Rated Current	Rated Voltage	Description
	Switch	Diode	Fuse	Movistor			
D1 Array output	✓				30 amps	250 V	DC switch
D2 Array output			✓		30 amps	125 V	DC slow-blow with switch
D3 Controller to load	✓				20 amps	250 V	DC Switch
D4 Controller to load			✓		20 amps	125 V	DC slow-blow with switch
D5 Battery	✓		✓		30 amps	125 V	Fused Switch
D6 Freezer circuit	✓				20 amps	250 V	Manual switch
D7							
D8							
D9							
D10							
D11							
D12							
D13							
D14							

Reverse current protection provided in controller.
Array and load switches have integral fuses.

DC WIRE SIZING SPECIFICATION

E1 Wire Runs	E2 System Voltage (V)	E3 Maximum Current (A)	E4 One Way Length (FT)	E5 Allowed Voltage Drop (%)	E6 Allowance for Temperature Derate	E7 AWG Number	E8 Wire Type
Array Circuit							
Module to Module	12	3	2	1%	0%	#12	
Array to Controller or Battery	12	21	40	3%	0%	#2	USE Moisture resistant
DC Circuits							
Battery to Battery	—	—					
Battery to DC Loads	12	13	15	3%	0%	# 8	USE Moisture resistant
Branch Circuits							
A							
B							
C							
D							
E							
Battery Charger to Batteries							
Battery to Inverter Or Converter							

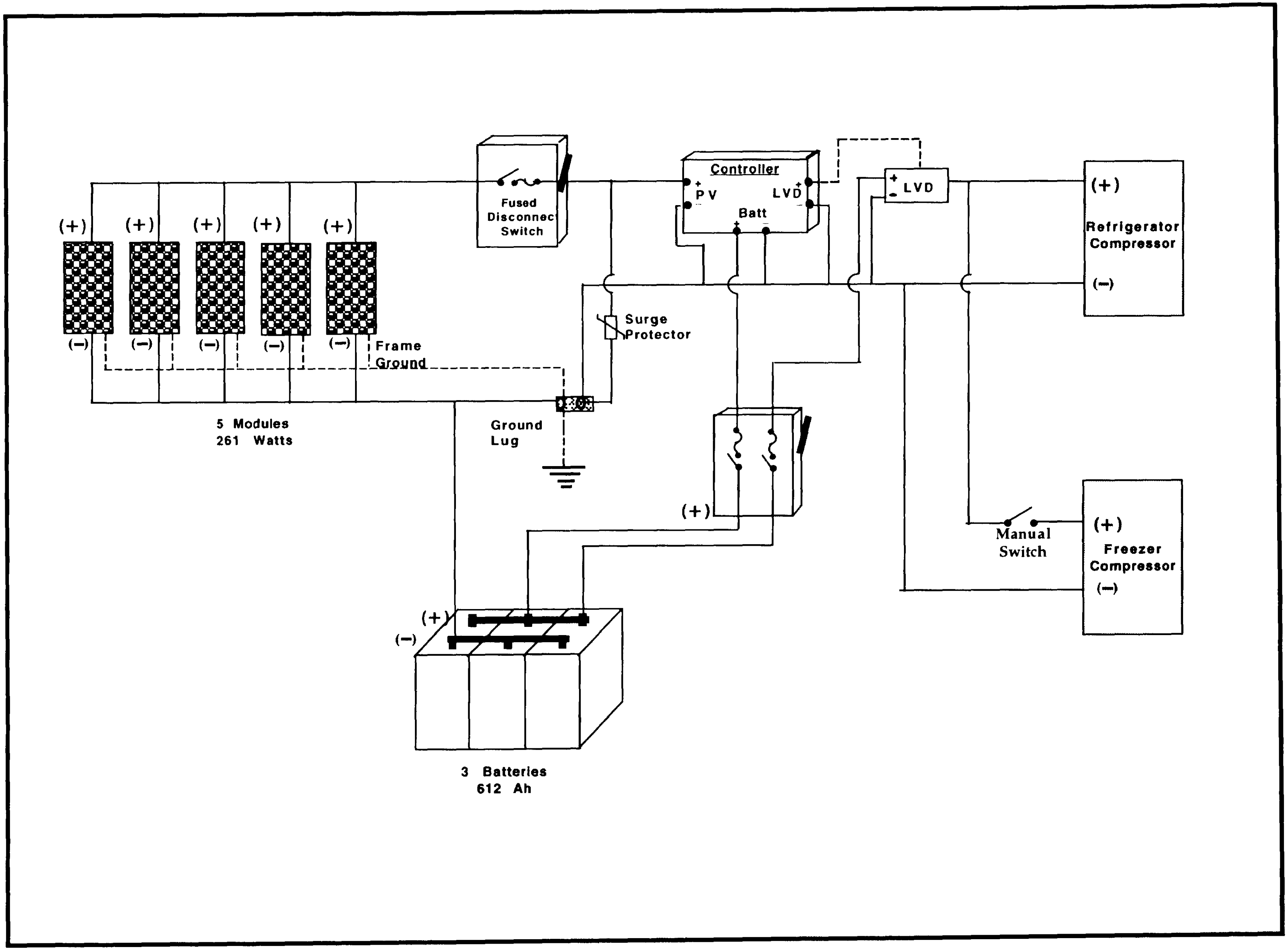
System Grounding	Wire Type	AWG Number	Type of Earth Ground
E9 Equipment Ground	Bare Copper	#2	Copper Rod
E10 System Ground	Bare Copper	#2	Copper Rod

DESIGN NOTES:

No allowance for temperature because ambient temperature of 30°C expected.

All external wiring except module to module installed in conduit.

Ground point is near building.


(+)
(+)
(+)
(+)
(+)
(–)
(–)
(–)
(–)
(–)
Frame Ground
5 Modules
261 Watts
Fused Disconnect Switch
Ground Lug
Surge Protector
Controller
+ PV –
Batt
+ –
LVD
+ –
+ LVD –
(+)
Refrigerator Compressor
(–)
(+)
Manual Switch
(+)
Freezer Compressor
(–)
(+)
(–)
3 Batteries
612 Ah

ECONOMICS ANALYSIS

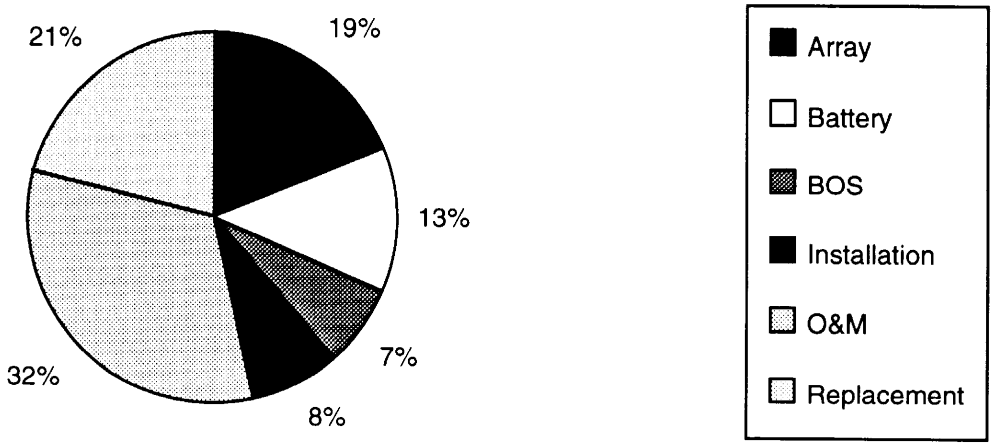
LIFE-CYCLE COST ANALYSIS
POINT DESIGN: VACCINE REFRIGERATOR/FREEZER

Item		Dollar Amount ($)	Present Worth ($)	Percent Total LCC cost (%)
1. CAPITAL COSTS:				
Array		$1,700	$1,700	18.9
Battery		1,224	1,224	13.6
BOS Components		650	650	7.3
Installation		750	750	8.4
A - SUBTOTAL (Equipment & Installation)		**4,324**	**4,324**	**48.2**
2. OPERATION & MAINTENANCE				
B - Annual Inspection		200	2,975	33.1
3. REPLACEMENT:	(YEAR)			
Battery	5	1,224	833	11.9
Battery	10	1,224	567	8.1
Battery	15	1,224	385	5.5
Controller	10	168	78	0.7
C - SUBTOTAL (Replacement Cost)		**5,676**	**1,863**	**20.8**
4. SALVAGE:	(YEAR)			
D - 20% of Original	20	**(714)**	**(184)**	**(2.1)**
TOTAL LIFE-CYCLE COST (A + B + C - D)			**$8,978**	**100.0**

ECONOMIC NOTES:

1) The LCC analysis does not include capital cost of refrigerator.
2) The refrigerator has a compartment for batteries so no additional enclosure is needed.

COST ELEMENTS AS A PERCENT OF LCC (%)



COMMUNICATIONS

Power system reliability is critical for most communications applications and availability must be near 100 percent. Most systems are in remote locations with limited access and often with extreme weather conditions (wind, snow, ice) part of the year. For these reasons, PV systems are increasingly being used to supply power for telecommunication applications. Hybrid systems are sometimes used to reduce initial cost, particularly if the peak power demand is much greater than the average demand. Deep-cycle lead-acid batteries or NiCd batteries are recommended for this application. Even though NiCd batteries are more expensive initially, they may be the best choice because of the low maintenance required and their ability to withstand extreme cold. All specified electronics must be able to withstand the temperature extremes. Lightning is a common problem that must be considered in system design.

APPLICATIONS

- Two-Way Radio
- Radio Communications
- Telephone
- Mobile Radio Systems

USERS

- Utilities
- Military
- Government Agencies
- Businesses

LOAD

UHF, VHF, AM and FM receivers and transmitters for this application will typically operate on 12 volt dc or 24 volt dc. Load current varies depending on operating mode and duty cycle of the radio. Transmitting loads are the largest load and range from 10 to 50 amperes depending on the power of the transmitter. In the receive mode, currents are typically in the 2 to 10 ampere range, while in standby the currents are typically less than 2 amperes. Standby loads can be reduced by turning down volume and squelch. Microwave radios for this application will typically operate on 24 volt dc or 48 volt dc. Load current averages 2.5 to 15 amperes. The permissible voltage range of microwave radio equipment is often lower than the highest possible voltage of the battery. If so, battery charge regulation must be set to terminate charging before the upper voltage limit of the radio equipment is reached. Additional loads may include alarm equipment, ventilation fans, lights and small appliances used on site.

ARRAY

Modules will typically be mounted on towers, on the communications building, or ground mounted. Wind loads and snow accumulations are major considerations. Support structures should be anodized aluminum, galvanized or stainless steel designed for maximum anticipated wind velocities (125 mph typical). Stainless steel fasteners with lockwashers, nylock or pel nuts are advised. Snow depth must be considered in array placement. Snow can build up in front of the array and prevent the snow from sliding off the array. Ice buildup and windloads on array wiring can cause strains on connections. Array wiring should be heavy-duty USE or UF type cable with all connections in water-tight junction boxes with strain relief connectors. All wiring should be laced and attached to the support structure with wire ties. PVC conduit is often used for output wiring to the regulator and batteries. The array should be grounded, usually to the support structure. DC-rated fuses and switches should be used near the charge controller to provide a manual disconnect for the equipment. The array azimuth should be true south (north) with tilt angle as determined in sizing calculations.

BATTERIES

Batteries must have low standby losses combined with occasional deep discharge capability, low water consumption, and minimal maintenance requirements. Transport to remote sites must be considered. Lead acid and nickel cadmium types specifically designed for photovoltaic applications are suggested. The length of time for personnel to get to the site must be considered. Response times of 2 to 5 days are typical when the weather is bad. High and low voltage alarms are advised for systems with large battery banks. Battery capacity must be derated to account for temperature. In extreme climates, batteries should be insulated to minimize temperature extremes. Nonsealed batteries must be installed with adequate ventilation as they can produce explosive and corrosive gas during charging. For this reason, it is not advisable to locate radio equipment near nonsealed batteries. Using sealed batteries minimizes the problem of ventilation and corrosion. Two hundred to twelve hundred ampere-hour battery capacity is typical for PV powered radio repeater sites. One thousand to five thousand ampere-hour battery capacity is typical for PV powered microwave sites. Large capacity cells should be utilized in order to keep the number of batteries in parallel to a minimum. As the short-circuit current available from the battery bank is large, each parallel string of batteries should be protected by a fuse installed at the battery output terminal. Closely follow battery manufacturer's installation and maintenance requirements.

CONTROL

Simplicity and redundancy is the rule. Be sure that controls will operate over the range of expected temperatures. Some controllers have low temperature limits of 0°C. This can easily be exceeded at some sites. Controls that offer temperature compensation should be used for sites where batteries will experience large temperature fluctuations. As charge currents can be high, multiple charge controllers in parallel are often used in lieu of a single high-current controller. In this case, the array is divided into subarrays each connected to a separate charge controller. Metering of battery voltage, charge current, and load current is advised along with high and low battery voltage or state of charge alarms. Protection against lightning-induced electrical damage should be included in the controls. Metal oxide varistors are typically used from the positive conductor to ground. At sites with high lightning potential, additional protection such as gas discharge tubes may be required.

POINT DESIGN NO. 4

MICROWAVE REPEATER

This hybrid system was located in themountains in Idaho. System availability was critical. Two charge controllers were used in parallel to provide reliability. Both were housed in a NEMA 13 enclosure with analog voltage and current meters mounted to the door. The controllers had the temperature compensation feature with temperature sensors attached to the batteries. An adjustable low-voltage sensor was used to control operation of the generator. When the batteries reached 2.0 volts/cell, (approximately 50 percent state-of-charge) the generator was started and provided load power and charged the batteries to 80 percent SOC (2.3 volts/cell). A battery charger was connected to the generator through the load center located inside the repeater building. When the generator starts, the battery charger turns on and remains on until its cycle is complete. The shutdown of the generator terminates the battery charger cycle. The array was mounted on an aluminum support structure that was attached to a wooden platform elevated 7 feet above the ground. Two inch PVC conduit was used for all exposed wiring. A fused, two-pole, 30-ampere dc rated switch in the communications building was installed to disconnect the array. A dc to dc converter was installed, because this particular repeater had both 12-volt and 24-volt dc loads. The converter obtains its power from the 24-volt battery bank through conductors running in conduit from the control box to the converter and its loads.

KEY DESIGN INFORMATION

APPLICATION:	Microwave Repeater		
SITE:	Iron Mountain, Idaho		
LOCATION/ELEVATION:	44°N	115° 3' W	2540 m
ENVIRONMENT:	Mountain Top		
TEMPERATURE RANGE (°C):	-30 to 24		
MAXIMUM WIND SPEED (m/s):	40		
AVAILABILITY REQUIRED:	Critical		
DAYS OF STORAGE:	4 (Hybrid)		
LOAD PROFILES:	Variable		

INSTALLATION

The array support structure consists of pressure treated wooden utility poles that provide an elevated platform for the array. This mounting prevents heavy winter snow accumulation from obstructing the array. The array mounting system consists of aluminum supports designed to meet the wind load requirements of the site. All module interconnections were made using type USE sunlight resistant cable, secured at the module junction boxes with strain relief connectors. The parallel module connections were made inside weatherproof junction boxes mounted on the back of the array frame and interconnected with PVC conduit. The array conductors were run in PVC conduit from the parallel junction boxes to the control box inside the building. The array and its mounting structure are grounded to a grounding electrode at the base of the support structure. The negative conductors in the photovoltaic system were grounded. Positive conductors were fused in a double pole safety switch. All metal enclosures in the repeater station were bonded to the existing grounding system. As a precaution against transient voltages, metal-oxide varistors were installed between each ungrounded conductor and the grounding system. A current limiting fuse was placed in the positive lead to the battery to prevent load and array fuses from blowing in the event of a serious fault.

WORKSHEET #1 **CALCULATE THE LOADS** (FOR EACH MONTH OR SEASON AS REQUIRED)

1 Load Description	2 QTY		3 Load Current (A)		4 Load Voltage (V)		5A DC Load Power (W)		5B AC Load Power (W)		6 Daily Duty Cycle (HRS/DAY)		7 Weekly Duty Cycle (DAYS/WK)		8 Power Conversion Efficiency (DECIMAL) D		9 Nominal System Voltage (V)		10 Amp-Hour Load (AH/DAY)
Microwave Radio DC	1	X	5	X	24	=	120		N/A	X	24	X	7 ÷7	÷	1.0	÷	24	=	120.0
VHF Radio Transmit DC	1	X	15	X	12	=	180		N/A	X	10.5	X	7 ÷7	÷	0.8	÷	24	=	98.4
VHF Radio Receive DC	1	X	3.2	X	12	=	38.4		N/A	X	10.5	X	7 ÷7	÷	0.8	÷	24	=	21.0
VHF Radio Standby DC	1	X	0.32	X	12	=	3.8		N/A	X	3.0	X	7 ÷7	÷	0.8	÷	24	=	0.6
AC		X		X			N/A	=		X		X	÷7	÷		÷		=	
AC		X		X			N/A	=		X		X	÷7	÷		÷		=	
AC		X		X			N/A	=		X		X	÷7	÷		÷		=	
AC		X		X			N/A	=		X		X	÷7	÷		÷		=	

11 Total Load Power (W)	DC 11A	AC 11B	12 Total Amp-Hour Load (AH/DAY)
	342.2		240

13 Total DC Load Power (W) 11A		14 Total AC Load Power (W) 11B		15 Nominal System Voltage (V) 9		16 Peak Current Draw (A)	17 Total Amp-Hour Load (AH/DAY) 12		18 Wire Efficiency Factor (DECIMAL) D		19 Battery Efficiency Factor (DECIMAL) D		20 Corrected Amp-Hour Load (AH/DAY)
300 ✱	+	0	÷	24	=	12.5	240	÷	0.98	÷	0.95	=	258

DESIGN NOTES:

Use 24V system, this is the largest load and the current will be half that of a 12V system. Use a DC to DC converter for 12 v loads.

✱ 300 watts is the maximum load. This occurs when both VHF and microwave radios are transmitting.

WORKSHEET #2 DESIGN CURRENT AND ARRAY TILT

DESIGN NOTES:

21					
System Location	Iron Mountain, ID	Latitude	46° N	Longitude	115° 3' W
Insolation Location	Boise, ID	Latitude	43° 3'N	Longitude	116° 1'W

	Tilt at Latitude -15°					Tilt at Latitude					Tilt at Latitude +15°				
MONTH	22A Corrected Load (AH/DAY) 20		23A Peak Sun (HRS/DAY)		24A Design Current (A)	22B Corrected Load (AH/DAY) 20		23B Peak Sun (HRS/DAY)		24B Design Current (A)	22C Corrected Load (AH/DAY) 20		23C Peak Sun (HRS/DAY)		24C Design Current (A)
J	258	÷	2.33	=	112.7	258	÷	2.58	=	100	258	÷	2.69	=	95.9
F		÷		=			÷		=			÷		=	
M		÷		=			÷		=			÷		=	
A		÷		=			÷		=			÷		=	
M		÷		=			÷		=			÷		=	
J		÷		=			÷		=			÷		=	
J		÷		=			÷		=			÷		=	
A		÷		=			÷		=			÷		=	
S		÷		=			÷		=			÷		=	
O		÷		=			÷		=			÷		=	
N		÷		=			÷		=			÷		=	
D	258	÷	2.30	=	112.2	258	÷	2.62	=	98.5	258	÷	2.78	=	92.8

Select the largest design current and corresponding peak sun from each latitude and enter below

Latitude -15°	
25A Peak Sun (HRS/DAY)	26A Design Current (A)
2.3	112.2

Latitude	
25B Peak Sun (HRS/DAY)	26B Design Current (A)
2.58	100

Latitude +15°	
25C Peak Sun (HRS/DAY)	26C Design Current (A)
2.69	95.9

Now select the smallest design current and corresponding peak sun

27 Peak Sun (HRS/DAY		28 Design Current (A)
2.69		95.9
Tilt Angle	=	~60°

NOTE: DO NOT MIX TRACKING AND FIXED ARRAY DATA ON THE SAME SHEET.

WORKSHEET #3 CALCULATE SYSTEM BATTERY SIZE

29 Corrected Amp-Hour Load (AH/DAY) 20		30 Storage Days D		31 Maximum Depth of Discharge (DECIMAL) D		32 Derate for Temperature (DECIMAL) D		33 Required Battery Capacity (AH)		34 Capacity of Selected Battery (AH)		35 Batteries in Parallel
258	X	16	÷	0.8	÷	0.8	=	6450	÷	1200	=	6

NOTE: BLOCK 35. ROUND UP FOR CONSERVATIVE DESIGN.

36 Nominal System Voltage (V) 9		37 Nominal Battery Voltage (V)		38 Batteries in Series		39 Batteries in Parallel 35		40 Total Batteries
24	÷	2	=	12	X	6	=	72

BATTERY INFORMATION	
Make	GNB
Model	75A27
Type	Lead Acid
Nominal Voltage (V)	2
Rated Capacity (AH)	1200

41 Batteries in Parallel 35		42 Capacity of Selected Battery (AH) 34		43 System Battery Capacity (AH)		44 Maximum Depth of Discharge (DECIMAL) 31		45 Usable Battery Capacity (AH)
6	X	1200	=	7200	X	0.8	=	5760

NOTE: USE MANUFACTURER'S DATA TO FILL IN BATTERY INFORMATION BLOCK

DESIGN NOTES:

WORKSHEET #4 CALCULATE SYSTEM ARRAY SIZE

DESIGN NOTES:

46 Design Current (A) 28		47 Module Derate Factor (DECIMAL) D		48 Derated Design Current (A)		49 Rated Module Current (A) D		50 Modules in Parallel
95.9	÷	0.9	=	106.6	÷	3	=	36

		51 Nominal Battery Voltage 37		52 Batteries in Series 38	53 Voltage Required for Load (V)		54 Highest Temperature Module Voltage (V)		55 Modules in Series		56 Modules in Parallel 50		57 Total Modules
1.20	X	2	X	12	28.8	÷	15	=	2	X	36	=	72

NOTE: USE MANUFACTURER'S SPECIFICATIONS TO FILL IN PV MODULE INFORMATION BLOCK.

58 Modules in Parallel 50		59 Rated Module Current (A)		60 Rated Array Current (A)
	X	3.0	=	108
		61 Module Short Circuit Current (A)		62 Array Short Circuit Current (A)
	X	3.34	=	120

63 Modules in Series 55		64 Rated Module Voltage (V)		65 Array Rated Voltage (V)
	X	16.5	=	33
		66 Open Circuit Module Voltage (V)		67 Array Open Circuit Voltage (V)
	X	20.3	=	40.6

PV MODULE INFORMATION

Make/Model	Solec S-50		**Nominal Volts**	12
Length	51	**Width** 13	**Thickness**	1.5
Weight	12 lbs.		**Bypass Diode**	[✓ Y] N
Voltage (V)	**At STC**	**Open Circuit**	**At Highest Expected Temperature**	
	16.5	20.3	15	
Current (A)	**At STC**	**Short Circuit**		
	3.0	3.34		

NOTES: BLOCK 50 - ROUND UP FOR CONSERVATIVE DESIGN.

BLOCK 55 - ROUND UP OR SELECT ANOTHER MODULE WITH SUFFICIENT VOLTAGE TO CHARGE THE BATTERIES WHEN OPERATING AT THE HIGHEST EXPECTED TEMPERATURE.

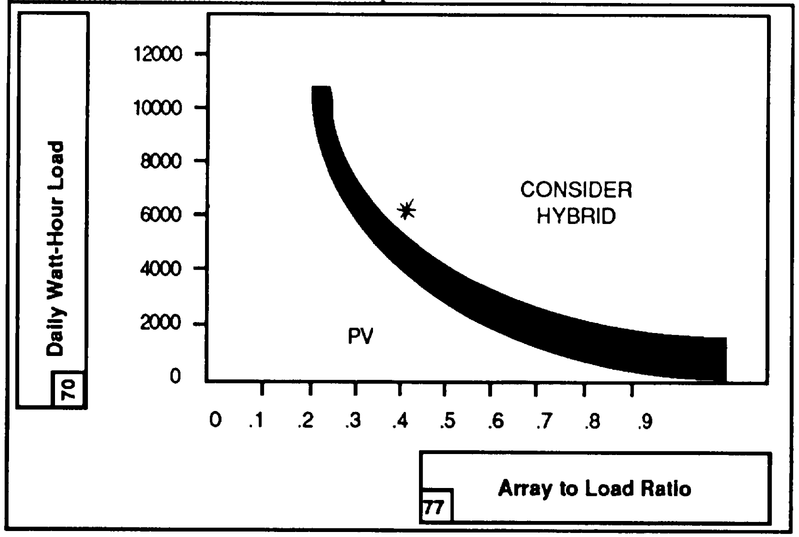
WORKSHEET #5 HYBRID DESIGN DETERMINATION

DESIGN NOTES:

68 Corrected Amp-Hour Load (AH/DAY) 20		69 Nominal System Voltage (V) 9		70 Watt-Hour Load (WH/DAY)		71 Conversion Factor		72 Annual Kilowatt-Hr Load (KWH/YEAR)
258	X	24	=	6192	X	.365	=	2260

73 Derated Design Current (A) 48		74 Nominal System Voltage (V) 9		75 Design Array Power (W)		76 Watt-Hour Load (WH/DAY) 70		77 Array to Load Ratio (DECIMAL)
106.6	X	24	=	2558	÷	6192	=	0.41

78 **Hybrid Indicator**



Hybrid Design Flag

Yes ☑ No ☐

IF YES, USE HYBRID WORKSHEETS TO COMPLETE SIZING OF A HYBRID SYSTEM. IF NO, PROCEED TO FUNCTIONAL SPECIFICATION SHEETS.

HYBRID WORKSHEET #1 HY

CALCULATE THE BATTERY CAPACITY, GENERATOR SIZE, AND PERCENT CONTRIBUTION OF THE ARRAY AND GENERATOR

1Y Corrected Amp-Hour Load (AH/DAY) 20		2Y D Storage Days for Hybrid System		3Y D Maximum Depth of Discharge (DECIMAL)		4Y D Derate for Temperature (DECIMAL)		5Y Hybrid Battery Capacity (AH)		6Y Peak Current Draw (A) 16		7Y Battery Discharge Time (HOURS)
258	X	4	÷	0.8	÷	0.75	=	1720	÷	12.5	=	138

8Y Hybrid Battery Capacity (AH) 5Y		9Y D Battery Charge Time (HOURS)		10Y Maximum Battery Charge Rate (A)		11Y Nominal System Voltage (V) 9		12Y Nominal Charging Power (W)		13Y D Efficiency of Battery Charger (DECIMAL)		14Y D Generator Derate Factor (DECIMAL)		15Y Generator Size (W)
1720	÷	8	=	215	X	24	=	5160	÷	0.85	÷	0.625*	=	9700

16Y D Hybrid Array to Load Ratio	17Y D Load Provided by Array (DECIMAL)
0.2 ⊠	0.75

		18Y Load Provided by Array (DECIMAL) 17Y		19Y Load Provided by Generator (DECIMAL)		20Y Annual Kilowatt-Hour Load (KWH/YR) 72		21Y Annual Generator Output (KWH)
1.0	−	0.75	=	0.25	X	2260	=	565

22Y Annual Generator Output (KWH) 21Y		23Y Conversion Factor		24Y Nominal Charging Power (W) 12Y		25Y Annual Generator Run Time (HRS)		26Y D Oil Change Interval (HRS)		27Y Services per Year (NUMBER)
565	X	**1000**	÷	5160	=	110	÷	100	=	1

DESIGN NOTES:

Temperature derate from figure 5 for 0°C.

* Generator derated 37.5% for operation at ~ 7500 feet elevation (1 − .375) = 0.625

⊠ Chosen so PV array would provide 75% of annual load.

HYBRID WORKSHEET #2 HY

CALCULATE THE NUMBER OF MODULES AND BATTERIES IN SERIES AND PARALLEL

28Y D Hybrid Array to Load Ratio 16Y		29Y Watt-Hour Load (WH/DAY) 70		30Y Hybrid Array Power (W)		31Y Nominal System Voltage (V) 9		32Y Rated Module Current (A) 59		33Y Modules in Parallel
0.2	X	6192	=	1238	÷	24	÷	3.0	=	17

34Y Nominal System Voltage (V) 9		35Y Nominal Module Voltage (V)		36Y Modules in Series		37Y Modules in Parallel 33Y		38Y Total Modules
24	÷	12	=	2	X	17	=	34

39Y Hybrid Battery Capacity (AH) 5Y		40Y Capacity of Selected Battery (AH)		41Y Hybrid Batteries in Parallel		42Y Nominal System Voltage (V) 9		43Y Nominal Battery Voltage (V) 36		44Y Hybrid Batteries in Series		45Y Hybrid Batteries in Parallel 41Y		46Y Total Hybrid Batteries
1720	÷	1800	=	1		24	÷	2	=	12	X	1	=	12

47Y Hybrid Batteries in Parallel 41Y		48Y Capacity of Selected Battery (AH) 40Y		49Y Hybrid System Battery Capacity (AH)		50Y Maximum Depth of Discharge (DECIMAL) 3Y		51Y Usable Battery Capacity (AH)
1	X	1800	=	1800	X	0.8	=	1440

DESIGN NOTES:

Selected a higher capacity battery to more closely match the required capacity.

CONTROLLER SPECIFICATION

		A1 Array Short Circuit Current (A) 62		A2 Minimum Controller Current (A)		A3 Rated Controller Current) (A)		A4 Controllers in Parallel
1.25	X	51	=	63.8	÷	30	=	2

A5 (CONTROLLER)

Make/Model Specialty Concepts SCI-1-24A

Rated Voltage 24

Rated Current ______

Features

Temperature Compensation ✓

Reverse Current Protection ______

Adjustable Set Points)

High Voltage Disconnect ______

High Voltage Re-connect ______

Low Voltage Disconnect ______

Low Voltage Re-connect ______

Meters

Battery Voltage ✓

Array Current ✓

Load Current ✓

DESIGN NOTES:

Controller provides reverse current protection.

POWER CONDITIONING UNITS SPECIFICATION

Inverter

System Requirements

B1 Wave Form N/A

B2 DC System Voltage ______ (V)

B3 AC System Voltage ______ (V)

B4 Surge Capacity ______ (W)

B5 Total AC Watts ______ (W)

B6 Maximum Single AC Load ______ (W)

B7 Maximum Simultaneous AC Load ______ (W)

B8 Inverter Run Time at Maximum Simultaneous Load ______ (MIN)

B9 Inverter Continuous Duty Rating ______ (W)

B10 Required Inverter Efficiency at Load ______ (%)

B11 Inverter Specifications

Make N/A

Model ______

Wave Form ______

Input Voltage (DC) ______ (V)

Output Voltage (AC) ______ (V)

Surge Capacity ______ (W)

FEATURES:

- Battery Charging ( )
- Voltmeter ( )
- Remote Control ( )
- Generator Start ( )
- Transfer Switch ( )
- Maximum Power Tracking ( )

DESIGN NOTES:

Converter

System Requirements

C1 Input DC Voltage 23 to 30 (V)

C2 Output DC Voltage 12.5 to 13.5 (V)

C3 Output Power ______ (W)

C4 Operating Temperature 0 to 50 (C°)

C5 Converter

Make Willmore Electronics

Model 1265-24-13-30

Input Voltage 20-29 (V)

Output Voltage 12 (V)

Output Current 30 (A)

Operating Temperature -30 to 71 (C°)

FEATURES:

Adjustable Output Voltage ______ (V)

PROTECTION COMPONENTS SPECIFICATION

Protected Circuit	Protection Device				Rated Current	Rated Voltage	Description
	Switch	Diode	Fuse	Movistor			
D1 Array output	✓				100amps	200 V	DC switch
D2 Array output			✓		50 amp	125 V	DC slow-blow
D3 Controller to Load	✓				20amp	200 V	DC switch
D4 Controller to load			✓		20amp	125 V	DC fuse
D5 Battery			✓		50amp	250 V	DC slow-blow
D6							
D7							
D8							
D9							
D10							
D11							
D12							
D13							
D14							

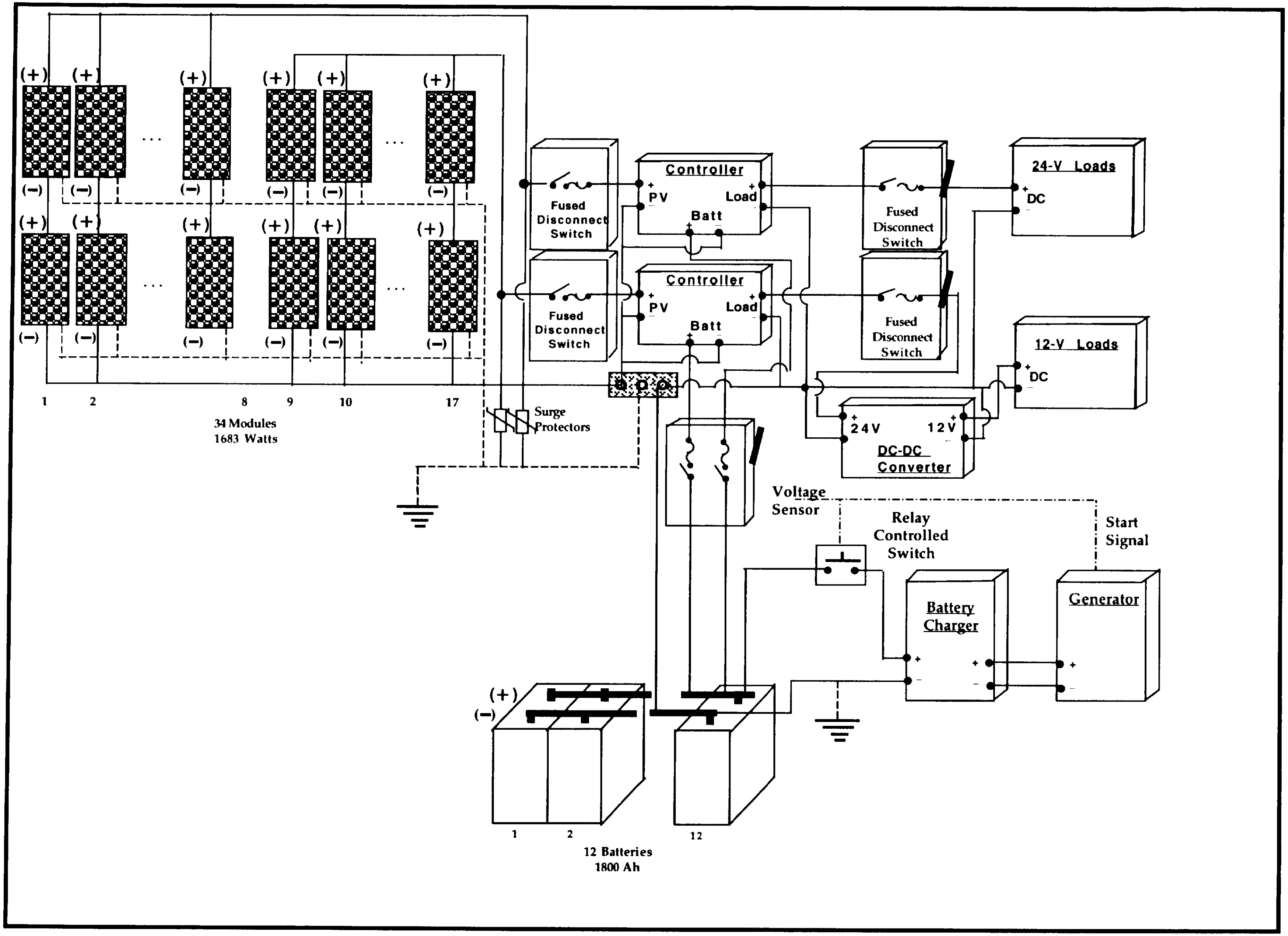
The junction box for all connections, switches, fuses, and controllers is mounted on the wall inside the building.
The controller provides reverse current protection.

E1 Wire Runs	E2 System Voltage (V)	E3 Maximum Current (A)	E4 One Way Length (FT)	E5 Allowed Voltage Drop (%)	E6 Allowance for Temperature Derate	E7 AWG Number	E8 Wire Type
Array Circuit							
Module to Module	24	4	2	—	—	10	USE Sunlight Resistant
Array to Controller or Battery	24	63.8/2=31.9	20	2	0	4	THHN
DC Circuits							
Battery to Battery	24	—	1	1	0	6	TW Flame Retardant Thermoplastic
Battery or Controller to DC Loads	24	9.4	10	2	—	8	USE
Branch Circuits							
A ______							
B ______							
C ______							
D ______							
E ______							
Battery Charger to Batteries							
Battery to Inverter Or Converter	24	6.2	10	2	—	8	USE

System Grounding	**Wire Type**	**AWG Number**	**Type of Earth Ground**
E9 **Equipment Ground**	Bare Copper	#4	To buried grid
E10 **System Ground**	Bare Copper	#4	installed for radio ground.

DESIGN NOTES:

All wiring except array installed in conduit with rain hoods.


(+)
(−)
1
2
8
9
10
17
34 Modules
1683 Watts
Surge
Protectors
Fused
Disconnect
Switch
Fused
Disconnect
Switch
Controller
PV
Load
Batt
Controller
PV
Load
Batt
Fused
Disconnect
Switch
Fused
Disconnect
Switch
24-V Loads
DC
12-V Loads
DC
24 V
12 V
DC-DC
Converter
Voltage
Sensor
Relay
Controlled
Switch
Start
Signal
Battery
Charger
Generator
1
2
12
12 Batteries
1800 Ah

ECONOMICS ANALYSIS

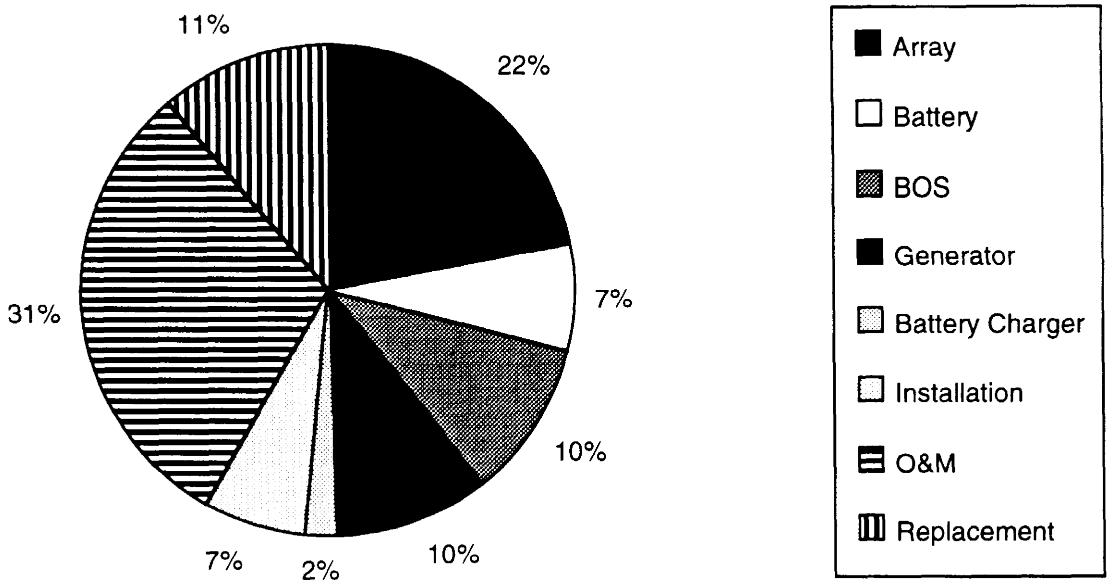
LIFE-CYCLE COST ANALYSIS
POINT DESIGN: MICROWAVE REPEATER

Item		Dollar Amount ($)	Present Worth ($)	Percent Total LCC cost (%)
1. CAPITAL COSTS:				
Array		$10,940	$10,940	22.4
Battery		3,600	3,600	7.4
BOS + Mounting + Control Center		5,100	5,100	10.4
Generator		5,000	5,000	10.2
Battery Charger		1,000	1,000	2.0
Installation		3,500	3,500	7.2
A - SUBTOTAL (Equipment & Installation)		**29,140**	**29,140**	**59.8**
2. OPERATION & MAINTENANCE				
Generator Inspection (Annual)		250	3,718	7.6
Annual Fuel Cost		640	10,464	21.4
Annual Inspection		75	1,115	2.3
B - SUBTOTAL (Operation & Maintenance)		**815**	**15,297**	**31.3**
3. REPLACEMENT:	(YEAR)			
Battery	10	3,600	2,678	5.5
Generator Rebuild	5	1,000	863	1.8
Generator Rebuild	10	1,000	744	1.5
Generator Rebuild	15	1,000	642	1.3
Controller	10	600	446	0.9
C - SUBTOTAL (Replacement Cost)		**9,000**	**5,373**	**11.0**
4. SALVAGE:	(YEAR)			
D - 15% of Original (5)	20	**(3,846)**	**(992)**	**(2.1)**
TOTAL LIFE-CYCLE COST (A + B + C - D)			**$48,818**	**100.0**

ECONOMIC NOTES:

1) LCC analysis includes the complete cost of the power system including PV system and generator.
2) Generator uses propane fuel. Estimated cost is $2.00 per gallon delivered to the site.
3) Generator and PV power system should be inspected each year when the microwave equipment IS checked. No extra travel costs are included.
4) Parts of the control center will be replaced once during the life of the system--assumed to be in year 10 when the batteries are replaced.
5) Salvage value set at 15% because of difficulty in dismantling and removing equipment from site.
6) Two percent discount rate used to calculatepresent worth of fuel cost.

COST ELEMENTS AS A PERCENT OF LCC (%)



POINT DESIGN NO. 5

RADIO REPEATER

This 350-watt PV system powers a radio repeater in Oregon. The load demand peaks in the summer when use is approximately three times the winter usage. Use of two solid-state charge controllers increase reliability. The solid-state regulators have the low operating temperature range needed for this site. Low voltage disconnect capability is desired but is not possible in the current range for the regulator chosen. A separate 30 amp power relay was installed and activated by the low-voltage disconnect provided by the regulator. Movistors were placed across positive and negative conductors to ground. The negative of the battery was not grounded. This system contains large, deep cycle, maintenance free, batteries. The batteries require no electrolyte replacement and they are not susceptible to freezing. The critical availability of the system is provided by the large storage capacity of the batteries.

KEY DESIGN INFORMATION

APPLICATION:	VHF Radio Repeater
SITE:	East of Prineville, Oregon
LOCATION/ELEVATION:	44°12' N 120° 30' w 1300 m
ENVIRONMENT:	High Desert
TEMPERATURE RANGE (°C):	-20 to 35
MAXIMUM WIND SPEED (m/s):	50
AVAILABILITY REQUIRED:	Critical
DAYS OF STORAGE:	14
LOAD PROFILES:	Variable

INSTALLATION

The array was ground mounted on a concrete foundation. Array conductors were run directly into a weatherproof control box located on the back of the array mounting structure. Charge regulators, lightning arrestors, fuses, switches, and load management equipment are all located inside the weatherproof control box. The batteries are contained in an insulated weatherproof enclosure which is ground mounted beneath the array and connected to the control box with watertight flexible conduit. Power leads to the nearby repeater are enclosed in PVC conduit, properly sized to contain the No. 6 copper conductors from the control box. Neither conductor of the PV system is grounded and fuses are installed in both leads. Lightning or transient suppression is provided by varistors between the conductors and a grounding electrode. Current limiting fuses were installed on the battery leads to prevent damage from catastrophic short circuits.

WORKSHEET #1A CALCULATE THE LOADS (FOR EACH MONTH OR SEASON AS REQUIRED)

1 Load Description	2 QTY		3 Load Current (A)		4 Load Voltage (V)		5A DC Load Power (W)		5B AC Load Power (W)		6 Daily Duty Cycle (HRS/DAY)		7 Weekly Duty Cycle (DAYS/WK)		8 Power Conversion Efficiency (DECIMAL) D		9 Nominal System Voltage (V)		10 Amp-Hour Load (AH/DAY)
Transmit DC	1	X	21	X	12	=	252		N/A	X	6	X	7 ÷7	÷	1.0	÷	12	=	126
Receive DC	1	X	2	X	12	=	24		N/A	X	6	X	7 ÷7	÷	1.0	÷	12	=	12
Standby DC	1	X	.42	X	12	=	5		N/A	X	12	X	7 ÷7	÷	1.0	÷	12	=	5
DC		X		X		=			N/A	X		X	÷7	÷		÷		=	
AC		X		X			N/A	=		X		X	÷7	÷		÷		=	
AC		X		X			N/A	=		X		X	÷7	÷		÷		=	
AC		X		X			N/A	=		X		X	÷7	÷		÷		=	
AC		X		X			N/A	=		X		X	÷7	÷		÷		=	

11 Total Load Power (W)	DC 11A 281	AC 11B	
12 Total Amp-Hour Load (AH/DAY)	143		

13 Total DC Load Power (W) 11A		14 Total AC Load Power (W) 11B		15 Nominal System Voltage (V) 9		16 Peak Current Draw (A)	17 Total Amp-Hour Load (AH/DAY) 12		18 Wire Efficiency Factor (DECIMAL) D		19 Battery Efficiency Factor (DECIMAL) D		20 Corrected Amp-Hour Load (AH/DAY)
252	+	0	÷	12	=	21*	143	÷	0.98	÷	0.95	=	153.6

DESIGN NOTES:

Summer load is April to September.

* Transmit mode will be largest load. Unit cannot be in more than one mode at any one time.

WORKSHEET #1a CALCULATE THE LOADS (FOR EACH MONTH OR SEASON AS REQUIRED)

1 Load Description	2 QTY		3 Load Current (A)		4 Load Voltage (V)		5A DC Load Power (W)		5B AC Load Power (W)		6 Daily Duty Cycle (HRS/DAY)		7 Weekly Duty Cycle (DAYS/WK)		8 Power Conversion Efficiency (DECIMAL) D		9 Nominal System Voltage (V)		10 Amp-Hour Load (AH/DAY)
Transmit DC	1	X	21	X	12	=	252		N/A	X	2	X	7 ÷7	÷	1.0	÷	12	=	42
Receive DC	1	X	2	X	12	=	24		N/A	X	2	X	7 ÷7	÷	1.0	÷	12	=	4
Standby DC	1	X	.42	X	12	=	5		N/A	X	20	X	7 ÷7	÷	1.0	÷	12	=	8.3
DC		X		X		=			N/A	X		X	÷7	÷		÷		=	
AC		X		X			N/A	=		X		X	÷7	÷		÷		=	
AC		X		X			N/A	=		X		X	÷7	÷		÷		=	
AC		X		X			N/A	=		X		X	÷7	÷		÷		=	
AC		X		X			N/A	=		X		X	÷7	÷		÷		=	

11 Total Load Power (W)	DC 11A 281	AC 11B	12 Total Amp-Hour Load (AH/DAY) 54.3

13 Total DC Load Power (W) 11A		14 Total AC Load Power (W) 11B		15 Nominal System Voltage (V) 9		16 Peak Current Draw (A)	17 Total Amp-Hour Load (AH/DAY) 12		18 Wire Efficiency Factor (DECIMAL) D		19 Battery Efficiency Factor (DECIMAL) D		20 Corrected Amp-Hour Load (AH/DAY)
252 ✱	+	0	÷	12	=	21	54.3	÷	0.98	÷	0.95	=	58.3

DESIGN NOTES:

Winter load is October to March.

✱ Transmit mode will be largest load. Unit cannot be in more than one mode at any one time.

RADIO REPEATER

WORKSHEET #2 DESIGN CURRENT AND ARRAY TILT Summer

21					
System Location	Prineville, OR	Latitude	44° 12' N	Longitude	120° 30' W
Insolation Location	*	Latitude		Longitude	

	Tilt at Latitude -15°					Tilt at Latitude					Tilt at Latitude +15°				
MONTH	22A Corrected Load (AH/DAY) 20		23A Peak Sun (HRS/DAY)		24A Design Current (A)	22B Corrected Load (AH/DAY) 20		23B Peak Sun (HRS/DAY)		24B Design Current (A)	22C Corrected Load (AH/DAY) 20		23C Peak Sun (HRS/DAY)		24C Design Current (A)
J		÷		=			÷		=			÷		=	
F		÷		=			÷		=			÷		=	
M		÷		=			÷		=			÷		=	
A	153.6	÷	5.5	=	27.9	153.6	÷	5.3	=	29	153.6	÷	4.8	=	32
M	153.6	÷	6.3	=	24.4	153.6	÷	5.8	=	26.5	153.6	÷	5.1	=	30.1
J	153.6	÷	6.4	=	24	153.6	÷	6.3	=	24.4	153.6	÷	5.4	=	28.4
J	153.6	÷	7.7	=	19.9	153.6	÷	7.1	=	21.6	153.6	÷	6.2	=	24.8
A	153.6	÷	7.2	=	21.3	153.6	÷	6.9	=	22.3	153.6	÷	6.3	=	24.4
S	153.6	÷	6.1	=	25.2	153.6	÷	6.2	=	24.8	153.6	÷	6.0	=	25.6
O		÷		=			÷		=			÷		=	
N		÷		=			÷		=			÷		=	
D		÷		=			÷		=			÷		=	

Select the largest design current and corresponding peak sun from each latitude and enter below

Latitude -15°		Latitude		Latitude +15°	
25A Peak Sun (HRS/DAY)	26A Design Current (A)	25B Peak Sun (HRS/DAY)	26B Design Current (A)	25C Peak Sun (HRS/DAY)	26C Design Current (A)
5.5	27.9	5.3	29	4.8	32

Now select the smallest design current and corresponding peak sun

27 Peak Sun (HRS/DAY	28 Design Current (A)
5.5	27.9

Tilt Angle = ~ 30°

NOTE: DO NOT MIX TRACKING AND FIXED ARRAY DATA ON THE SAME SHEET.

DESIGN NOTES:

Prineville has greater local insolation than Medford, Oregon Data supplied in Appendix A. Insolation data were interpolated from three locations surrounding the sight.

WORKSHEET #2

DESIGN CURRENT AND ARRAY TILT Winter

21					
System Location	Prineville, OR	Latitude	44° 12' N	Longitude	120° 30' W
Insolation Location	*	Latitude		Longitude	

DESIGN NOTES:

* See notes on Summer Worksheet.

	Tilt at Latitude -15°					Tilt at Latitude					Tilt at Latitude +15°				
MONTH	22A Corrected Load (AH/DAY) 20		23A Peak Sun (HRS/DAY)		24A Design Current (A)	22B Corrected Load (AH/DAY) 20		23B Peak Sun (HRS/DAY)		24B Design Current (A)	22C Corrected Load (AH/DAY) 20		23C Peak Sun (HRS/DAY)		24C Design Current (A)
J	58.3	÷	1.8	=	32.4	58.3	÷	1.9	=	30.7	58.3	÷	2.0	=	29.2
F	58.3	÷	3.0	=	19.4	58.3	÷	3.2	=	18.2	58.3	÷	3.2	=	18.2
M	58.3	÷	4.2	=	13.9	58.3	÷	4.2	=	13.9	58.3	÷	4.0	=	14.6
A		÷		=			÷		=			÷		=	
M		÷		=			÷		=			÷		=	
J		÷		=			÷		=			÷		=	
J		÷		=			÷		=			÷		=	
A		÷		=			÷		=			÷		=	
S		÷		=			÷		=			÷		=	
O	58.3	÷	4.2	=	13.9	58.3	÷	4.5	=	13	58.3	÷	4.6	=	12.7
N	58.3	÷	2.4	=	24.3	58.3	÷	2.6	=	22.4	58.3	÷	2.7	=	21.6
D	58.3	÷	1.5	=	38.9	58.3	÷	1.7	=	34.1	58.3	÷	1.8	=	32.4

Select the largest design current and corresponding peak sun from each latitude and enter below

Latitude -15°		Latitude		Latitude +15°	
25A Peak Sun (HRS/DAY)	26A Design Current (A)	25B Peak Sun (HRS/DAY)	26B Design Current (A)	25C Peak Sun (HRS/DAY)	26C Design Current (A)
1.5	38.9	1.7	34.1	1.8	32.4

Now select the smallest design current and corresponding peak sun

27 Peak Sun (HRS/DAY	28 Design Current (A)
1.8	32.4
Tilt Angle =	~ 60°

NOTE: DO NOT MIX TRACKING AND FIXED ARRAY DATA ON THE SAME SHEET.

WORKSHEET #3

CALCULATE SYSTEM BATTERY SIZE

29 Corrected Amp-Hour Load (AH/DAY) 20		30 Storage Days D		31 Maximum Depth of Discharge (DECIMAL) D		32 Derate for Temperature (DECIMAL) D		33 Required Battery Capacity (AH)		34 Capacity of Selected Battery (AH)		35 Batteries in Parallel
58.3	X	14	÷	0.8	÷	0.6	=	1700	÷	930	=	2

NOTE: BLOCK 35. ROUND UP FOR CONSERVATIVE DESIGN.

36 Nominal System Voltage (V) 9		37 Nominal Battery Voltage (V)		38 Batteries in Series		39 Batteries in Parallel 35		40 Total Batteries
12	÷	6	=	2	X	2	=	4

BATTERY INFORMATION	
Make	GNB
Model	3-75A21
Type	Deep Cycle
Nominal Voltage (V)	6
Rated Capacity (AH)	930

41 Batteries in Parallel 35		42 Capacity of Selected Battery (AH) 34		43 System Battery Capacity (AH)		44 Maximum Depth of Discharge (DECIMAL) 31		45 Usable Battery Capacity (AH)
2	X	930	=	1860	X	0.8	=	1488

NOTE: USE MANUFACTURER'S DATA TO FILL IN BATTERY INFORMATION BLOCK

DESIGN NOTES:

WORKSHEET #4 CALCULATE SYSTEM ARRAY SIZE

DESIGN NOTES:

46 Design Current (A) 28		47 Module Derate Factor (DECIMAL) D		48 Derated Design Current (A)		49 Rated Module Current (A) D		50 Modules in Parallel
32.4	÷	0.9	=	36	÷	3.02	=	12

	51 Nominal Battery Voltage 37		52 Batteries in Series 38			53 Voltage Required for Load (V)		54 Highest Temperature Module Voltage (V)		55 Modules in Series		56 Modules in Parallel 50		57 Total Modules
1.20	x	6	x	2	▨		14.4	÷	14.4	=	1	x	12	=	12

NOTE: USE MANUFACTURER'S SPECIFICATIONS TO FILL IN PV MODULE INFORMATION BLOCK.

58 Modules in Parallel 50		59 Rated Module Current (A)		60 Rated Array Current (A)
	x	3.02	=	36.2
		61 Module Short Circuit Current (A)		62 Array Short Circuit Current (A)
	x	3.25	=	39

PV MODULE INFORMATION

Make/Model	Kyocera K51			Nominal Volts	12
Length	38.8	Width	17.5	Thickness	1.4
Weight	13.5 lbs.			Bypass Diode	Y [✓ N]
Voltage (V)	At STC	Open Circuit		At Highest Expected Temperature	
	16.9	20.7		14.4	
Current (A)	At STC	Short Circuit			
	3.02	3.25			

63 Modules in Series 55		64 Rated Module Voltage (V)		65 Array Rated Voltage (V)
	x	16.9	=	16.9
		66 Open Circuit Module Voltage (V)		67 Array Open Circuit Voltage (V)
	x	20.7	=	20.7

NOTES: BLOCK 50 - ROUND UP FOR CONSERVATIVE DESIGN.

BLOCK 55 - ROUND UP OR SELECT ANOTHER MODULE WITH SUFFICIENT VOLTAGE TO CHARGE THE BATTERIES WHEN OPERATING AT THE HIGHEST EXPECTED TEMPERATURE.

WORKSHEET #5

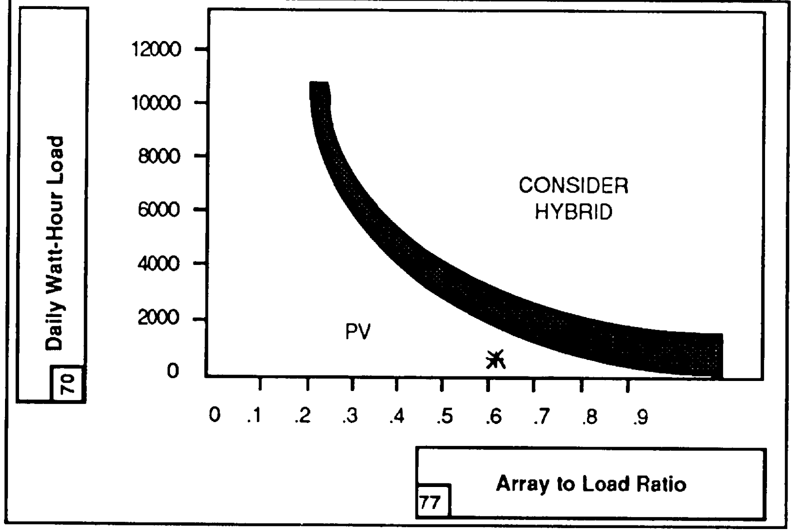
HYBRID DESIGN DETERMINATION

DESIGN NOTES:

68 Corrected Amp-Hour Load (AH/DAY) 20		69 Nominal System Voltage (V) 9		70 Watt-Hour Load (WH/DAY)		71 Conversion Factor		72 Annual Kilowatt-Hr Load (KWH/YEAR)
58.3	X	12	=	700	X	.365	=	255

73 Derated Design Current (A) 48		74 Nominal System Voltage (V) 9		75 Design Array Power (W)		76 Watt-Hour Load (WH/DAY) 70		77 Array to Load Ratio (DECIMAL)
36	X	12	=	432	÷	700	=	0.62

78 **Hybrid Indicator**



Hybrid Design Flag

Yes	No
☐	☑

IF YES, USE HYBRID WORKSHEETS TO COMPLETE SIZING OF A HYBRID SYSTEM. IF NO, PROCEED TO FUNCTIONAL SPECIFICATION SHEETS.

	A1 62	Array Short Circuit Current (A)	A2	Minimum Controller Current (A)	A3	Rated Controller Current) (A)	A4	Controllers in Parallel
1.25	X	39	=	48.8	÷	30	=	2

DESIGN NOTES:

A5

(CONTROLLER)

Make/Model Trace C30A

Rated Voltage 12

Rated Current 30amp

Features

Temperature Compensation ✓

Reverse Current Protection ✓

Adjustable Set Points)

High Voltage Disconnect ____

High Voltage Re-connect ____

Low Voltage Disconnect ____

Low Voltage Re-connect ____

Meters

Battery Voltage ✓

Array Current ✓

Load Current ____

PROTECTION COMPONENTS SPECIFICATION

Protected Circuit	Protection Device				Rated Current	Rated Voltage	Description
	Switch	Diode	Fuse	Movistor			
D1 Array output	✓				30amp	125 V	DC switch &
D2 Array output			✓		30amp	125 V	DC Fuse
D3 Controller to Load	✓				50amp	125 V	DC switch &
D4 Controller to Load			✓		30amp	125 V	DC Fuse
D5 Battery			✓		60amp	125 V	Fused switch
D6							
D7							
D8							
D9							
D10							
D11							
D12							
D13							
D14							

Two controllers used - each circuit carries less than 30 A. Current from controllers to battery may reach 40 A.

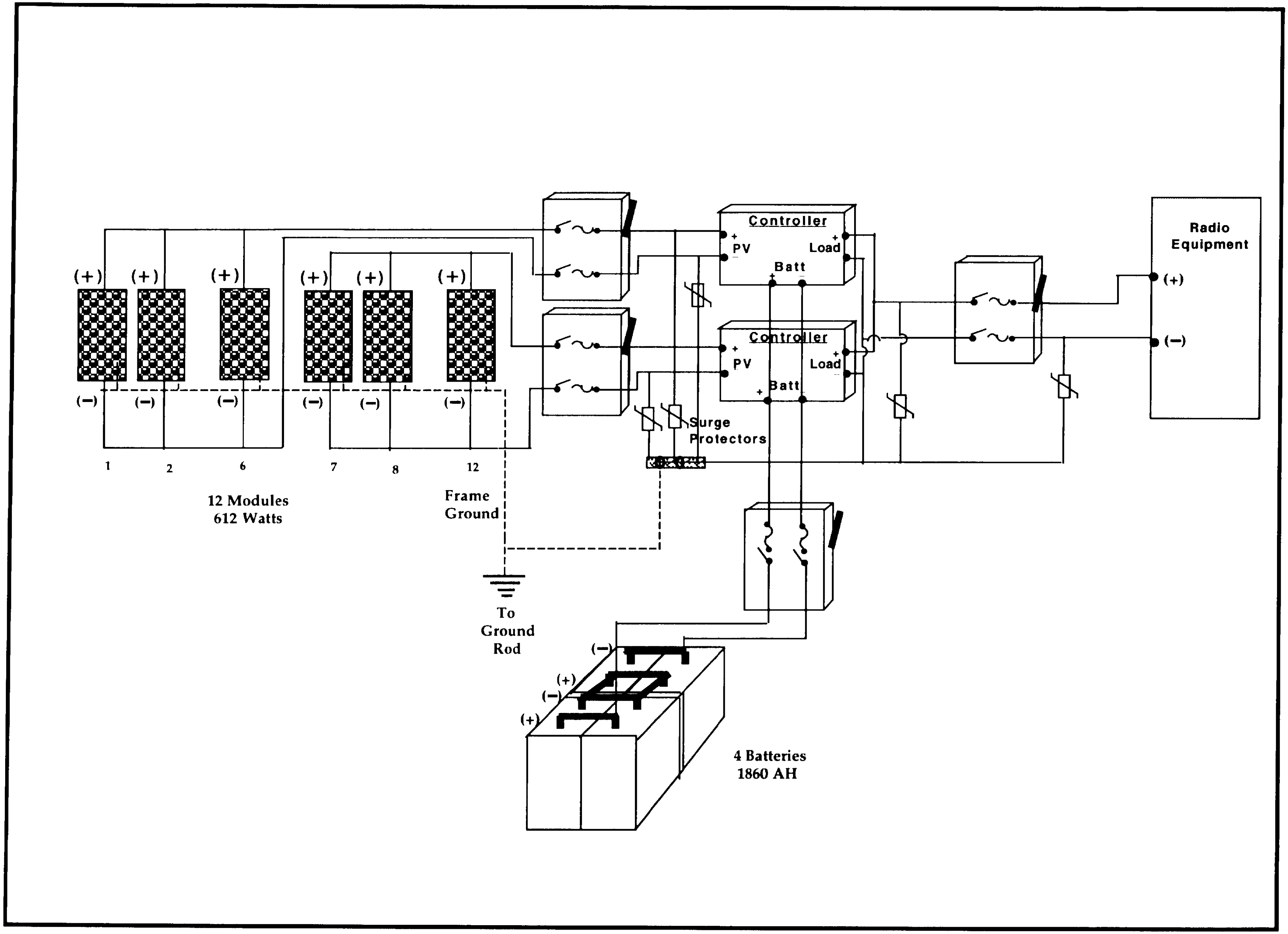
DC WIRE SIZING SPECIFICATION

E1 Wire Runs	E2 System Voltage (V)	E3 Maximum Current (A)	E4 One Way Length (FT)	E5 Allowed Voltage Drop (%)	E6 Allowance for Temperature Derate	E7 AWG Number	E8 Wire Type
Array Circuit							
Module to Module	12	4	2	—	—	#12	USE Sunlight Resistant
Array to Controller or Battery	12	20 *	16	2%	—	#6	THWN in conduit
DC Circuits							
Battery to Battery	12	—	2	—	—	#6	THWN
Battery to Loads ~~DC Loads~~ or Controller	12	40	7	2%	—	#6	THWN in conduit
Branch Circuits							
A Transmitter	12	25	8	2%	—	#8	THWN
B							
C							
D							
E							
Battery Charger to Batteries							
Battery to Inverter Or Converter							

System Grounding	Wire Type	AWG Number	Type of Earth Ground
E9 Equipment Ground	Bare Copper	#6	Buried Grid
E10 System Ground	Bare Copper	#6	Buried Grid

DESIGN NOTES:

* Two separate circuits used.


(+)
(−)
1
2
6
7
8
12
12 Modules
612 Watts
Frame Ground
To Ground Rod
Controller
PV
Load
Batt
Controller
PV
Load
Batt
Surge Protectors
Radio Equipment
(+)
(−)
4 Batteries
1860 AH

ECONOMICS ANALYSIS

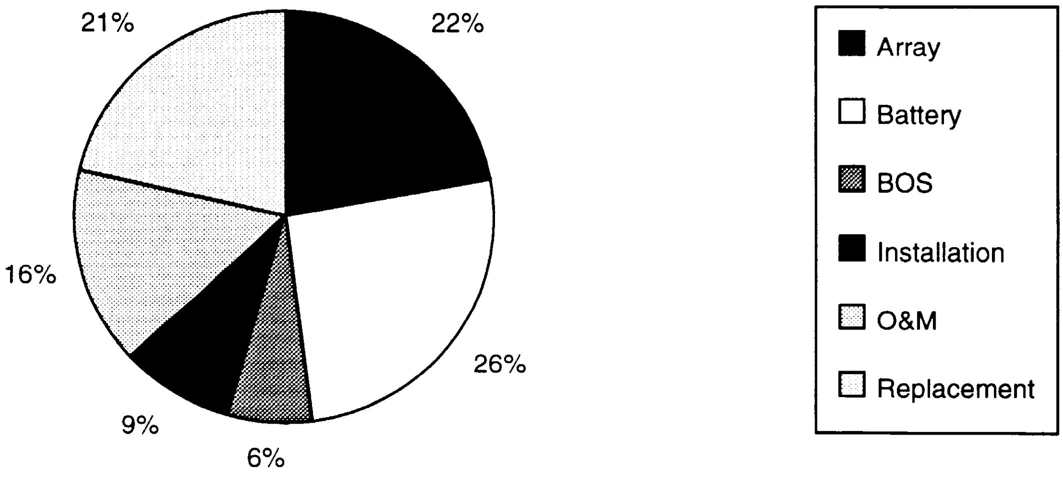
LIFE-CYCLE COST ANALYSIS
POINT DESIGN: RADIO REPEATER

Item		Dollar Amount ($)	Present Worth ($)	Percent Total LCC cost (%)
1. CAPITAL COSTS:				
Array		$3,160	$3,160	22.0
Battery		3,720	3,720	26.8
BOS Components		930	930	6.7
installation		1,250	1,250	9.0
A - SUBTOTAL (Equipment & Installation)		**9,060**	**9,060**	**65.3**
2. OPERATION & MAINTENANCE				
B - Annual Inspection		150	2,232	13.1
3. REPLACEMENT:	(YEAR)			
Battery Bank	10	3,720	2,768	19.9
Controllers	10	360	275	2.0
C - SUBTOTAL (Replacement Cost)		**5,940**	**4,427**	**21.9**
4. SALVAGE:	(YEAR)			
D - 20% of Original	20	**(1,812)**	**(467)**	**(3.3)**
TOTAL LIFE-CYCLE COST (A + B + C - D)			**$13,868**	**100.0**

ECONOMIC NOTES:

1) LCC includes an annual inspection of all equipment. Travel costs are included for one trip per year.

COST ELEMENTS AS A PERCENT OF LCC (%)



POINT DESIGN NO. 6

TRAVELLER'S INFORMATION RADIO

The State of New Mexico recently installed several short range radio systems to broadcast historical facts and folklore to passing motorists. These PV powered systems were installed along highways in the southern part of the State. The land varies from high desert to mountains with elevations greater than 12,000 feet. The pole mounted 12 volt dc sys terns include the PV modules, battery, controller, transmitter and tape player. The messages play continuously. The load demand is dominated by the transmitter; its current requirement depends on the effectiveness of the antenna ground plane. Initial testing showed the current demand to be about one ampere but under worst-case conditions could go as high as 1.5 ampere. This worst-case value was used for the design. State personnel plan to inspect the systems for operation every six months.

KEY DESIGN INFORMATION

APPLICATION:	Traveller's Information Radio
SITE:	Southern New Mexico
LOCATION/ELEVATION:	31-36° N 103-109° W 1300 m
ENVIRONMENT:	High Desert
TEMPERATURE RANGE (°C):	-10 to 45
MAXIMUM WIND SPEED (m/s):	50
AVAILABILITY REQUIRED:	Noncritical
DAYS OF STORAGE:	5
LOAD PROFILES:	Continuous

INSTALLATION

The pole mounted array was tilted at 50° to optimize wintertime insolation capture. The batteries were buried near the foot of the pole and the transmitter antenna was located on top of the pole. Array conductors were run to a weatherproof control box located behind the modules. The negative conductor was grounded to the pole and a movistor was used from the positive conductor to ground. A controller with low voltage disconnect was used. This system uses deep cycle maintenance free batteries and the batteries are large enough to keep state of charge over 60 percent in all but the worst conditions. Operating in this manner, the batteries should provide many years of trouble free service and not be susceptible to freezing. The batteries are connected to the control box with watertight flexible conduit. Power conductors to the antenna are inside the pole. An in-line fuse was installed on the battery conductors. A single pole switch was installed to disconnect array power from the system.

WORKSHEET #1 **CALCULATE THE LOADS** (FOR EACH MONTH OR SEASON AS REQUIRED)

1 Load Description	2 QTY		3 Load Current (A)		4 Load Voltage (V)		5A DC Load Power (W)	5B AC Load Power (W)		6 Daily Duty Cycle (HRS/DAY)		7 Weekly Duty Cycle (DAYS/WK)		8 Power Conversion Efficiency (DECIMAL) D		9 Nominal System Voltage (V)		10 Amp-Hour Load (AH/DAY)
Transmitter DC	1	X	1.5	X	12	=	18	N/A	X	24	X	7 ÷7	÷	1.0	÷	12	=	36
DC		X		X		=		N/A	X		X	÷7	÷		÷		=	
DC		X		X		=		N/A	X		X	÷7	÷		÷		=	
DC		X		X		=		N/A	X		X	÷7	÷		÷		=	
AC		X		X		N/A		=	X		X	÷7	÷		÷		=	
AC		X		X		N/A		=	X		X	÷7	÷		÷		=	
AC		X		X		N/A		=	X		X	÷7	÷		÷		=	
AC		X		X		N/A		=	X		X	÷7	÷		÷		=	

11 Total Load Power (W)	DC 11A	AC 11B	12 Total Amp-Hour Load (AH/DAY)
			36

13 Total DC Load Power (W) 11A		14 Total AC Load Power (W) 11B		15 Nominal System Voltage (V) 9		16 Peak Current Draw (A)	17 Total Amp-Hour Load (AH/DAY) 12		18 Wire Efficiency Factor (DECIMAL) D		19 Battery Efficiency Factor (DECIMAL) D		20 Corrected Amp-Hour Load (AH/DAY)
18	+		÷	12	=	1.5	36	÷	0.98	÷	0.9	=	40.8

DESIGN NOTES:

The load current will vary depending on location of antenna and effectiveness of ground plane. Worst case assumption used.

WORKSHEET #2 DESIGN CURRENT AND ARRAY TILT

21	System Location	Southern 2/3 of NM	Latitude	31-36°N	Longitude	103-109° W
	Insolation Location	Albq NM / El Paso TX	Latitude	——	Longitude	——

	Tilt at Latitude -15°					Tilt at Latitude					Tilt at Latitude +15°				
MONTH	22A Corrected Load (AH/DAY) 20		23A Peak Sun (HRS/DAY)		24A Design Current (A)	22B Corrected Load (AH/DAY) 20		23B Peak Sun (HRS/DAY)		24B Design Current (A)	22C Corrected Load (AH/DAY) 20		23C Peak Sun (HRS/DAY)		24C Design Current (A)
J		÷		=			÷		=		40.8	÷	4.0	=	10.2
F		÷		=			÷		=			÷		=	
M		÷		=			÷		=			÷		=	
A		÷		=			÷		=			÷		=	
M		÷		=			÷		=			÷		=	
J		÷		=			÷		=			÷		=	
J		÷		=			÷		=			÷		=	
A		÷		=			÷		=			÷		=	
S		÷		=			÷		=			÷		=	
O		÷		=			÷		=			÷		=	
N		÷		=			÷		=			÷		=	
D		÷		=			÷		=		40.8	÷	4.0	=	10.2

Select the largest design current and corresponding peak sun from each latitude and enter below

Latitude -15°		Latitude		Latitude +15°	
25A Peak Sun (HRS/DAY)	26A Design Current (A)	25B Peak Sun (HRS/DAY)	26B Design Current (A)	25C Peak Sun (HRS/DAY)	26C Design Current (A)
				4.0	10.2

Now select the smallest design current and corresponding peak sun

27 Peak Sun (HRS/DAY	28 Design Current (A)
4.0	10.2
Tilt Angle =	~50°

NOTE: DO NOT MIX TRACKING AND FIXED ARRAY DATA ON THE SAME SHEET.

DESIGN NOTES:

Wintertime tilt chosen - load is assumed constant all year.

Worst case weather data for Ruidoso NM indicates 4 peak sun hours may be the maximum received in winter.

WORKSHEET #3

CALCULATE SYSTEM BATTERY SIZE

29 Corrected Amp-Hour Load (AH/DAY) 20		30 Storage Days D		31 Maximum Depth of Discharge (DECIMAL) D		32 Derate for Temperature (DECIMAL) D		33 Required Battery Capacity (AH)		34 Capacity of Selected Battery (AH)		35 Batteries in Parallel
40.8	X	5	÷	0.6	÷	1	=	340	÷	150	=	2

NOTE: BLOCK 35. ROUND UP FOR CONSERVATIVE DESIGN.

36 Nominal System Voltage (V) 9		37 Nominal Battery Voltage (V)		38 Batteries in Series		39 Batteries in Parallel 35		40 Total Batteries
12	÷	12	=	1	X	2	=	2

BATTERY INFORMATION	
Make	Deka Solar
Model	8G4D
Type	Gelled Electrolyte
Nominal Voltage (V)	12
Rated Capacity (AH)	150

41 Batteries in Parallel 35		42 Capacity of Selected Battery (AH) 34		43 System Battery Capacity (AH)		44 Maximum Depth of Discharge (DECIMAL) 31		45 Usable Battery Capacity (AH)
2	X	150	=	300	X	0.6	=	180

NOTE: USE MANUFACTURER'S DATA TO FILL IN BATTERY INFORMATION BLOCK

DESIGN NOTES:

WORKSHEET #4 CALCULATE SYSTEM ARRAY SIZE

46 Design Current (A) 28		47 Module Derate Factor (DECIMAL) D		48 Derated Design Current (A)		49 Rated Module Current (A) D		50 Modules in Parallel
10.2	÷	0.9	=	11.3	÷	3.5	=	3

		51 Nominal Battery Voltage 37		52 Batteries in Series 38	53 Voltage Required for Load (V)		54 Highest Temperature Module Voltage (V)		55 Modules in Series		56 Modules in Parallel 50		57 Total Modules
1.20	x	12	x	1	14.4	÷	14.5	=	1	x	3	=	3

NOTE: USE MANUFACTURER'S SPECIFICATIONS TO FILL IN PV MODULE INFORMATION BLOCK.

<table>
<tr><th colspan="5">PV MODULE INFORMATION</th></tr>
<tr><td>Make/Model</td><td colspan="2">Solarex MSX60</td><td>Nominal Volts</td><td>12</td></tr>
<tr><td>Length</td><td>44</td><td>Width 20</td><td>Thickness</td><td>2</td></tr>
<tr><td>Weight</td><td colspan="2">16 lbs.</td><td>Bypass Diode</td><td>Y [✓ N]</td></tr>
<tr><td rowspan="2">Voltage (V)</td><td>At STC</td><td>Open Circuit</td><td colspan="2">At Highest Expected Temperature</td></tr>
<tr><td>17.1</td><td>21.1</td><td colspan="2">14.5</td></tr>
<tr><td rowspan="2">Current (A)</td><td>At STC</td><td>Short Circuit</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>3.5</td><td>3.8</td></tr>
</table>

58 Modules in Parallel 50		59 Rated Module Current (A)		60 Rated Array Current (A)
	x	3.5	=	10.5
		61 Module Short Circuit Current (A)		62 Array Short Circuit Current (A)
	x	3.8	=	11.4

63 Modules in Series 55		64 Rated Module Voltage (V)		65 Array Rated Voltage (V)
	x	17.1	=	17.1
		66 Open Circuit Module Voltage (V)		67 Array Open Circuit Voltage (V)
	x	21.1	=	21.1

NOTES: BLOCK 50 - ROUND UP FOR CONSERVATIVE DESIGN.

BLOCK 55 - ROUND UP OR SELECT ANOTHER MODULE WITH SUFFICIENT VOLTAGE TO CHARGE THE BATTERIES WHEN OPERATING AT THE HIGHEST EXPECTED TEMPERATURE.

DESIGN NOTES:

A hybrid system is not applicable.

CONTROLLER SPECIFICATION

		A1 Array Short Circuit Current (A) 62		A2 Minimum Controller Current (A)		A3 Rated Controller Current) (A)		A4 Controllers in Parallel
1.25	x	11.4	=	14.3	÷	15	=	1

A5 **(CONTROLLER)**

Make/Model SCI Mark III/15

Rated Voltage 12

Rated Current ____

Features

Temperature Compensation ____

Reverse Current Protection ✓

Adjustable Set Points)

High Voltage Disconnect ____

High Voltage Re-connect ____

Low Voltage Disconnect ____

Low Voltage Re-connect ____

Meters

Battery Voltage ____

Array Current ✓

Load Current ____

DESIGN NOTES:

PROTECTION COMPONENTS SPECIFICATION

Protected Circuit	Protection Device				Rated Current	Rated Voltage	Description
	Switch	Diode	Fuse	Movistor			
D1 Array output	✓				20amp	200 V	SPST Switch
D2 Battery			✓		3amp	125 V	DC In-line Fuse
D3							
D4							
D5							
D6							
D7							
D8							
D9							
D10							
D11							
D12							
D13							
D14							

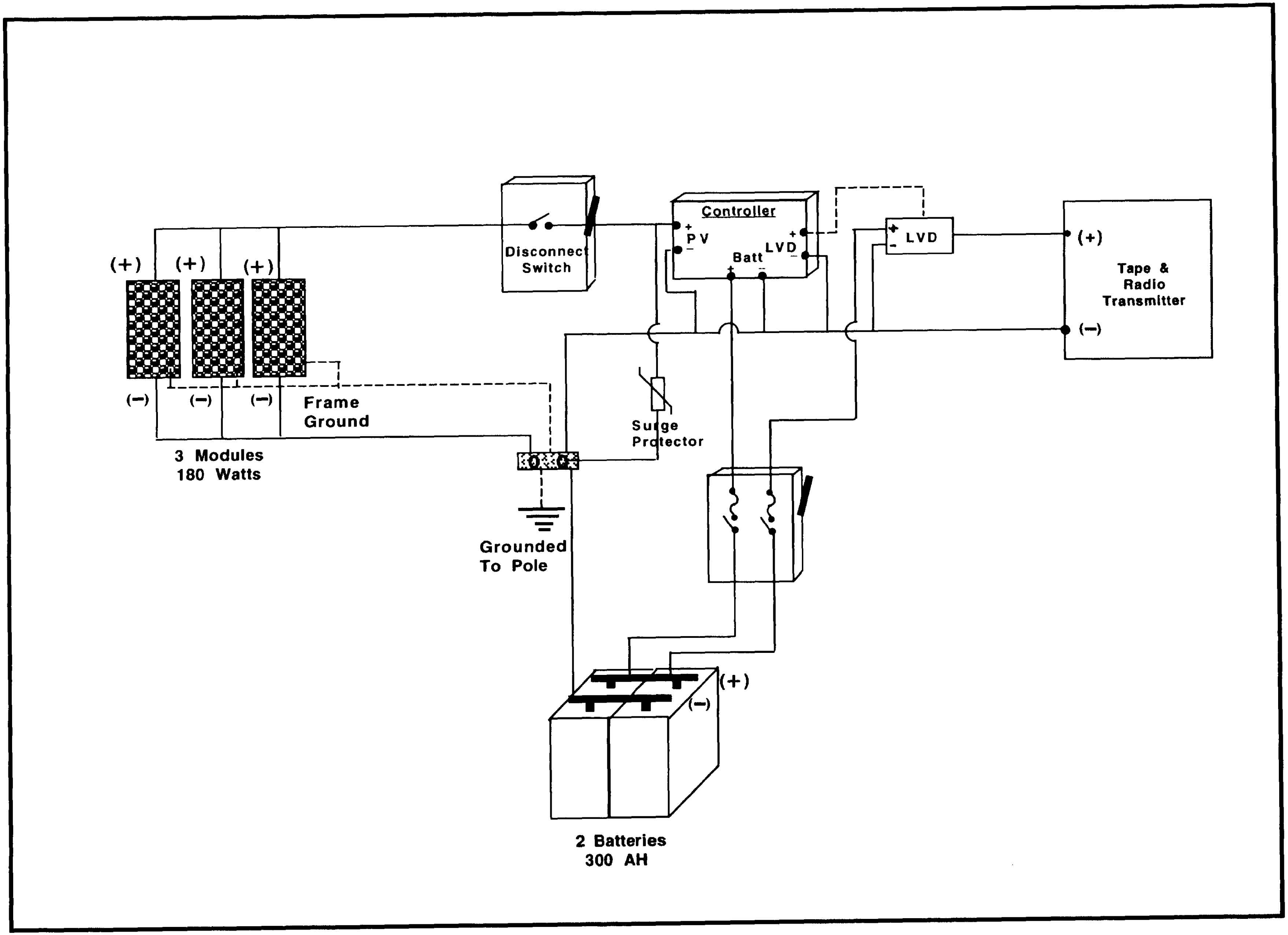
Only one fuse is used to protect transmitter, controller, and array from the battery.

DC WIRE SIZING SPECIFICATION

E1 Wire Runs	E2 System Voltage (V)	E3 Maximum Current (A)	E4 One Way Length (FT)	E5 Allowed Voltage Drop (%)	E6 Allowance for Temperature Derate	E7 AWG Number	E8 Wire Type
Array Circuit							
Module to Module	12	4	2	—	—	#14	USE Sunlight Resistant
Array to Controller or Battery	12	14	20	2%	—	# 8	USE in conduit
DC Circuits							
Battery to Battery	12	—	2	—	—	# 6	USE
Battery to DC Loads	12	2	5	—	—	#14	USE
Branch Circuits							
A							
B							
C							
D							
E							
Battery Charger to Batteries							
Battery to Inverter Or Converter							

System Grounding	**Wire Type**	**AWG Number**	**Type of Earth Ground**
E9 **Equipment Ground**	Bare Copper	#8	Ground Rod
E10 **System Ground**	Bare Copper	#8	Ground Rod

DESIGN NOTES:


(+)
(+)
(+)
(−)
(−)
(−)
Frame
Ground
3 Modules
180 Watts
Disconnect
Switch
Controller
+
PV
−
Batt
+
−
+
LVD
−
+
−
LVD
(+)
Tape &
Radio
Transmitter
(−)
Surge
Protector
Grounded
To Pole
(+)
(−)
2 Batteries
300 AH

ECONOMICS ANALYSIS

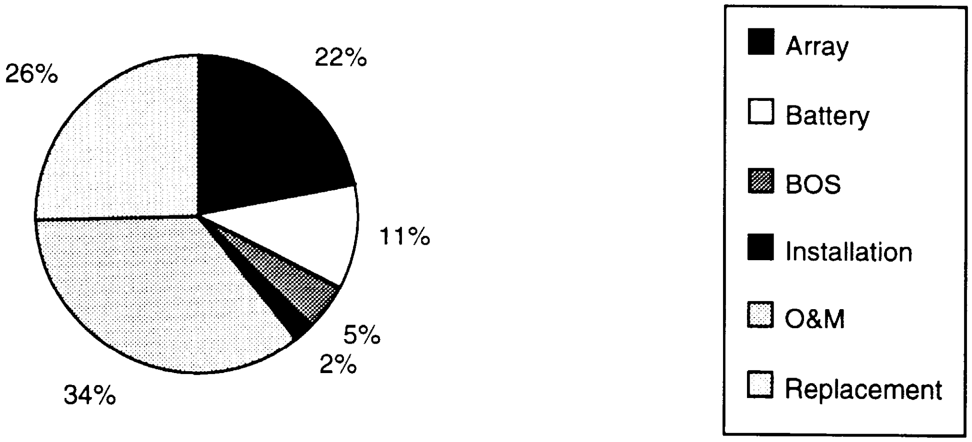
LIFE-CYCLE COST ANALYSIS
POINT DESIGN: TRAVELLER'S INFORMATION RADIO

Item	Dollar Amount ($)	Present Worth ($)	Percent Total LCC cost (%)
1. CAPITAL COSTS:			
Array	$1,170	$1,170	22.0
Battery	600	600	11.3
BOS + Mounting Hardware	250	250	4.7
Installation	125	125	2.4
A - SUBTOTAL (Equipment & Installation)	**2,145**	**2,145**	**40.4**
2. OPERATION & MAINTENANCE			
B - Annual Inspection	**125**	**1859**	**35.0**
3. REPLACEMENT: (YEAR)			
Battery Bank 5	600	520	9.8
Battery Bank 10	600	447	8.4
Battery Bank 15	600	387	7.3
Controller 10	76	57	1.1
C - SUBTOTAL (Replacement Cost)	**1,876**	**1,411**	**26.6**
4. SALVAGE: (YEAR)			
D - 20% of Original 20	**(404)**	**(104)**	**(2.0)**
TOTAL LIFE-CYCLE COST (A + B + C - D)		**$5,311**	**100.0**

ECONOMIC NOTES:

1) The tourist information tape system and transmitter are not included in the LCC analysis.
2) The sealed lead-acid batteries are scheduled for replacement every 5 years.

COST ELEMENTS AS A PERCENT OF LCC (%)



RESIDENTIAL

An increasing number of people living in remote areas are using PV systems or PV-generator hybrid systems because they are clearly the best economic option. Some estimates for utility line extension range up to $30,000 per mile depending on terrain. In such situations, PV systems are the economic choice, even for homeowners who want to maintain their suburban life-style. For the owner of a weekend cabin, recreational vehicle, or boat, the choice of PV is often based on the desire for serenity. PV systems make no noise and fuel delivery is automatic and free. Thousands of 30-200 watt systems are being installed for residential power in developing countries. These small systems are usually dc only and require 12 volt or 24 volt dc appliances. Stand-alone inverters are available from 100 watts to 5,000 watts. An inverter is often used in the larger systems to allow the owner the wider selection of ac appliances.

Stand-alone residential PV systems must handle a diverse set of loads. However, unlike other systems the owner/operator has direct control over the use of the loads and therefore, the power demand placed on the system. Training is an important part of owner satisfaction with system performance.

APPLICATIONS

- Residences
- Recreational Vehicles

USERS

- Homeowners

* * *

LOAD

The designer should consider the following options to conserve energy and minimize initial PV system cost:

- Use fluorescent light bulbs and fixtures-they are four to five times more efficient than incandescent lights for the same level of illumination.
- Use alternatives such as propane for the major household loads; in particular, refrigerators, ovens, ranges, clothes dryers, hot water, and space heat systems.
- Use high-efficiency appliances.

As a general rule, the designer should consider using a 12 or 24 volt dc systems for demands less than 1,000 watts. When the ac load is less than 1,500 watts, a 12-volt system with inverter is typically selected. A 24-volt system should be considered for ac loads (120/240 volts) in the 2,500-5,000 watt range, and a hybrid system may be the preferred option for large home power demands.

ARRAY

Arrays should be designed for easy expansion as the needs of the users increase. If the array is at ground level, access should be restricted to authorized personnel. Roof-mounted arrays should use a stand-off mount (>3 inches) and should not face more than 20° from true south. A specially designed support structure will be required if the tilt angle of the roof is not close to the tilt angle determined as optimum for the array. Roof-mounted arrays are less subject to accidental damage but are more difficult to test and maintain. Wiring should be sunlight resistant USE or UF type cable. All connections should be in water-tight junction boxes with strain relief connectors. Array wiring should be laced and attached to support structure with wire ties. Use conduit for output wiring to the controller and batteries. The array should be grounded using bare copper grounding wire (No. 8 or larger) securely attached to each support structure. Array tracking is sometimes used but the economic tradeoff of tracking structure versus more modules should be calculated. All disconnects or circuit breakers should be located in rainproof enclosures. Simple metering of voltage and current is recommended.

BATTERIES

Batteries should be installed in a temperature controlled environment in or near the building. Prevent children and pets from getting near batteries and provide adequate ventilation. The batteries should be placed in a nonmetallic enclosure to protect against potential spillage of corrosive electrolyte if flooded batteries are used. Do not place batteries on cold surfaces. Do not expose batteries to flames or electric sparks. Industrial grade deep-cycle batteries are recommended for full-time residences but sealed batteries may be used to minimize the problem of ventilation and corrosion and lower maintenance cost. Check battery availability in the local area. Meters and/or alarms are often used to alert the homeowner to a low battery state-of-charge. An in-line fuse should be installed at the battery output terminal. Follow battery manufacturer’s installation and maintenance requirements. Battery charge regulation is critical and directly affects battery life.

CONTROL/INVERTERS/ SWITCHGEAR

Charge controllers are recommended for residential systems and they should be sized to allow for future expansion of the system as the owner’s power demand increases. Meters or battery charging indicators are recommended to allow the homeowner to monitor performance. Some system installers tie their warranty to monthly reporting of selected parameters from the homeowner. A competent control technician/engineer should be consulted for hybrid systems controls.

CONTROL/INVERTERS/ SWITCHGEAR

The selection of an inverter is a critical decision in remote home power PV system design as it sets the dc voltage of the system. Before purchasing an inverter, verify that it will be capable of starting and operating the expected loads. Multiple inverters connected in parallel, may be used to power larger loads. Make sure that the battery is large enough to supply the surge current requirements of the loads. A rule of thumb for battery capacity to ampere draw of the inverter is 5:1. All wiring, fusing, etc. should conform to standard electrical procedures as discussed in the National Electrical Code (NEC) for home wiring. NEC Article 690 covers photovoltaics, Article 310 has information on wire types, and Article 250 contains grounding regulations. Check with local authorities for applicable codes.

MOUNTING

Ground mounts offer easy installation and maintenance and the possibility of seasonal adjustment of tilt angle. Fencing is recommended to protect the array from animals and children. Roof mounts may give better solar access in areas with a large number of trees or obstructions. Locate the array as close to the batteries as practical to keep wire length to a minimum. Support structures should be anodized aluminum, galvanized or stainless steel designed for maximum anticipated wind velocities. A good ground is required.

Point Design No. 7

DC SYSTEM

This system is designed to power lights, a stereo, and a refrigerator for a vacation cabin occupied three days per week, May through September, in the mountains of Vermont. The cabin is far from utility service and located in a scenic area where utility lines would not be welcome. A 4 cubic-foot refrigerator, typical of those used in the RV industry, is a major part of the load. The refrigerator will require power seven days per week during the summer period but on four of those days the unit will not be opened.

KEY DESIGN INFORMATION

APPLICATION:	Vacation Cabin dc System
SITE:	Vermont
LOCATION/ELEVATION:	44°N 73° w 560 m
ENVIRONMENT:	Mountains
TEMPERATURE RANGE (°C):	-25°C to 40°
MAXIMUM WIND SPEED (m/s):	20
AVAILABILITY REQUIRED:	Noncritical
LOAD PROFILES:	Variable when cabin is used-refrigerator only during other summer days

INSTALLATION

A two-story south-facing wall was used as the mounting surface for the array. This allowed much better solar access than a pitched roof or a ground mount and leakage was not a problem with the wall mount. The upper portion of the array was fastened directly to the wall, while the lower portion stood out from the wall on mounting legs to achieve the proper tilt. A weatherproof junction box was used to prevent moisture from following the array conductors into the building. The meters (array current, load current, and system voltage) were located in the kitchen area where they could be observed easily. The load center was located adjacent to the meters. The system batteries were located in an upstairs storage loft and vented to the outside. Because of the cabin construction (milled tongue & groove logs), all wiring was enclosed in metal raceways to prevent physical damage from exposure and rodents. Plugs and receptacles with a special dc configuration were used in place of standard receptacles. These units were approved for this application by the local electrical inspector. The use of special plugs and receptacles prevents an unfamiliar user from plugging the low voltage dc equipment into the standard ac receptacles that are also available in the cabin. (A portable ac generator is used for an occasional maintenance job or to run the vacuum cleaner.) The homeowners were supplied with a complete manual for their system. The manual describes expected system performance, what items require maintenance at what intervals, and some simple troubleshooting steps to be taken in case of system malfunction.

WORKSHEET #1 CALCULATE THE LOADS (FOR EACH MONTH OR SEASON AS REQUIRED)

1 Load Description	2 QTY		3 Load Current (A)		4 Load Voltage (V)		5A DC Load Power (W)		5B AC Load Power (W)		6 Daily Duty Cycle (HRS/DAY)		7 Weekly Duty Cycle (DAYS/WK)		8 Power Conversion Efficiency (DECIMAL) D		9 Nominal System Voltage (V)		10 Amp-Hour Load (AH/DAY)
Refrigerator RV Type DC	1	x	8.0	x	12	=	96.0		N/A	x	6	x	7 ÷7	÷	1.0	÷	12	=	48.0
Bathroom Light DC	1	x	0.7	x	12	=	8.4		N/A	x	1	x	3 ÷7	÷	1.0	÷	12	=	0.3
Kitchen Light DC	1	x	1.9	x	12	=	22.8		N/A	x	2	x	3 ÷7	÷	1.0	÷	12	=	1.6
Dining Light DC	1	x	1.4	x	12	=	16.8		N/A	x	2	x	3 ÷7	÷	1.0	÷	12	=	1.2
AC		x		x			N/A	=		x		x	÷7	÷		÷		=	
AC		x		x			N/A	=		x		x	÷7	÷		÷		=	
AC		x		x			N/A	=		x		x	÷7	÷		÷		=	
AC		x		x			N/A	=		x		x	÷7	÷		÷		=	
11 Total Load Power (W)					DC	11A	Continued	AC	11B					12 Total Amp-Hour Load (AH/DAY)					Continued

13 Total DC Load Power (W) 11A		14 Total AC Load Power (W) 11B		15 Nominal System Voltage (V) 9		16 Peak Current Draw (A)	17 Total Amp-Hour Load (AH/DAY) 12		18 Wire Efficiency Factor (DECIMAL) D		19 Battery Efficiency Factor (DECIMAL) D		20 Corrected Amp-Hour Load (AH/DAY)
	+		÷		=			÷		÷		=	

DESIGN NOTES:

Refrigerator runs 7 days/week but is not opened for 4 days as the cabin is occupied only 3 days/week.

Fluorescent lights were used where possible.

WORKSHEET #1 CALCULATE THE LOADS (FOR EACH MONTH OR SEASON AS REQUIRED)

DESIGN NOTES:

1 Load Description	2 QTY		3 Load Current (A)		4 Load Voltage (V)		5A DC Load Power (W)		5B AC Load Power (W)		6 Daily Duty Cycle (HRS/DAY)		7 Weekly Duty Cycle (DAYS/WK)		8 Power Conversion Efficiency (DECIMAL) D		9 Nominal System Voltage (V)		10 Amp-Hour Load (AH/DAY)
Reading Light DC	2	X	1.5	X	12	=	36.0		N/A	X	2	X	3 ÷7	÷	1.0	÷	12	=	2.6
Radio/Tape Player DC	1	X	2.0	X	12	=	24.0		N/A	X	2	X	3 ÷7	÷	1.0	÷	12	=	1.7
DC		X		X		=			N/A	X		X	÷7	÷		÷		=	
DC		X		X		=			N/A	X		X	÷7	÷		÷		=	
AC		X		X			N/A	=		X		X	÷7	÷		÷		=	
AC		X		X			N/A	=		X		X	÷7	÷		÷		=	
AC		X		X			N/A	=		X		X	÷7	÷		÷		=	
AC		X		X			N/A	=		X		X	÷7	÷		÷		=	

11 Total Load Power (W) DC 11A 204.0 AC 11B N/A

12 Total Amp-Hour Load (AH/DAY) 55.4

13 Total DC Load Power (W) 11A		14 Total AC Load Power (W) 11B		15 Nominal System Voltage (V) 9		16 Peak Current Draw (A)	17 Total Amp-Hour Load (AH/DAY) 12		18 Wire Efficiency Factor (DECIMAL) D		19 Battery Efficiency Factor (DECIMAL) D		20 Corrected Amp-Hour Load (AH/DAY)
204.0	+	N/A	÷	12	=	17.0	55.4	÷	0.98	÷	0.9	=	62.8

WORKSHEET #2 DESIGN CURRENT AND ARRAY TILT

21 System Location	Montpellier, VT	Latitude	44° N	Longitude	73° W
Insolation Location	Burlington, VT	Latitude	44°28'N	Longitude	73°1'W

MONTH	Tilt at Latitude -15°					Tilt at Latitude					Tilt at Latitude +15°				
	22A Corrected Load (AH/DAY) 20		23A Peak Sun (HRS/DAY)		24A Design Current (A)	22B Corrected Load (AH/DAY) 20		23B Peak Sun (HRS/DAY)		24B Design Current (A)	22C Corrected Load (AH/DAY) 20		23C Peak Sun (HRS/DAY)		24C Design Current (A)
J		÷		=			÷		=			÷		=	
F		÷		=			÷		=			÷		=	
M		÷		=			÷		=			÷		=	
A		÷		=			÷		=			÷		=	
M	62.8	÷	4.89	=	12.8	62.8	÷	4.51	=	13.9	62.8	÷	3.97	=	15.8
J	62.8	÷	5.24	=	12.0	62.8	÷	4.77	=	13.2	62.8	÷	4.13	=	15.2
J	62.8	÷	5.36	=	11.7	62.8	÷	4.94	=	12.7	62.8	÷	4.33	=	14.5
A	62.8	÷	4.99	=	12.7	62.8	÷	4.73	=	13.3	62.8	÷	4.30	=	14.6
S		÷		=			÷		=			÷		=	
O		÷		=			÷		=			÷		=	
N		÷		=			÷		=			÷		=	
D		÷		=			÷		=			÷		=	

Select the largest design current and corresponding peak sun from each latitude and enter below

Latitude -15°	
25A Peak Sun (HRS/DAY)	26A Design Current (A)
4.89	12.8

Latitude	
25B Peak Sun (HRS/DAY)	26B Design Current (A)
4.51	13.9

Latitude +15°	
25C Peak Sun (HRS/DAY)	26C Design Current (A)
3.97	15.8

Now select the smallest design current and corresponding peak sun

27 Peak Sun (HRS/DAY		28 Design Current (A)
4.89		12.8
Tilt Angle	=	30°

NOTE: DO NOT MIX TRACKING AND FIXED ARRAY DATA ON THE SAME SHEET.

DESIGN NOTES:

Local source is found for insolation data.

The cabin is used in summer only.

WORKSHEET #3 CALCULATE SYSTEM BATTERY SIZE

29 Corrected Amp-Hour Load (AH/DAY) 20		30 Storage Days D		31 Maximum Depth of Discharge (DECIMAL) D		32 Derate for Temperature (DECIMAL) D		33 Required Battery Capacity (AH)		34 Capacity of Selected Battery (AH)		35 Batteries in Parallel
62.8	X	3	÷	0.8	÷	1	=	236	÷	220	=	1

NOTE: BLOCK 35. ROUND UP FOR CONSERVATIVE DESIGN.

36 Nominal System Voltage (V) 9		37 Nominal Battery Voltage (V)		38 Batteries in Series		39 Batteries in Parallel 35		40 Total Batteries
12	÷	6	=	2	X	1	=	2

BATTERY INFORMATION

Make	Interstate
Model	U2S-100
Type	Flooded lead acid
Nominal Voltage (V)	6
Rated Capacity (AH)	220

41 Batteries in Parallel 35		42 Capacity of Selected Battery (AH) 34		43 System Battery Capacity (AH)		44 Maximum Depth of Discharge (DECIMAL) 31		45 Usable Battery Capacity (AH)
1	X	220	=	220	X	0.8	=	176

NOTE: USE MANUFACTURER'S DATA TO FILL IN BATTERY INFORMATION BLOCK

DESIGN NOTES:

3 days storage selected because the cabin is only used 3 days consecutively

WORKSHEET #4 CALCULATE SYSTEM ARRAY SIZE

46 Design Current (A) 28	47 Module Derate Factor (DECIMAL) D	48 Derated Design Current (A)	49 Rated Module Current (A) D	50 Modules in Parallel
12.8	÷ 0.9	= 14.2	÷ 5.8	= 2

	51 Nominal Battery Voltage 37	52 Batteries in Series 38	53 Voltage Required for Load (V)	54 Highest Temperature Module Voltage (V)	55 Modules in Series	56 Modules in Parallel 50	57 Total Modules
1.20	x 6	x 2	14.4	÷ 14.7	= 1	x 2	= 2

NOTE: USE MANUFACTURER'S SPECIFICATIONS TO FILL IN PV MODULE INFORMATION BLOCK.

PV MODULE INFORMATION

Make/Model	Solec S-90		Nominal Volts	12	
Length	48	Width 25.5	Thickness	1.5	
Weight	22 lbs.		Bypass Diode	Y [✓ N]	
Voltage (V)	At STC	Open Circuit	At Highest Expected Temperature		
	15.5	20	14.7		
Current (A)	At STC	Short Circuit			
	5.8	6.2			

NOTES: BLOCK 50 - ROUND UP FOR CONSERVATIVE DESIGN.

BLOCK 55 - ROUND UP OR SELECT ANOTHER MODULE WITH SUFFICIENT VOLTAGE TO CHARGE THE BATTERIES WHEN OPERATING AT THE HIGHEST EXPECTED TEMPERATURE.

58 Modules in Parallel 50	59 Rated Module Current (A)	60 Rated Array Current (A)
	x 5.8	= 11.6
	61 Module Short Circuit Current (A)	62 Array Short Circuit Current (A)
	x 6.2	= 12.4

63 Modules in Series 55	64 Rated Module Voltage (V)	65 Array Rated Voltage (V)
	x 15.5	= 15.5
	66 Open Circuit Module Voltage (V)	67 Array Open Circuit Voltage (V)
	x 20	= 20

DESIGN NOTES:

Used two large modules that will produce over 80% of derated design current - non critical design.

Hybrid design not considered.

DC CABIN

CONTROLLER SPECIFICATION

		A1 Array Short Circuit Current (A) 62		A2 Minimum Controller Current (A)		A3 Rated Controller Current) (A)		A4 Controllers in Parallel
1.25	x	14.7	=	18.4	÷	30	=	1

A5 **(CONTROLLER)**

Make/Model Heliotrope CC20

Rated Voltage 12

Rated Current ______

Features

Temperature Compensation ✓

Reverse Current Protection ✓

Adjustable Set Points)

High Voltage Disconnect 15.0

High Voltage Re-connect 14.2

Low Voltage Disconnect 12.2

Low Voltage Re-connect 13.0

Meters

Battery Voltage ✓

Array Current ✓

Load Current ______

DESIGN NOTES:

Controller is mounted in the kitchen where meters can be read by the homeowner.

Low voltage disconnect was included.

PROTECTION COMPONENTS SPECIFICATION

Protected Circuit	Protection Device				Rated Current	Rated Voltage	Description
	Switch	Diode	Fuse	Movistor			
D1 Array output	✓				20amp	250 V	DC Fused disconnect switch
D2 Array output			✓		25 amp	125 V	
D3 Controller to load	✓*						* Circuit breaker in each lead circuit
D4 Battery			✓		30amp	125V	Fused switch
D5 Controller input				✓			Surge protection
D6							
D7							
D8							
D9							
D10							
D11							
D12							
D13							
D14							

DC WIRE SIZING SPECIFICATION

E1 Wire Runs	E2 System Voltage (V)	E3 Maximum Current (A)	E4 One Way Length (FT)	E5 Allowed Voltage Drop (%)	E6 Allowance for Temperature Derate	E7 AWG Number	E8 Wire Type
Array Circuit							
Module to Module							
Array to Controller or Battery	12	13.3	15'	2%		12	THHN
DC Circuits							
Battery to Battery							
Battery to DC Loads	12	21	8'	2%		8	THHN
Branch Circuits							
A *1	12	~5.7	30'	3%		10	NM
B *2	12	~5.3	40'	3%		10	NM
C Refrigerator	12	8.0	20'	3%		8	THHN
D							
E							
Battery Charger to Batteries	N/A						
Battery to Inverter Or Converter	N/A						

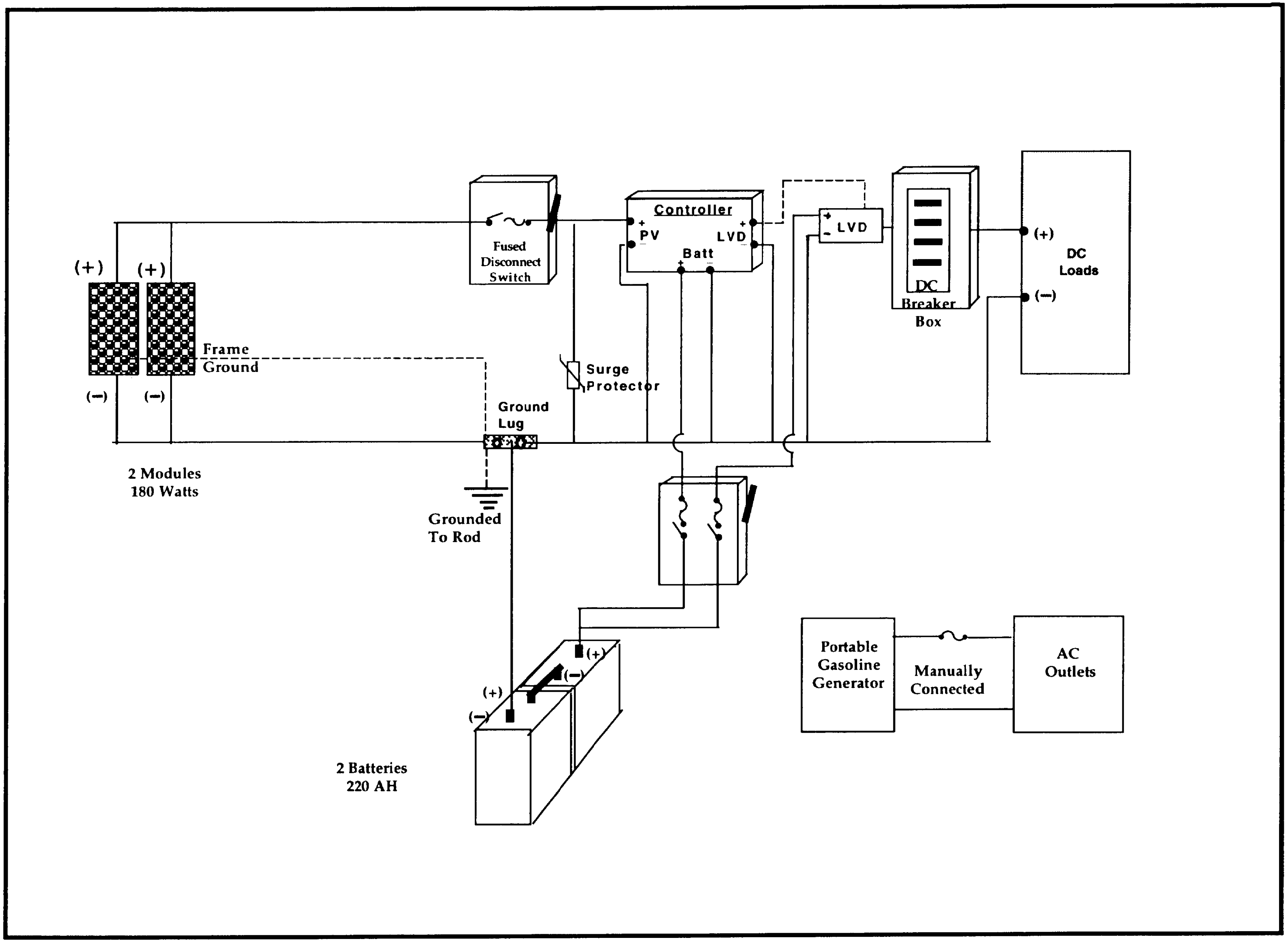
System Grounding	Wire Type	AWG Number	Type of Earth Ground
E9 Equipment Ground	Bare Copper	# 8	To ground rod
E10 System Ground	Bare Copper	#8	To ground rod

DESIGN NOTES:

In load center with breakers.

*1 Livingroom
Kitchen lights
Radio

*2 Bathroom
Bedroom lights
Radio


(+)
(+)
(−)
(−)
Frame Ground
2 Modules 180 Watts
Fused Disconnect Switch
Surge Protector
Ground Lug
Grounded To Rod
Controller
+ PV −
+ LVD −
+ Batt −
+ LVD −
DC Breaker Box
(+)
(−)
DC Loads
(+)
(−)
(+)
(−)
2 Batteries 220 AH
Portable Gasoline Generator
Manually Connected
AC Outlets

ECONOMICS ANALYSIS

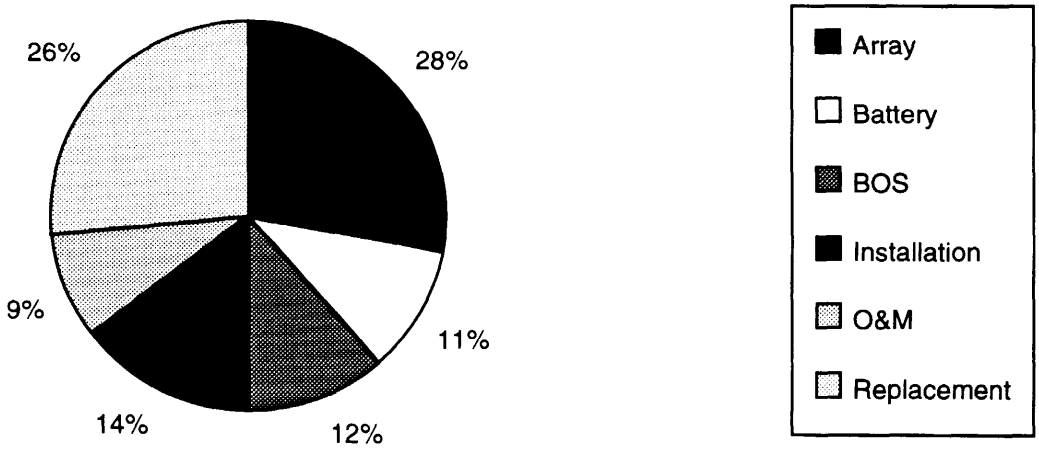
LIFE-CYCLE COST ANALYSIS
POINT DESIGN: DC SYSTEM

Item	Dollar Amount ($)	Present Worth ($)	Percent Total LCC cost (%)
1. CAPITAL COSTS:			
Array	$1,170	$1,170	29.1
Battery	440	440	10.9
BOS Hardware	480	480	11.9
Installation	600	600	14.9
A - SUBTOTAL (Equipment & Installation)	**2,690**	**2,690**	**66.8**
2. OPERATION & MAINTENANCE			
B - Annual Inspection	**25**	**372**	**9.2**
3. REPLACEMENT: (YEAR)			
Battery Bank 5	440	380	9.4
Battery Bank 10	440	327	8.1
Battery Bank 15	440	282	7.0
Controller 10	150	112	2.8
C - SUBTOTAL (Replacement Cost)	**1,470**	**1,101**	**27.3**
4. SALVAGE: (YEAR)			
D - 20% of Original 20	**(538)**	**(139)**	**(3.3)**
TOTAL LIFE-CYCLE COST (A + B + C - D)		**$4,024**	**100.0**

ECONOMIC NOTES:

1) LCC analysis does not include refrigerator or other loads in the cabin.

COST ELEMENTS AS A PERCENT OF LCC (%)



POINT DESIGN NO. 8

AC/DC RESIDENTIAL

A homeowner living full time in a remote location has been using a portable generator to provide ac power to his home. The family is not happy with the generator noise and need for fuel. They already have a battery bank that is charged with the generator and dc power is used for some lighting. The major loads such as washing machines, pumps, etc., use ac power. They designed this example PV system to supply their power needs. They made provision to manually switch the generator on and charge the batteries in an emergency.

KEY DESIGN INFORMATION

APPLICATION: AC/DC Residence
SITE: Colorado
LOCATION/ELEVATION: 41° N 105° W 2000 m
ENVIRONMENT: Mountains
TEMPERATURE RANGE (°C): -15 to 33
MAXIMUM WIND SPEED (m/s): 15
AVAILABILITY REQUIRED: Noncritical
LOAD PROFILES: Variable

INSTALLATION

The array was ground mounted on a series of concrete poles about 100 feet from the home. This configuration allowed the array to be oriented at true south while avoiding the high wind hazard associated with a roof mount. Because of the long wire run, aluminum conductors were used to minimize cost. The conductors, installed underground in metallic conduit, were terminated using the appropriate lugs for aluminum wire. The central electrical distribution system was located near the laundry room in the house. This location was for ready access to existing distributionequipment in the house. The house circuits were already segregated into two service panels, one panel containing the dc circuits and the other the ac circuits. The dc panel was served directly by the battery bank through the controller. A current limiting fuse was used in the positive battery lead. A manual transfer switch was used to allow the generator to charge the batteries. All equipment was grounded according to Article 250 of the NEC. The inverter was protected by a fused safety switch, so it could be easily isolated from the batteries for maintenance. Fused safety switches also isolated the controller from the battery and array. The negative conductor of the dc system and neutral conductor of the (240) ac system were connected to ground. All ungrounded conductors were protected by either circuit breakers or fuses. Surge arresters were installed in both the ungrounded dc and ac system conductors to suppress transients induced by lightning. A low voltage alarm (visual indicator) was placed in the kitchen to alert the homeowner of a low battery state-of-charge,

WORKSHEET #1 CALCULATE THE LOADS (FOR EACH MONTH OR SEASON AS REQUIRED)

DESIGN NOTES:

1 Load Description	2 QTY	3 Load Current (A)	4 Load Voltage (V)	5A DC Load Power (W)	5B AC Load Power (W)	6 Daily Duty Cycle (HRS/DAY)	7 Weekly Duty Cycle (DAYS/WK)	8 Power Conversion Efficiency (DECIMAL) D	9 Nominal System Voltage (V)	10 Amp-Hour Load (AH/DAY)
DC Lights DC	5	x 1.0	x 24	= 120.0	N/A	x 4.0	x 7 ÷7	÷ 1.0	÷ 24	= 20.0
Incandescent Lights DC	2	x 2.1	x 24	= 100.8	N/A	x 1.0	x 7 ÷7	÷ 1.0	÷ 24	= 4.2
DC		x	x	=	N/A	x	x ÷7	÷	÷	=
DC		x	x	=	N/A	x	x ÷7	÷	÷	=
Well Pump AC	1	x 12.0	x 240	N/A	= 2880	x 1.0	x 1 ÷7	÷ 0.85	÷ 24	= 20.2
Washing Machine AC	1	x 8.4	x 120	N/A	= 1008	x 0.7	x 1 ÷7	÷ 0.85	÷ 24	= 4.9
Vaccuum AC	1	x 2.5	x 120	N/A	= 300	x 0.25	x 7 ÷7	÷ 0.85	÷ 24	= 3.7
Television AC	1	x 1.0	x 120	N/A	= 120	x 1.0	x 7 ÷7	÷ 0.85	÷ 24	= 5.9
11 Total Load Power (W)			DC	11A Continued	AC 11B Continued			12 Total Amp-Hour Load (AH/DAY)		Continued

13 Total DC Load Power (W) 11A	14 Total AC Load Power (W) 11B	15 Nominal System Voltage (V) 9	16 Peak Current Draw (A)	17 Total Amp-Hour Load (AH/DAY) 12	18 Wire Efficiency Factor (DECIMAL) D	19 Battery Efficiency Factor (DECIMAL) D	20 Corrected Amp-Hour Load (AH/DAY)
	+	÷	=		÷	÷	=

WORKSHEET #1 **CALCULATE THE LOADS** (FOR EACH MONTH OR SEASON AS REQUIRED)

1 Load Description	2 QTY	3 Load Current (A)	4 Load Voltage (V)	5A DC Load Power (W)	5B AC Load Power (W)	6 Daily Duty Cycle (HRS/DAY)	7 Weekly Duty Cycle (DAYS/WK)	8 Power Conversion Efficiency (DECIMAL) D	9 Nominal System Voltage (V)	10 Amp-Hour Load (AH/DAY)
DC		X	X	=	N/A	X	X ÷7	÷	÷	=
DC		X	X	=	N/A	X	X ÷7	÷	÷	=
DC		X	X	=	N/A	X	X ÷7	÷	÷	=
DC		X	X	=	N/A	X	X ÷7	÷	÷	=
Toaster Oven AC	1	X 9.2	X 120	N/A	= 1104	X 0.15	X 7 ÷7	÷ 0.85	÷ 24	= 8.1
Microwave Oven AC	1	X 5.0	X 120	N/A	= 600	X 0.20	X 7 ÷7	÷ 0.85	÷ 24	= 5.9
AC		X	X	N/A	=	X	X ÷7	÷	÷	=
AC		X	X	N/A	=	X	X ÷7	÷	÷	=
11 Total Load Power (W)			DC	11A 220.8	AC 11B 6012		12 Total Amp-Hour Load (AH/DAY)			72.9

13 Total DC Load Power (W) 11A	14 Total AC Load Power (W) 11B	15 Nominal System Voltage (V) 9	16 Peak Current Draw (A)	17 Total Amp-Hour Load (AH/DAY) 12	18 Wire Efficiency Factor (DECIMAL) D	19 Battery Efficiency Factor (DECIMAL) D	20 Corrected Amp-Hour Load (AH/DAY)
220.8	+ 6012	÷ 24	= 259.7	72.9	÷ 0.98	÷ 0.9	= 82.7

DESIGN NOTES:

AC loads dominate. Select 24 VDC for system because 24 VDC inverter will provide AC power.

One inverter is sufficient because the water pump which is approxamately half the load will not be pumping when the other loads are in use.

WORKSHEET #2 DESIGN CURRENT AND ARRAY TILT

21	System Location	Ft.Collins, CO	Latitude	40° N	Longitude	105° W
	Insolation Location	Denver, CO	Latitude	40° N	Longitude	105° W

MONTH	Tilt at Latitude -15°					Tilt at Latitude					Tilt at Latitude +15°				
	22A Corrected Load (AH/DAY) 20		23A Peak Sun (HRS/DAY)		24A Design Current (A)	22B Corrected Load (AH/DAY) 20		23B Peak Sun (HRS/DAY)		24B Design Current (A)	22C Corrected Load (AH/DAY) 20		23C Peak Sun (HRS/DAY)		24C Design Current (A)
J	82.7	÷	4.01	=	20.6	82.7	÷	4.56	=	18.1	82.7	÷	4.84	=	17.1
F	82.7	÷	4.65	=	17.8	82.7	÷	6.01	=	16.5	82.7	÷	5.08	=	16.3
M		÷		=			÷		=			÷		=	
A		÷		=			÷		=			÷		=	
M		÷		=			÷		=			÷		=	
J		÷		=			÷		=			÷		=	
J		÷		=			÷		=			÷		=	
A		÷		=			÷		=			÷		=	
S		÷		=			÷		=			÷		=	
O		÷		=			÷		=			÷		=	
N	82.7	÷	4.29	=	19.3	82.7	÷	4.90	=	16.9	82.7	÷	5.22	=	15.8
D	82.7	÷	3.75	=	22.1	82.7	÷	4.36	=	19.0	82.7	÷	4.72	=	17.5

Select the largest design current and corresponding peak sun from each latitude and enter below

Latitude -15°		Latitude		Latitude +15°	
25A Peak Sun (HRS/DAY)	26A Design Current (A)	25B Peak Sun (HRS/DAY)	26B Design Current (A)	25C Peak Sun (HRS/DAY)	26C Design Current (A)
3.75	22.1	4.36	19.0	4.72	17.5

Now select the smallest design current and corresponding peak sun

27 Peak Sun (HRS/DAY	28 Design Current (A)
4.72	17.5
Tilt Angle =	55°

NOTE: DO NOT MIX TRACKING AND FIXED ARRAY DATA ON THE SAME SHEET.

DESIGN NOTES:

Designed for winter maximum load.

Local solar data used for design.

WORKSHEET #3 CALCULATE SYSTEM BATTERY SIZE

29 Corrected Amp-Hour Load (AH/DAY) 20		30 Storage Days D		31 Maximum Depth of Discharge (DECIMAL) D		32 Derate for Temperature (DECIMAL) D		33 Required Battery Capacity (AH)		34 Capacity of Selected Battery (AH)		35 Batteries in Parallel
82.7	X	6	÷	0.7	÷	1.0	=	709	÷	350	=	2

NOTE: BLOCK 35. ROUND UP FOR CONSERVATIVE DESIGN.

36 Nominal System Voltage (V) 9		37 Nominal Battery Voltage (V)		38 Batteries in Series		39 Batteries in Parallel 35		40 Total Batteries
24	÷	6	=	4	X	2	=	8

BATTERY INFORMATION	
Make	Trojan
Model	L-16
Type	Lead Antimony
Nominal Voltage (V)	6
Rated Capacity (AH)	350

41 Batteries in Parallel 35		42 Capacity of Selected Battery (AH) 34		43 System Battery Capacity (AH)		44 Maximum Depth of Discharge (DECIMAL) 31		45 Usable Battery Capacity (AH)
2	X	350	=	700	X	0.7	=	490

NOTE: USE MANUFACTURER'S DATA TO FILL IN BATTERY INFORMATION BLOCK

DESIGN NOTES:

Batteries are located in the storage room to maintain moderate temperatures.

WORKSHEET #4 CALCULATE SYSTEM ARRAY SIZE

46 Design Current (A) 28		47 Module Derate Factor (DECIMAL) D		48 Derated Design Current (A)		49 Rated Module Current (A) D		50 Modules in Parallel
17.5	÷	0.9	=	20	÷	3	=	6

		51 Nominal Battery Voltage 37		52 Batteries in Series 38	53 Voltage Required for Load (V)		54 Highest Temperature Module Voltage (V)		55 Modules in Series		56 Modules in Parallel 50		57 Total Modules
1.20	x	6	x	4	28.8	÷	14.4	=	2	x	6	=	12

DESIGN NOTES:

Non critical design therefore number of modules was rounded down.

Highest module temperature expected to be 50° C.

NOTE: USE MANUFACTURER'S SPECIFICATIONS TO FILL IN PV MODULE INFORMATION BLOCK.

58 Modules in Parallel 50		59 Rated Module Current (A)		60 Rated Array Current (A)	
	x	3.0	=	18	
		61 Module Short Circuit Current (A)		62 Array Short Circuit Current (A)	
	x	3.4	=	20.4	
63 Modules in Series 55		64 Rated Module Voltage (V)		65 Array Rated Voltage (V)	
	x	15.9	=	31.8	
		66 Open Circuit Module Voltage (V)		67 Array Open Circuit Voltage (V)	
	x	19.8	=	39.6	

PV MODULE INFORMATION

Make/Model	Siemens M75		Nominal Volts	12	
Length	48	Width	13	Thickness	1.5
Weight	12 lbs.		Bypass Diode	Y [✓ N]	
Voltage (V)	At STC	Open Circuit	At Highest Expected Temperature		
	15.9	19.8	14.4		
Current (A)	At STC	Short Circuit			
	3.0	3.4			

NOTES: BLOCK 50 - ROUND UP FOR CONSERVATIVE DESIGN.
BLOCK 55 - ROUND UP OR SELECT ANOTHER MODULE WITH SUFFICIENT VOLTAGE TO CHARGE THE BATTERIES WHEN OPERATING AT THE HIGHEST EXPECTED TEMPERATURE.

WORKSHEET #5 HYBRID DESIGN DETERMINATION

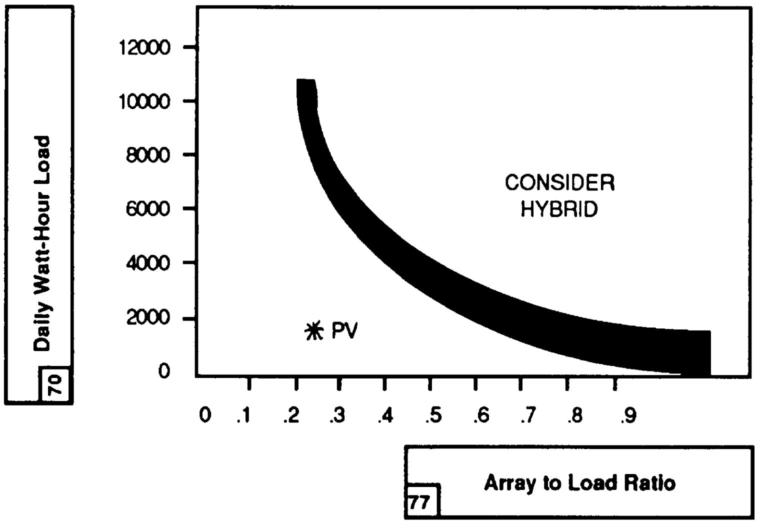
DESIGN NOTES:

Generator used in emergencies only.

68 Corrected Amp-Hour Load (AH/DAY) 20		69 Nominal System Voltage (V) 9		70 Watt-Hour Load (WH/DAY)		71 Conversion Factor		72 Annual Kilowatt-Hr Load (KWH/YEAR)
72.9	X	24	=	1750	X	.365	=	639

73 Derated Design Current (A) 48		74 Nominal System Voltage (V) 9		75 Design Array Power (W)		76 Watt-Hour Load (WH/DAY) 70		77 Array to Load Ratio (DECIMAL)
18.1	X	24	=	435	÷	1750	=	0.25

78 **Hybrid Indicator**



Hybrid Design Flag

☐ Yes ☑ No

IF YES, USE HYBRID WORKSHEETS TO COMPLETE SIZING OF A HYBRID SYSTEM. IF NO, PROCEED TO FUNCTIONAL SPECIFICATION SHEETS.

CONTROLLER SPECIFICATION

	A1 62 Array Short Circuit Current (A)		A2 Minimum Controller Current (A)		A3 Rated Controller Current) (A)		A4 Controllers in Parallel	
1.25	X	20.4	=	26	÷	30	=	1

A5

(CONTROLLER)

Make/Model Bobier Electronics NDR-30

Rated Voltage 24V option

Rated Current ____

Features

Temperature Compensation ____

Reverse Current Protection ✓

Adjustable Set Points) †

High Voltage Disconnect ____

High Voltage Re-connect ____

Low Voltage Disconnect ____

Low Voltage Re-connect ____

Meters

Battery Voltage *

Array Current ____

Load Current ____

DESIGN NOTES:

†set at factory

*LED charging indicators.

POWER CONDITIONING UNITS SPECIFICATION

Inverter

System Requirements

B1 Wave Form Modified Sine

B2 DC System Voltage 24 (V)

B3 AC System Voltage 120/240 (V)

B4 Surge Capacity 15,000 (W)

B5 Total AC Watts 5,000 (W)

B6 Maximum Single AC Load 2,880 (W)

B7 Maximum Simultaneous AC Load 3,900 (W)

B8 Inverter Run Time at Maximum Simultaneous Load 45 (MIN)

B9 Inverter Continuous Duty Rating 2,500 (W)

B10 Required Inverter Efficiency at Load 80 (%)

B11 Inverter Specifications

Make Photocomm (4800 W)

Model 24/48

Wave Form Modified Sine

Input Voltage (DC) 24 (V)

Output Voltage (AC) 120/240 (V)

Surge Capacity 14,400 (W)

FEATURES:

Battery Charging ( )

Voltmeter ( )

Remote Control ( )

Generator Start ( )

Transfer Switch ( )

Maximum Power Tracking ( )

DESIGN NOTES:

Water pump operation automatically isolates the washing machine and toaster oven AC loads from the inverter to prevent overloading.

Converter

System Requirements

C1 Input DC Voltage ____ to ____ (V)

C2 Output DC Voltage ____ to ____ (V)

C3 Output Power ____ (W)

C4 Operating Temperature ____ to ____ (C°)

C5 Converter

Make ____

Model ____

Input Voltage ____ (V)

Output Voltage ____ (V)

Output Current ____ (A)

Operating Temperature ____ (C°)

FEATURES:

Adjustable Output Voltage ____ (V)

PROTECTION COMPONENTS SPECIFICATION

	Protected Circuit	Protection Device				Rated Current	Rated Voltage	Description
		Switch	Diode	Fuse	Movistor			
D1	Array output	✓				30amp	250V	DC Fused disconnect switch
D2	Array output			✓		30amp	250V	DC Fuse
D3	Controller to inverter	✓				250amp	250 V	DC Fused disconnect switch
D4	Controller to inverter			✓		250amp	250 V	DC Fuse
D5	AC Distribution	✓				15/20 circuit breakers	220V	AC Circuit breakers
D6	Load input to AC	✓				60amp	220 V	AC Manual switch
D7	load panel							
D8	Battery charger	✓				100amp	250V	DC Manual switch
D9	Battery			✓		250amp	250V	DC In-line fuse
D10								
D11								
D12								
D13								
D14								

DC WIRE SIZING SPECIFICATION

E1 Wire Runs	E2 System Voltage (V)	E3 Maximum Current (A)	E4 One Way Length (FT)	E5 Allowed Voltage Drop (%)	E6 Allowance for Temperature Derate	E7 AWG Number	E8 Wire Type
Array Circuit							
Module to Module	24	3	2	—	—	12	UF
Array to Controller or Battery	24	26	100	3%	—	1/0*	THWN Aluminum
DC Circuits							
Battery to Battery							
Battery or Controller to DC Loads	24	10	10	2%	—	10	THHN
Branch Circuits							
A Lighting	24	15A	70	2%	—	12	NMB
B Lighting	24	15A	65	2%	—	12	NMB
C Lighting	24	15A	75	2%	—	12	NMB
D Lighting	24	15A	68	2%	—	12	NMB
E Lighting	24	15A	50	2%	—	12	NMB
F Lighting	24	15A	27	2%	—	12	NMB
Battery Charger to Batteries							
Battery to Each Inverter Or Converter	24	130	6	3%	—	1/0	THHN

System Grounding	Wire Type	AWG Number	Type of Earth Ground
E9 Equipment Ground	Stranded Copper	1/0	Ground Rod
E10 System Ground	Stranded Copper	1/0	Ground Rod

DESIGN NOTES:

*Sized for extra capacity

AC WIRE SIZING SPECIFICATION

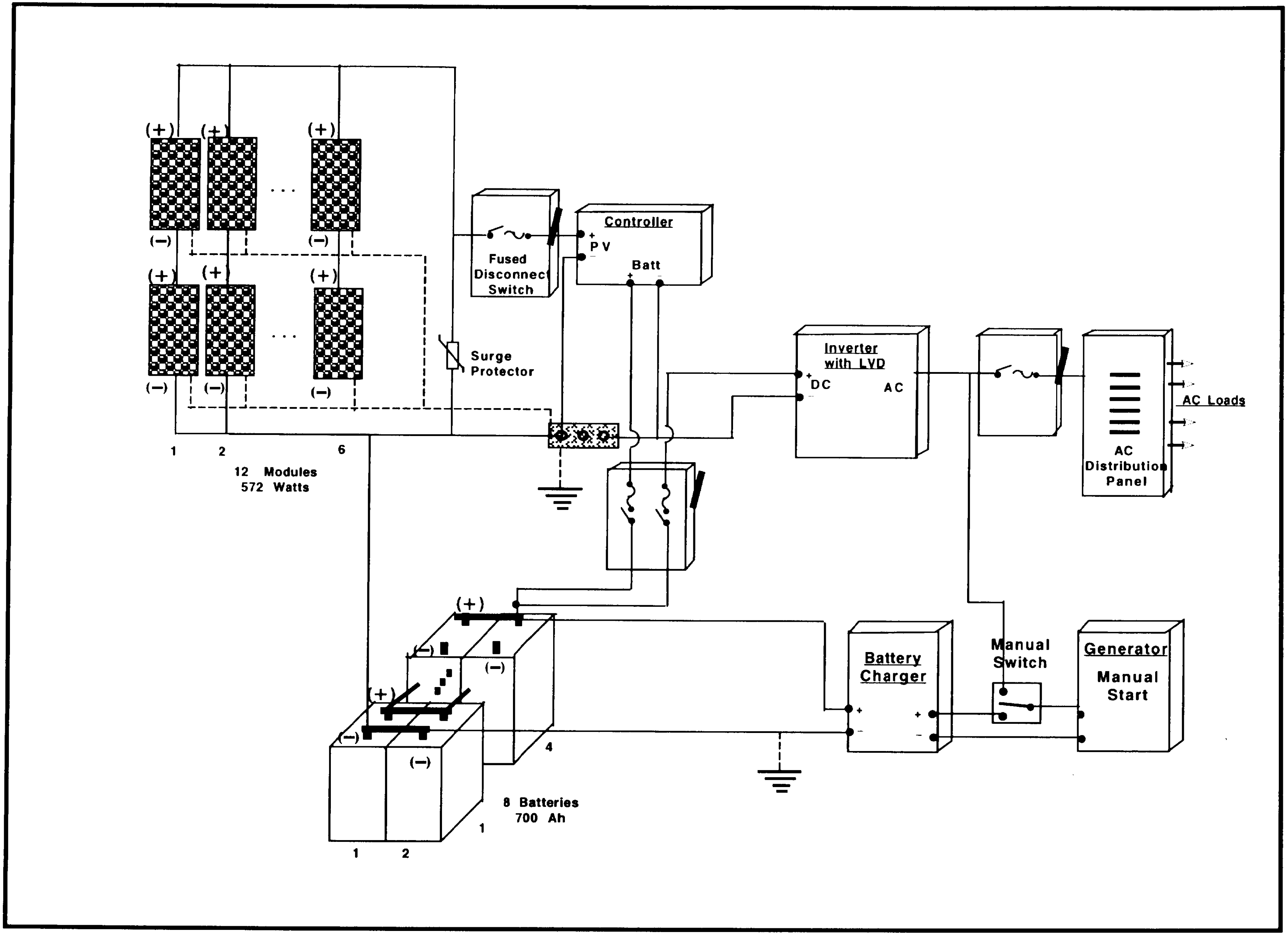
Wire Sizing And Specification (DC Side)

F1 Wire Runs	F2 System Voltage (V)	F3 Maximum Current (A)	F4 One Way Length (FT)	F5 Allowed Voltage Drop (%)	F6 Allowance for Temperature Derate	F7 AWG Number	F8 Wire Type
AC Circuits							
Inverter to AC Loads	120/240	26	12	1%		10 CU	THHN
Branch Circuits							
A Laundry	120	20	30	2%		12 CU	NM
B Kitchen(2)	120	20 (2)	50(2)	2%		12 CU	NM
C Well Pump	240	12	500	2%		4 CU	TW
D *Wall Appliances	120	20 (3)	60 (3)	2%		12 CU	NM
E							
F							
G							
Generator							
Generator to Battery Charger							
Generator to AC Load Center							

System Grounding	Wire Type	AWG Number	Type of Earth Ground
F9 Equipment Ground	Bare Copper	6	Ground Rod
F10 System Ground	Bare Copper	6	Ground Rod

DESIGN NOTES:

* (3) wall outlets


(+)
(+)
(+)
(−)
(−)
(+)
(+)
(+)
(−)
(−)
(−)
1
2
6
12 Modules
572 Watts
Surge Protector
Fused Disconnect Switch
Controller
+ PV −
Batt
+ −
Inverter with LVD
+ DC −
AC
AC Distribution Panel
AC Loads
(+)
(−)
(−)
(+)
(−)
(−)
4
1
1
2
8 Batteries
700 Ah
Battery Charger
+
−
+
−
Manual Switch
Generator
Manual Start

ECONOMICS ANALYSIS

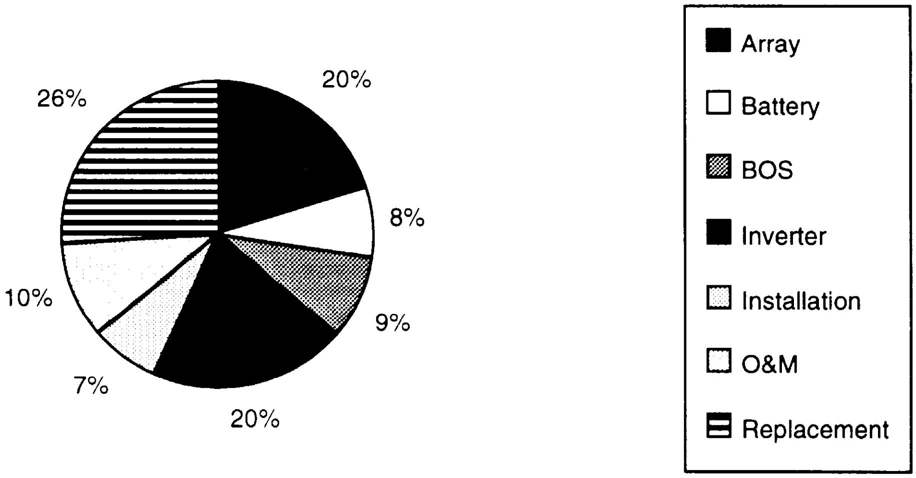
LIFE-CYCLE COST ANALYSIS
POINT DESIGN: AC/DC RESIDENTIAL

Item	Dollar Amount ($)	Present Worth ($)	Percent Total LCC cost (%)
1. CAPITAL COSTS:			
Array	$3,720	$3,720	20.8
Battery	1,400	1,400	7.8
BOS Hardware + Mounting	1,635	1,635	9.2
Inverters	3,750	3,750	21.0
Installation	1,300	1,300	7.3
A - SUBTOTAL (Equipment & Installation)	**11,805**	**11,805**	**66.1**
2. OPERATION & MAINTENANCE			
B - Annual Inspection	**125**	**1,860**	**10.4**
3. REPLACEMENT: (YEAR)			
Battery Bank 5	1,400	1,208	6.8
Battery Bank 10	1,400	1,042	5.8
Battery Bank 15	1,400	899	5.0
Rebuild Inverters 10	2,000	1,488	8.3
Controller 10	210	156	0.9
C - SUBTOTAL (Replacement Cost)	**6,410**	**4,793**	**26.8**
4. SALVAGE: (YEAR)			
D - 20% of Original 20	**(2,361)**	**(609)**	**(3.3)**
TOTAL LIFE-CYCLE COST (A + B + C - D)		**$17,849**	**100.0**

ECONOMIC NOTES:

1) The cost of the ac distribution panel, generator transfer switch & battery charger is included in the BOS cost.

COST ELEMENTS AS A PERCENT OF LCC (%)



POINT DESIGN NO. 9

HYBRID RESIDENTIAL

This hybrid system is located on a house on a private island off the coast of South Carolina. The homeowner lives on the island year-round. The electrical demand is high because of a large air conditioning and space heating load from a ground-source heat pump. A hybrid (photovoltaic-generator) system was determined to be the most cost-effective design to accommodate the average daily load of about 5 kilowatt-hours. Since the homeowner already had the generator, the PV array was designed to supply about 45 percent of the total loads. This fully automatic system includes a sophisticated control system that starts the generator at specific battery states-of-charge and controls all aspects of system operation.

KEY DESIGN INFORMATION

APPLICATION:	Residence		
SITE:	South Carolina		
LOCATION/ELEVATION:	29° N	80° W	20 m
ENVIRONMENT:	Coastal		
TEMPERATURE RANGE (°C):	-5 to 37		
MAXIMUM WIND SPEED (m/s):	40		
AVAILABILITY REQUIRED:	Non-critical		

INSTALLATION

The array was mounted on the south facing roof of the residence with 3 inches of space between roof and array. Spacers were installed in the attic between the joists and the array was attached to these boards to prevent system damage during the hurricanes that may occur along the coast of South Carolina. The mechanical support structure was placed in pitch pans to reduce the possibilities of moisture penetration and to facilitate replacement of the roofing material. The array conductors were secured to the module junction boxes with strain relief connectors. Interconnecting wires were tied to the back of the modules to prevent chafing against the roof. Anodized aluminum was used for all metal supports to prevent corrosion in the humid climate. The array conductors were run in conduit to the battery room and inverter area in the attic space. The enclosures for the flooded-cell batteries were vented to the outside. The array and all equipment were grounded to a copper rod beneath the house. The negative conductor of the dc circuits and the neutral conductor of the ac circuits were connected to this same ground. All ungrounded conductors in both ac and dc circuits were fused. Lightning arresters were installed on all ungrounded conductors. A set of schematic drawings and an owners manual was provided as well as a battery maintenance kit including maintenance procedures, electrolyte replenishment container, hydrometer, and battery terminal corrosion inhibitor.

WORKSHEET #1 CALCULATE THE LOADS (FOR EACH MONTH OR SEASON AS REQUIRED)

DESIGN NOTES:

1 Load Description	2 QTY	3 Load Current (A)	4 Load Voltage (V)	5A DC Load Power (W)	5B AC Load Power (W)	6 Daily Duty Cycle (HRS/DAY)	7 Weekly Duty Cycle (DAYS/WK)	8 Power Conversion Efficiency (DECIMAL) D	9 Nominal System Voltage (V)	10 Amp-Hour Load (AH/DAY)
DC		X	X	=	N/A	X	X ÷7	÷	÷	=
DC		X	X	=	N/A	X	X ÷7	÷	÷	=
DC		X	X	=	N/A	X	X ÷7	÷	÷	=
DC		X	X	=	N/A	X	X ÷7	÷	÷	=
Lights (Marathon) AC	10	X 0.13	X 120	N/A	= 156	X 6.0	X 7 ÷7	÷ 0.8	÷ 48	= 24.4
Water Pump AC	1	X 3.77	X 240	N/A	= 904	X 0.25	X 7 ÷7	÷ 0.8	÷ 48	= 5.9
Washing Machine AC	1	X 2.80	X 120	N/A	= 332	X 0.30	X 7 ÷7	÷ 0.8	÷ 48	= 2.6
Clothes Dryer (Gas) AC	1	X 8.40	X 120	N/A	= 1008	X 0.35	X 2 ÷7	÷ 0.8	÷ 48	= 2.6
11 Total Load Power (W)			DC 11A	N/A	AC 11B Continued			12 Total Amp-Hour Load (AH/DAY)		Continued

13 Total DC Load Power (W) 11A	14 Total AC Load Power (W) 11B	15 Nominal System Voltage (V) 9	16 Peak Current Draw (A)	17 Total Amp-Hour Load (AH/DAY) 12	18 Wire Efficiency Factor (DECIMAL) D	19 Battery Efficiency Factor (DECIMAL) D	20 Corrected Amp-Hour Load (AH/DAY)
	+	÷	=		÷	÷	=

WORKSHEET #1 **CALCULATE THE LOADS** (FOR EACH MONTH OR SEASON AS REQUIRED)

DESIGN NOTES:

1 Load Description	2 QTY		3 Load Current (A)		4 Load Voltage (V)		5A DC Load Power (W)	5B AC Load Power (W)		6 Daily Duty Cycle (HRS/DAY)		7 Weekly Duty Cycle (DAYS/WK)		8 Power Conversion Efficiency (DECIMAL) D		9 Nominal System Voltage (V)		10 Amp-Hour Load (AH/DAY)
DC		X		X		=		N/A	X		X	÷7	÷		÷		=	
DC		X		X		=		N/A	X		X	÷7	÷		÷		=	
DC		X		X		=		N/A	X		X	÷7	÷		÷		=	
DC		X		X		=		N/A	X		X	÷7	÷		÷		=	
Microwave AC	1	X	6.20	X	120		N/A	= 744	X	0.50	X	7 ÷7	÷	0.8	÷	48	=	9.7
Toaster AC	1	X	9.2	X	120		N/A	= 1104	X	0.15	X	7 ÷7	÷	0.8	÷	48	=	4.3
Dock / Bridge Lights AC	8	X	0.68	X	120		N/A	= 653	X	1.00	X	7 ÷7	÷	0.8	÷	48	=	17.0
Air Conditioner AC	1	X	2.04	X	240		N/A	= 489	X	3.00	X	7 ÷7	÷	0.8	÷	48	=	38.3

11 Total Load Power (W)	DC 11A N/A	AC 11B 5390	12 Total Amp-Hour Load (AH/DAY)	104.8

13 Total DC Load Power (W) 11A	14 Total AC Load Power (W) 11B	15 Nominal System Voltage (V) 9	16 Peak Current Draw (A)	17 Total Amp-Hour Load (AH/DAY) 12	18 Wire Efficiency Factor (DECIMAL) D	19 Battery Efficiency Factor (DECIMAL) D	20 Corrected Amp-Hour Load (AH/DAY)
NA	+ 5390	÷ 48	= 112.3	104.8	÷ 0.98	÷ 0.9	= 118.8

WORKSHEET #2 DESIGN CURRENT AND ARRAY TILT

21 System Location	Charleston, SC	Latitude	33°N	Longitude	80°W
Insolation Location	Charleston, SC	Latitude	33°N	Longitude	80°W

	Tilt at Latitude -15°					Tilt at Latitude					Tilt at Latitude +15°				
MONTH	22A Corrected Load (AH/DAY) 20		23A Peak Sun (HRS/DAY)		24A Design Current (A)	22B Corrected Load (AH/DAY) 20		23B Peak Sun (HRS/DAY)		24B Design Current (A)	22C Corrected Load (AH/DAY) 20		23C Peak Sun (HRS/DAY)		24C Design Current (A)
J	118.8	÷	2.87	=	41.4	118.8	÷	3.17	=	37.5	118.8	÷	3.30	=	36.0
F		÷		=			÷		=			÷		=	
M		÷		=			÷		=			÷		=	
A		÷		=			÷		=			÷		=	
M		÷		=			÷		=			÷		=	
J		÷		=			÷		=			÷		=	
J		÷		=			÷		=			÷		=	
A		÷		=			÷		=			÷		=	
S		÷		=			÷		=			÷		=	
O		÷		=			÷		=			÷		=	
N	118.8	÷	3.73	=	31.8	118.8	÷	4.19	=	28.4	118.8	÷	4.42	=	26.9
D	118.8	÷	2.92	=	40.7	118.8	÷	3.31	=	35.9	118.8	÷	3.52	=	33.8

Select the largest design current and corresponding peak sun from each latitude and enter below

Latitude -15°		Latitude		Latitude +15°	
25A Peak Sun (HRS/DAY)	26A Design Current (A)	25B Peak Sun (HRS/DAY)	26B Design Current (A)	25C Peak Sun (HRS/DAY)	26C Design Current (A)
2.87	41.4	3.17	37.5	3.30	36.0

Now select the smallest design current and corresponding peak sun

27 Peak Sun (HRS/DAY	28 Design Current (A)
3.30	36.0
Tilt Angle =	48°

NOTE: DO NOT MIX TRACKING AND FIXED ARRAY DATA ON THE SAME SHEET.

DESIGN NOTES:

Local solar data was available.

Designed for minimum winter insolation.

WORKSHEET #3

CALCULATE SYSTEM BATTERY SIZE

DESIGN NOTES:

29 Corrected Amp-Hour Load (AH/DAY) 20		30 Storage Days D		31 Maximum Depth of Discharge (DECIMAL) D		32 Derate for Temperature (DECIMAL) D		33 Required Battery Capacity (AH)		34 Capacity of Selected Battery (AH)		35 Batteries in Parallel
118.8	X	5	÷	0.8	÷	1	=	742.5	÷	185	=	4

NOTE: BLOCK 35. ROUND UP FOR CONSERVATIVE DESIGN.

36 Nominal System Voltage (V) 9		37 Nominal Battery Voltage (V)		38 Batteries in Series		39 Batteries in Parallel 35		40 Total Batteries
48	÷	12	=	4	X	4	=	16

BATTERY INFORMATION	
Make	Cloride (Real Goods)
Model	75N05
Type	Flooded Lead Acid
Nominal Voltage (V)	12
Rated Capacity (AH)	185

41 Batteries in Parallel 35		42 Capacity of Selected Battery (AH) 34		43 System Battery Capacity (AH)		44 Maximum Depth of Discharge (DECIMAL) 31		45 Usable Battery Capacity (AH)
4	X	185	=	740	X	0.8	=	592

NOTE: USE MANUFACTURER'S DATA TO FILL IN BATTERY INFORMATION BLOCK

WORKSHEET #4 CALCULATE SYSTEM ARRAY SIZE

DESIGN NOTES:

46 Design Current (A) 28		47 Module Derate Factor (DECIMAL) D		48 Derated Design Current (A)		49 Rated Module Current (A) D		50 Modules in Parallel
36	÷	0.9	=	40	÷	3.0	=	13

		51 Nominal Battery Voltage 37		52 Batteries in Series 38	53 Voltage Required for Load (V)		54 Highest Temperature Module Voltage (V)		55 Modules in Series		56 Modules in Parallel 50		57 Total Modules
1.20	x	12	x	4	57.6	÷	14.5	=	4	x	13	=	52

58 Modules in Parallel 50		59 Rated Module Current (A)		60 Rated Array Current (A)
	x	3	=	39
		61 Module Short Circuit Current (A)		62 Array Short Circuit Current (A)
	x	3.3	=	42.9

63 Modules in Series 55		64 Rated Module Voltage (V)		65 Array Rated Voltage (V)
	x	16.9	=	67.6
		66 Open Circuit Module Voltage (V)		67 Array Open Circuit Voltage (V)
	x	21.2	=	84.8

NOTE: USE MANUFACTURER'S SPECIFICATIONS TO FILL IN PV MODULE INFORMATION BLOCK.

PV MODULE INFORMATION

Make/Model	Kyocera LA361K51		**Nominal Volts**	12
Length	39	**Width** 18	**Thickness**	2
Weight	13 lbs.		**Bypass Diode**	[✓ Y] N
Voltage (V)	**At STC**	**Open Circuit**	**At Highest Expected Temperature**	
	16.9	21.2	14.5	
Current (A)	**At STC**	**Short Circuit**		
	3.0	3.3		

NOTES: BLOCK 50 - ROUND UP FOR CONSERVATIVE DESIGN.

BLOCK 55 - ROUND UP OR SELECT ANOTHER MODULE WITH SUFFICIENT VOLTAGE TO CHARGE THE BATTERIES WHEN OPERATING AT THE HIGHEST EXPECTED TEMPERATURE.

WORKSHEET #5

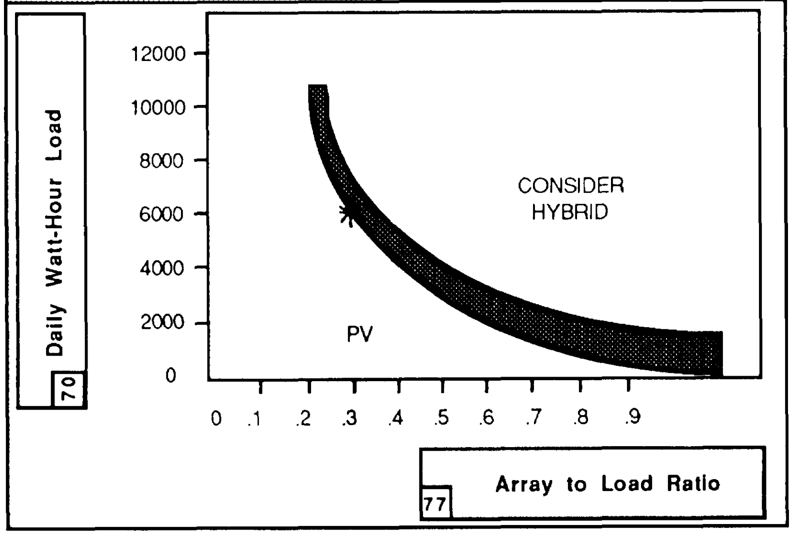
HYBRID DESIGN DETERMINATION

DESIGN NOTES:

68 Corrected Amp-Hour Load (AH/DAY) 20		69 Nominal System Voltage (V) 9		70 Watt-Hour Load (WH/DAY)		71 Conversion Factor		72 Annual Kilowatt-Hr Load (KWH/YEAR)
118.8	X	48	=	5702	X	.365	=	2081

73 Derated Design Current (A) 48		74 Nominal System Voltage (V) 9		75 Design Array Power (W)		76 Watt-Hour Load (WH/DAY) 70		77 Array to Load Ratio (DECIMAL)
40	X	48	=	1920	÷	5702	=	0.34

78 Hybrid Indicator



Hybrid Design Flag

Yes	No
☒	☐

IF YES, USE HYBRID WORKSHEETS TO COMPLETE SIZING OF A HYBRID SYSTEM. IF NO, PROCEED TO FUNCTIONAL SPECIFICATION SHEETS.

HYBRID WORKSHEET #1 HY

CALCULATE THE BATTERY CAPACITY, GENERATOR SIZE, AND PERCENT CONTRIBUTION OF THE ARRAY AND GENERATOR

1Y Corrected Amp-Hour Load (AH/DAY) 20	2Y D Storage Days for Hybrid System	3Y D Maximum Depth of Discharge (DECIMAL)	4Y D Derate for Temperature (DECIMAL)	5Y Hybrid Battery Capacity (AH)	6Y Peak Current Draw (A) 16	7Y Battery Discharge Time (HOURS)
118.8	X 4	÷ 0.8	÷ 1	= 594	÷ 112	= 5.3

8Y Hybrid Battery Capacity (AH) 5Y	9Y D Battery Charge Time (HOURS)	10Y Maximum Battery Charge Rate (A)	11Y Nominal System Voltage (V) 9	12Y Nominal Charging Power (W)	13Y D Efficiency of Battery Charger (DECIMAL)	14Y D Generator Derate Factor (DECIMAL)	15Y Generator Size (W)
594	÷ 5	= 118.8	X 48	= 5702	÷ 0.8	÷ 0.97	= 7348

16Y D Hybrid Array to Load Ratio	17Y D Load Provided by Array (DECIMAL)		18Y Load Provided by Array (DECIMAL) 17Y	19Y Load Provided by Generator (DECIMAL)	20Y Annual Kilowatt-Hour Load (KWH/YR) 72	21Y Annual Generator Output (KWH)
.125	.45	1.0	− .45	= .55	X 2081	= 1145

22Y Annual Generator Output (KWH) 21Y	23Y Conversion Factor	24Y Nominal Charging Power (W) 12Y	25Y Annual Generator Run Time (HRS)	26Y D Oil Change Interval (HRS)	27Y Services per Year (NUMBER)
1145	X 1000	÷ 5700	= 200	÷ 50	= 4

DESIGN NOTES:

Four storage days were chosen because industrial grade deep cycle batteries will be used.

To size the generator, the battery charger and other system loads were summed.

A 12.5 KW generator was specified to run the battery charger (7400 w) and the maximum system loads of 5400 watts simultaneously.

The load management system allows a 3 KW shedding of PV array during battery charging.

Generator Specifications:
Onan / Industrial
12.5 KW 1800 RPM
Propane fuel

Battery Charger Specifications:
100 Amp
240 Vac input / 100 VDC max output

CONTROLLER SPECIFICATION

		A1 Array Short Circuit Current (A) 62		A2 Minimum Controller Current (A)		A3 Rated Controller Current) (A)		A4 Controllers in Parallel
1.25	X	16.5	=	20.6	÷	30	=	1

A5

(CONTROLLER)

Make/Model ____

Rated Voltage 48

Rated Current 30

Features

Temperature Compensation ✓

Reverse Current Protection ✓

Adjustable Set Points)

High Voltage Disconnect ✓

High Voltage Re-connect ✓

Low Voltage Disconnect ✓

Low Voltage Re-connect ✓

Meters

Battery Voltage ✓

Array Current ✓

Load Current ✓

DESIGN NOTES:

A central control system coordinates all system functions automatically. Generator operation, load management, and battery charging are controlled.

An analog indicator shows battery state of charge.

POWER CONDITIONING UNITS SPECIFICATION

Inverter

System Requirements

B1 Wave Form Modified Sine

B2 DC System Voltage 48 (V)

B3 AC System Voltage 120/240 (V)

B4 Surge Capacity 15,000 (W)

B5 Total AC Watts 5390 (W)

B6 Maximum Single AC Load 1008 (W)

B7 Maximum Simultaneous AC Load 5390 (W)

B8 Inverter Run Time at Maximum Simultaneous Load 10 (MIN)

B9 Inverter Continuous Duty Rating 5000 (W)

B10 Required Inverter Efficiency at Load 80 (%)

B11 Inverter Specifications

Make Westec

Model W5000 48

Wave Form Modified Sine

Input Voltage (DC) 48 (V)

Output Voltage (AC) 120/240 (V)

Surge Capacity 25,000 (W)

FEATURES:

Battery Charging ( )

Voltmeter ( )

Remote Control ( )

Generator Start ( )

Transfer Switch ( )

Maximum Power Tracking ( )

Other Features:

Input Protection (✓)

Output Protection (✓)

DESIGN NOTES:

Converter

System Requirements

C1 Input DC Voltage ____ to ____ (V)

C2 Output DC Voltage ____ to ____ (V)

C3 Output Power ____ (W)

C4 Operating Temperature ____ to ____ (C°)

C5 Converter

Make ____

Model ____

Input Voltage ____ (V)

Output Voltage ____ (V)

Output Current ____ (A)

Operating Temperature ____ (C°)

FEATURES:

Adjustable Output Voltage ____ (V)

SWITCHES & PROTECTION COMPONENTS

Circuit	Protection Device				Rated Current	Rated Voltage	Description
	Switch	Diode	Fuse	Surge			
D1 Array Output	✓		✓		30	250	Fused disconnect
D2 Battery-Controller	CB ✓				30	250	Circuit breaker
D3 Battery - Inverter	CB ✓				175*	250	DC-rated circuit breaker
D4 Battery charger	✓				100	250	Relay controlled Contactor
D5 Array output				✓			Movistors
D6 Inverter Input				✓			Movistors
D7							
D8							
D9							
D10							
D11							
D12							
D13							
D14							

* Inverter current = 5000 ÷ 48 ÷ 0.9 = 116 ; Derated for NEC & UL ≐ 175 A.

DC WIRE SIZING SPECIFICATION

E1 Wire Runs	E2 System Voltage (V)	E3 Maximum Current (A)	E4 One Way Length (FT)	E5 Allowed Voltage Drop (%)	E6 Allowance for Temperature Derate	E7 AWG Number	E8 Wire Type
Array Circuit							
Module to Module	48	3.8	2	—	18%	12	THHN
Array to Controller or Battery	48	20.6	35	2%	18%	8	THHN
DC Circuits							
Battery to Battery							
Battery or Controller to DC Loads							
Branch Circuits							
A							
B							
C							
D							
E							
Battery Charger to Batteries	48	119	10	2%	—	2	THHN
Battery to Inverter Or Converter	48	142	8	2%	—	2	THHN

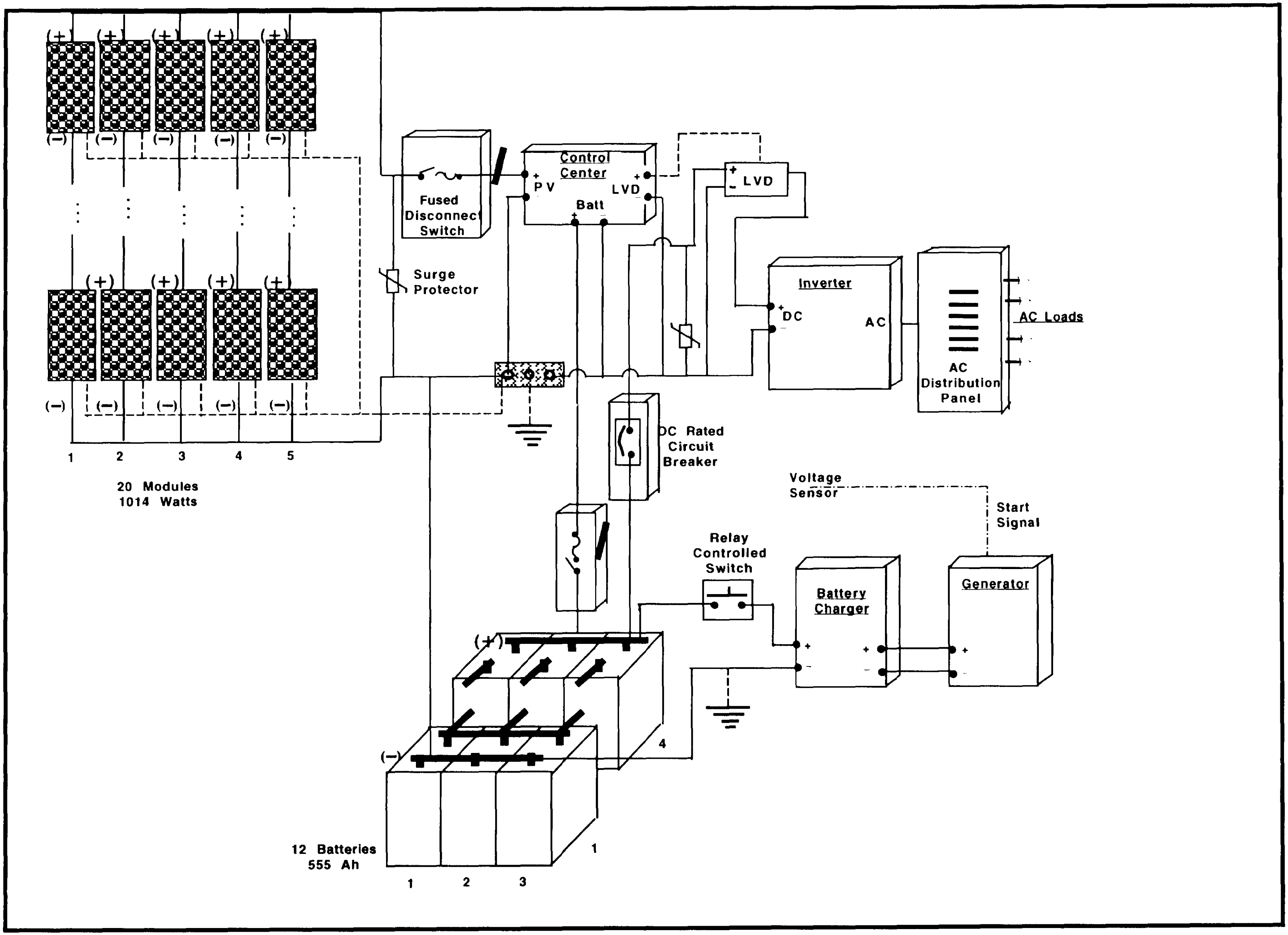
System Grounding	Wire Type	AWG Number	Type of Earth Ground
E9 Equipment Ground	Bare Copper	2	Ground Rod
E10 System Ground	Bare Copper	2	Ground Rod

DESIGN NOTES:

AC WIRE SIZING SPECIFICATION

DESIGN NOTES:

Wire Sizing And Specification (DC Side)							
F1 Wire Runs	F2 System Voltage (V)	F3 Maximum Current (A)	F4 One Way Length (FT)	F5 Allowed Voltage Drop (%)	F6 Allowance for Temperature Derate	F7 AWG Number	F8 Wire Type
AC Circuits							
Inverter to AC Loads	120/240	56	6'	3%		4	THHN
Branch Circuits							
A Air Conditioner	240 Vac	4.0	30'	2%		12/2	NM
B Kitchen(2)	120 Vac	20.0	20'	2%		12/2	NM
C Dock Bridge Lighting	120 Vac	1.0	500'	3%		12/2	VF
D Water Pump	240 Vac	3.7	200'	2%		12/2	VF
E Laundry	120 Vac	20.0	25'	1%		12/2	NM
F							
G							
Generator							
Generator to Battery Charger	240	24	10'	2%		8cu	THHW
Generator to AC Load Center	240	24	4'	1%		8cu	THHW
System Grounding		Wire Type		AWG Number		Type of Earth Ground	
F9 Equipment Ground		Bare Copper		2 cu		Ground Rod	
F10 System Ground		Bare Copper		2 cu		Ground Rod	


(+)
(−)
1
2
3
4
5
20 Modules
1014 Watts
Fused Disconnect Switch
Surge Protector
Control Center
PV
LVD
Batt
+
−
LVD
Inverter
DC
AC
AC Distribution Panel
AC Loads
DC Rated Circuit Breaker
Voltage Sensor
Start Signal
Relay Controlled Switch
Battery Charger
Generator
12 Batteries
555 Ah

ECONOMICS ANALYSIS

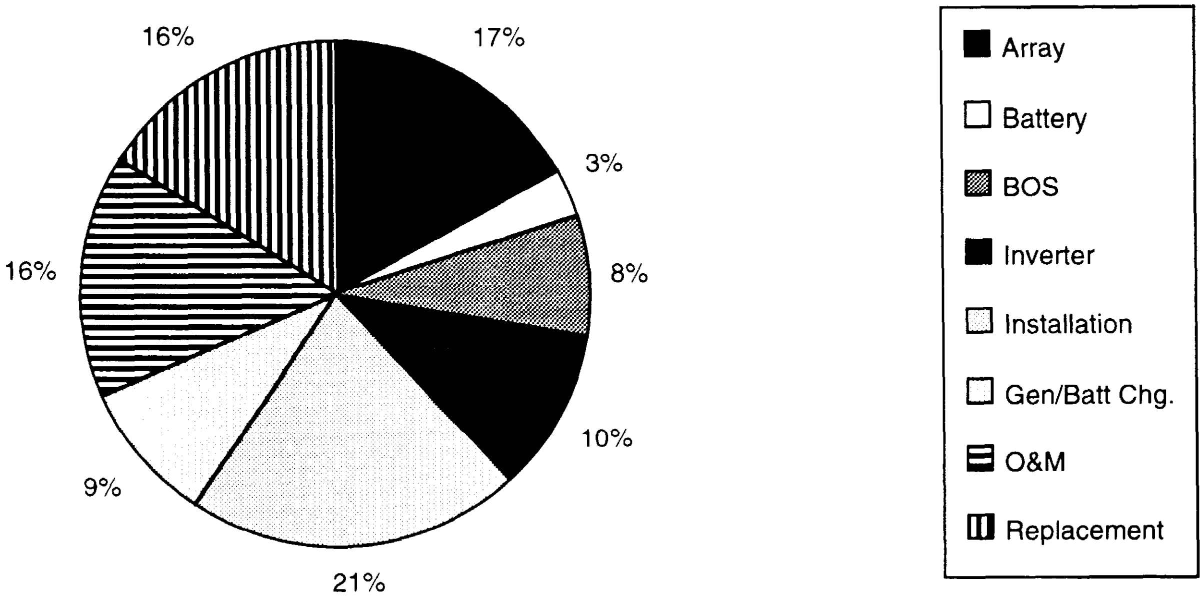
LIFE-CYCLE COST ANALYSIS
POINT DESIGN: HYBRID RESIDENTIAL

Item		Dollar Amount ($)	Present Worth ($)	Percent Total LCC cost (%)
1. CAPITAL COSTS:				
Array		$6,690	$6,690	17.8
Battery		1,665	1,665	3.0
Controller/BOS Components		1,245	1,245	2.1
Inverter		4,000	4,000	10.6
Generator & Battery Charger		8,400	8,400	22.4
Installation		3,500	3,500	9.3
A - SUBTOTAL (Equipment & Installation)		**26,695**	**26,695**	**71.1**
2. OPERATION & MAINTENANCE				
Annual Inspection		125	1,860	4.9
Generator Oil Change (4 per year)		200	2,976	7.9
Energy & Fuel (500 gallon propane)		840	1,250	3 3
B - SUBTOTAL (Operation & Maintenance)		**1,165**	**6,086**	**16.1**
3. REPLACEMENT:	(YEAR)			
Battery Bank	8	1,110	876	2.3
Battery Bank	16	1,110	692	1.8
Controller	10	400	300	0.8
Inverter	10	2,000	1,490	3.9
Generator Rebuild	12	4.000	2,800	7.5
C - SUBTOTAL (Replacement Cost)		**8,620**	**6,158**	**16.3**
4. SALVAGE:	(YEAR)			
D - 20% of Original	20	**(5,339)**	**(1,377)**	**(3.4)**
TOTAL LIFE-CYCLE COST (A + B + C - D)			**$37,562**	**100.0**

ECONOMIC NOTES:

1) The batteries are installed in a prepared space in the attic of the house and the additional cost is included in the LCC analysis.
2) Propane cost is assumed to be $1.40/gallon delivered to the site.

COST ELEMENTS AS A PERCENT OF LCC (%)



WATER PUMPING

Pumping water is a universal need around the world and the use of photovoltaic power is increasing for this application. PV powered pumping systems offer simplicity, reliability, and low maintenance for a broad range of applications between hand pumps and large generator driven irrigation pumps. Both ac and dc motors with rotary or displacement pumps are being used with PV power. Brushless dc motors are now available and provide low maintenance on shallow submersible pumps. The PV arrays are often mounted on passive trackers to increase the pumping time and production of water.

Many smaller systems use direct coupled dc rotary pumps. The most common type, a centrifugal pump, uses an rotating impeller that draws liquid through an intake at the center of the impeller and propels it outward by centrifugal force to an outlet at the perimeter of the impeller housing. A single stage centrifugal pump can be used for water levels (head) of 5-7 meters. A jet centrifugal pump redirects a small portion of the pumped water to the impeller intake. This can increase the suction lift to over 40 meters but the efficiency drops quickly with increasing head. Another method used to increase the pumping head is to stack impellers so that each pump moves water only from the unit below to the one above. This increases cost of the pump system and the efficiency decreases with the number of stages. For any rotary pump system, the water output is proportional to the current provided to the motor that drives the element, and this current is proportional to the solar irradiance which changes continually. Therefore, the efficiency of these pumps will vary widely during a typical day. Using an electronic matching device such as a linear current booster (LCB) will increase pump system efficiency and flow by better matching the array to the pump.

Volumetric or displacement pumps are used for deep wells. These pumps use a piston or diaphragm to move packets of liquid through a sealed chamber. These pumps are used to pump from greater depths as typified by the oil well pump jacks that use a “walking beam” to pull a long rod that operates a piston far below the surface. A small amount of liquid is moved upward during each cycle of the pump. The pumping rate is almost independent of depth but the current demand varies as the pump cycles from lifting water (upstroke) to accepting more (downstroke). A matching device (battery or electronic) is required between the pump and the array.

Regardless of the type of pump used, water is usually stored in a tank or reservoir for use at other times. Most pumping systems do not include batteries for on-demand water. However, batteries are sometimes used in systems where pumping time must be controlled because of low water demand or low source capacity.

APPLICATIONS

- Irrigation
- Village Water Supply
- Stock Watering
- Domestic Use

USERS

- Farmers /Ranchers
- Villages

LOAD

The load is the motor that drives the pump. It may be dc or ac. If an ac pump is used, the voltage required is typically 120 volts or 240 volts. Some manufacturers incorporate a dc to ac inverter into their pumping unit. Submersible brushless dc pump motors are available from a number of manufacturers. If a dc motor with brushes is used, the brushes will require periodic replacement. Wiring for submersible pumps must be a type approved for such applications. Electrical connections must be protected. Many pump dealers will provide waterproof splicing kits and instructions. The size of the power system will depend on water demand, total dynamic head, and efficiency of the pump system. The efficiency of pump systems will vary widely with insolation (which affects motor voltage, current, and speed). This can be improved by providing some matching, either electronic or with a battery, between the array and pump motor. Reasonable system sizing can be realized using average daily values of energy demand and daily insolation.

ARRAY

Wiring should be sunlight resistant USE or UF type cable with insulation rated for installation in damp conditions. All above ground connections should be in water-tight junction boxes with strain relief connectors. Array wiring should be laced and attached to support structure with wire ties. Use conduit for output wiring to the pump motor (or the controller and batteries.) The array should be grounded using bare copper grounding wire (No. 8 or larger) securely attached to each support structure. Array tracking is recommended for most pumping applications, A fused disconnect or circuit breaker in a rainproof enclosure should be installed at the array. Simple metering of voltage and current is recommended. Because PV powered pumps operate typically at low voltages, the currents will be high and wire size must be appropriate to keep wiring losses to less than 2.5 percent.

BATTERIES

Some designers use batteries between the array and motor to provide a stable voltage and current to the pump motor. In such cases, the batteries are not meant to operate the pump at night or on cloudy days. Shallow-cycle batteries may be used if the controller is set to limit discharge to less than 20 percent. The other reason for using batteries is when the pumping capability is greater than source replenishment. In this case batteries may be used to spread pumping time over a longer period (with a smaller pump). Deep cycle lead acid or nickel cadmium batteries specifically designed for photovoltaic applications are recommended. Batteries should be located in a weather-resistant enclosure. Nonmetallic enclosures are recommended for nonsealed batteries to prevent corrosion.

CONTROL

Direct-coupled PV water pumping systems do not require a controller but some systems include a linear current booster to improve the match between the array and motor. These are recommended. Water level switches or pressure switches may be used so the water level will control the pump. Systems that include batteries should use a controller for charge regulation. A low voltage disconnect is recommended to prevent deep discharge of the battery.

MOUNTING

Array tracking is recommended for most PV water pumping systems. Passive trackers that support up to 16 modules are available. Average wind velocities must be taken into account when considering the use of a tracking support structure. Wind velocities above 25 mph may prevent tracking if a passive freon-driven tracker is used. Support structures should be aluminum, galvanized or stainless steel designed for maximum anticipated wind velocities. Locate the array as close to the well as practical to keep wire runs to a minimum. Fencing may be required to protect the array from animals in stock watering applications. A good ground is required–many pump systems are struck by lightning. The ground can be made to the well casing or wellhead. Never use the metal pipe string because theground would be interrupted anytime the string was pulled for pump maintenance.

POINT DESIGN NO. 10

DC SURFACE PUMP

Rural electric cooperatives in the United States are beginning to supply PV power to their customers who need to pump water for livestock. The conventional method of service was to extend the grid line to the isolated well-even though the income from the customer could never pay for the maintenance of the line, let alone provide a return on the original investment. As these remote lines require replacement, either because of age or storm damage, a number of utilities have discovered that a PV pumping system can be provided for the customer at a fraction of the cost of replacing the line. This example is of a rancher in Nebraska that requires about 500 gallons of water per day for 40 cows. The pasture where the well is located is used in wintertime only There is a 2,500 gallon tank near the well that provides water (gravity fed) to smaller water tanks distributed throughout the pasture. The load is critical as the cattle cannot go without water more than one day in winter, This small pump uses a 12 volt dc two stage diaphragm pump and is designed to pump over 500 gallon per day (~ 2,000 liters per day) from a level of 20 meters. The water level in this well is only 10 meters with a maximum drawdown of 6 meters. A float switch in the main watering tank controls operation of the pump.

KEY DESIGN INFORMATION

APPLICATION:	Livestock Watering
SITE:	Near Potter, Nebraska
LOCATION/ELEVATION:	40° 30’ N 103° 30’ W 200 m
ENVIRONMENT:	Grassland
TEMPERATURE RANGE (°C):	-10 to 35
MAXIMUM WIND SPEED (m/s):	20
AVAILABILITY REQUIRED:	Critical
DAYS OF STORAGE:	Reinforced Fiberglass Tank
SOURCE:	Cased Borehole 3”
DYNAMIC HEAD (m):	17
WATER REQUIRED:	2000 lpd (500 gpd) October to March

INSTALLATION

The PV modules are mounted on a passively controlled tracking structure and tilted at 55° for maximum winter performance. Sunlight resistant USE wire is used to interconnect the modules. A switch box was attached to the pole and the linear current booster was installed in the box. The pump was attached to 2-inch plastic pipe and installed in the 3-inch bore hole. A float switch was installed near the top of the holding tank and the control cables are protected from damage by conduit. The system was grounded to the well casing using a short length of No. 6 stranded copper wire.

WATER PUMPING WORKSHEET #1 WP

CALCULATE THE WATER PUMPING LOAD

NOTE: THE UNITS FOR WATER VOLUME AND HEAD ARE LITERS AND METERS RESPECTIVELY.

1P Source Capacity (L/HR)	2P Water Required per Day (L/DAY)	3P Pumping Time Factor D	4P Peak Sun (HRS/DAY)	5P Pumping Rate (L/HR)
Large	2000	÷ 1.2	÷ 4.4*	= 379

6P Static Level (M)	7P Drawdown Level (M)	8P Static Lift (M)	9P Discharge Head (M)	10P Static Head (M)	11P Allowance For Friction (DECIMAL) D	12P Static Head (M) 10P	13P Total Dynamic Head (M)
10	+ 6	+ 1	+ 0	= 17	x 0.03	+ 17	= 17.5

14P Water Required per Day (L/DAY) 2P	15P Total Dynamic Head (M) 13P	16P Conversion Factor	17P Hydraulic Energy (WH/DAY)	18P Pump System Efficiency (DECIMAL)	19P Array Energy (WH/DAY)	20P Nominal System Voltage (V) D	21P Amp-Hour Load (AH/DAY)
2000	x 17.5	÷ **367**	= 95	÷ 0.25	= 380	÷ 12	= 31.7

WATER PUMP AND MOTOR INFORMATION	
Make/Model	Solarjack SDS-D-224
Pump Type	Diaphragm
Motor Type	1/10 hp DC
Input Voltage (AC/DC)	12V DC
Optimum Current (A)	2.7
Pumping Subsystem Efficiency	0.25

22P Amp-Hour Load (AH/DAY) 21P	23P Wire Loss Factor (DECIMAL) D	24P Battery Efficiency Factor (DECIMAL) D	25P Corrected Amp-Hour Load (AH/DAY)
31.7	÷ 0.99	÷ 1.0	= 32.0

NOTE: IF THE WATER PUMPING SYSTEM HAS NO BATTERY ENTER 1.0 IN BLOCK 24.

DESIGN NOTES:

Critical load-cattle must have about 500 gallons per day in winter.

Will use a passive tracker and a linear current booster to track peak power.

*From local source

WORKSHEET #2 DESIGN CURRENT AND ARRAY TILT

21					
System Location	near Potter, NE	Latitude	40° 30′ N	Longitude	103° 30′ W
Insolation Location	North Platte, NE	Latitude	40° 30′ N	Longitude	~ 101° W

MONTH	Tilt at Latitude -15°					Tilt at Latitude					Tilt at Latitude +15°				
	22A Corrected Load (AH/DAY) 20		23A Peak Sun (HRS/DAY)		24A Design Current (A)	22B Corrected Load (AH/DAY) 20		23B Peak Sun (HRS/DAY)		24B Design Current (A)	22C Corrected Load (AH/DAY) 20		23C Peak Sun (HRS/DAY)		24C Design Current (A)
J		÷		=			÷		=		35.6	÷	4.8	=	7.4
F		÷		=			÷		=		35.6	÷	5.7	=	6.2
M		÷		=			÷		=			÷		=	
A		÷		=			÷		=			÷		=	
M		÷		=			÷		=			÷		=	
J		÷		=			÷		=			÷		=	
J		÷		=			÷		=			÷		=	
A		÷		=			÷		=			÷		=	
S		÷		=			÷		=			÷		=	
O		÷		=			÷		=			÷		=	
N		÷		=			÷		=		35.6	÷	4.69	=	7.6
D		÷		=			÷		=		35.6	÷	4.4	=	8.1

Select the largest design current and corresponding peak sun from each latitude and enter below

Latitude -15°	
25A Peak Sun (HRS/DAY)	26A Design Current (A)

Latitude	
25B Peak Sun (HRS/DAY)	26B Design Current (A)

Latitude +15°	
25C Peak Sun (HRS/DAY)	26C Design Current (A)
4.4	8.1

Now select the smallest design current and corresponding peak sun

27 Peak Sun (HRS/DAY		28 Design Current (A)
4.4		8.1
Tilt Angle	=	~55°

NOTE: DO NOT MIX TRACKING AND FIXED ARRAY DATA ON THE SAME SHEET.

DESIGN NOTES:

Wintertime load dictates latitude +15°.

Use 1-axis tracking data.

Direct Pump no batteries used.

WORKSHEET #4 CALCULATE SYSTEM ARRAY SIZE

DESIGN NOTES:

46 Design Current (A) 28		47 Module Derate Factor (DECIMAL) D		48 Derated Design Current (A)		49 Rated Module Current (A) D		50 Modules in Parallel
8.1	÷	0.9	=	9	÷	3	=	3

		51 Nominal Battery Voltage 37		52 Batteries in Series 38		53 Voltage Required for Load (V)		54 Highest Temperature Module Voltage (V)		55 Modules in Series		56 Modules in Parallel 50		57 Total Modules
1.20	x	12	x	–		–	÷	13	=	1	x	3	=	3

NOTE: USE MODULE MANUFACTURER'S SPECIFICATION IN PV MODULE INFORMATION BLOCK.

58 Modules in Parallel 50		59 Rated Module Current (A)		60 Rated Array Current (A)
	x	3.0	=	9.0
		61 Module Short Circuit Current (A)		62 Array Short Circuit Current (A)
	x	3.4	=	10.2

63 Modules in Series 55		64 Rated Module Voltage (V)		65 Array Rated Voltage (V)
	x	15.9	=	15.9
		66 Open Circuit Module Voltage (V)		67 Array Open Circuit Voltage (V)
	x	19.8	=	19.8

PV MODULE INFORMATION

Make/Model	Siemens M75			Nominal Volts	12
Length	48'	Width	13"	Thickness	2"
Weight	11.6 #			Bypass Diode	Y [✓ N]
Voltage (V)	At STC	Open Circuit		At Highest Expected Temperature	
	15.9	19.8		13	
Current (A)	At STC	Short Circuit			
	3.02	3.4			

NOTES: BLOCK 50 - ROUND UP FOR CONSERVATIVE DESIGN.
BLOCK 55 - ROUND UP OR SELECT ANOTHER MODULE WITH SUFFICIENT VOLTAGE TO CHARGE THE BATTERIES WHEN OPERATING AT THE HIGHEST EXPECTED TEMPERATURE$_2$

WATER PUMPING WORKSHEET #2 WP

PUMPED WATER AND PUMPING RATE

26P		27P		28P		29P		30P		31P		32P		33P		34P
Modules in Parallel		Rated Module Current (A)		Nominal System Voltage (V)		Pump System Efficiency (DECIMAL)		Conversion Factor		Peak Sun (HRS/DAY)		Module Derate Factor (DECIMAL)		Total Dynamic Head (M)		Pumped Water (L/DAY)
50		49		20P		18P				4P		47		13P		
3	X	3.0	X	12	X	0.25	X	367	X	4.4	X	0.9	÷	17.5	=	2242

NOTE: MAKE SURE THE PUMPING RATE IN BLOCK 38P IS LESS THAN THE SOURCE CAPACITY IN BLOCK 1P.

35P		36P		37P		38P
Pumped Water (L/DAY)		Pumping Time Factor		Peak Sun (HRS/DAY)		Pumping Rate (L/HR)
34P		3P		4P		
2242	÷	1.2	÷	4.4	=	425

DESIGN NOTES:

CONTROLLER SPECIFICATION

		A1 Array Short Circuit Current (A) 62		A2 Minimum Controller Current (A)		A3 Rated Controller Current) (A)		A4 Controllers in Parallel
1.25	x	10.2	=	13	÷	20	=	1

A5

(CONTROLLER)

Make/Model SunSelector - Bobler LCB-20

Rated Voltage 12 adjustable

Rated Current ____

Features

Temperature Compensation ____

Reverse Current Protection ____

Adjustable Set Points)

High Voltage Disconnect ____

High Voltage Re-connect ____

Low Voltage Disconnect ____

Low Voltage Re-connect ____

Meters

Battery Voltage ____

Array Current ____

Load Current ____

DESIGN NOTES:

Linear current booster between array and pump

SWITCHES & PROTECTION COMPONENTS

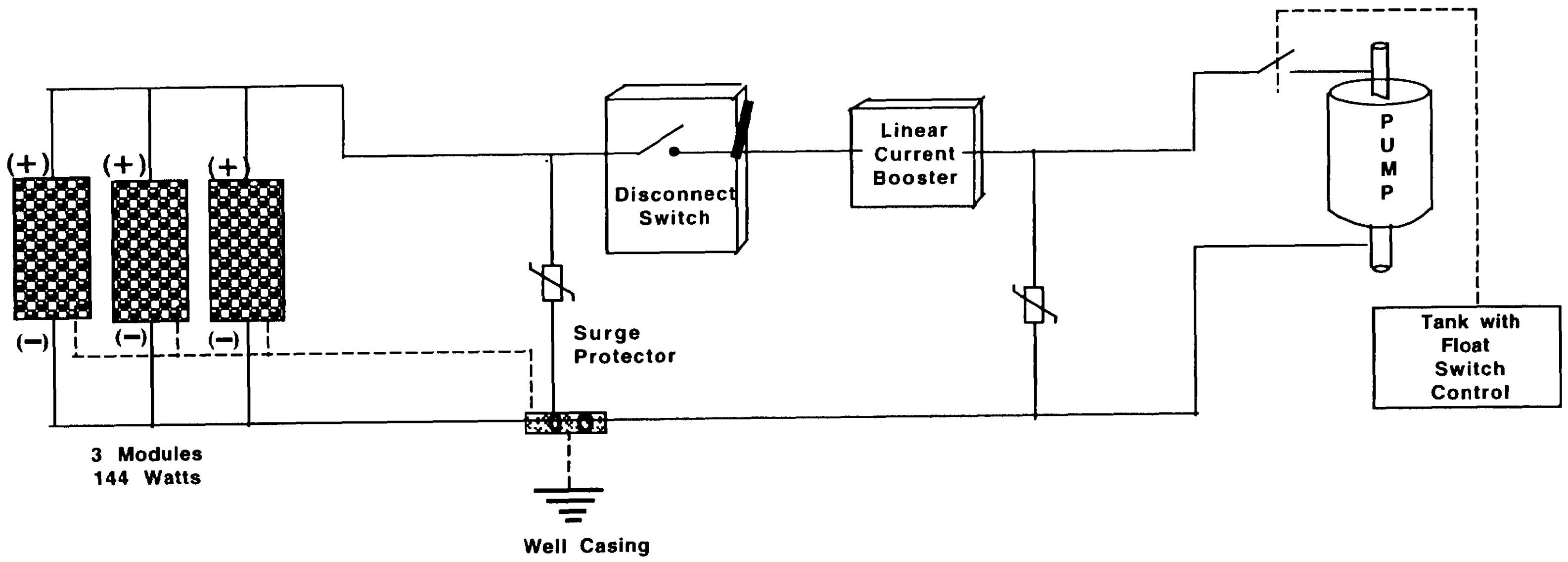
Circuit	Protection Device				Rated Current	Rated Voltage	Description
	Switch	Diode	Fuse	Surge			
D 1 Array Output	✓				15	125	Manual
D 2 Pump	✓				15	125	Float Activated
D 3 Array & Pump				✓			Silicon Oxide Varistors
D 4							
D 5							
D 6							
D 7							
D 8							
D 9							
D 10							
D 11							
D 12							
D 13							
D 14							

DC WIRE SIZING SPECIFICATION

E1 Wire Runs	E2 System Voltage (V)	E3 Maximum Current (A)	E4 One Way Length (FT)	E5 Allowed Voltage Drop (%)	E6 Allowance for Temperature Derate	E7 AWG Number	E8 Wire Type
Array Circuit							
Module to Module	12	3.8	3	2	18%	#12	UF
Array to Controller/ Battery	12	11.2	15	2	18	#8	USE
DC Circuits							
Battery to Battery							
Battery to DC Loads							
Branch Circuits							
A							
B							
C							
D							
E							
Battery Charger to Batteries							
Battery to Inverter Or Converter							

System Grounding	Wire Type	AWG Number	Type of Earth Ground
E9 Equipment Ground	Bare Copper	#8	Well casing
E10 System	Bare Copper	#8	Well casing

DESIGN NOTES:


(+)
(+)
(+)
(−)
(−)
(−)
3 Modules
144 Watts
Surge Protector
Well Casing
Disconnect Switch
Linear Current Booster
P U M P
Tank with Float Switch Control

ECONOMICS ANALYSIS

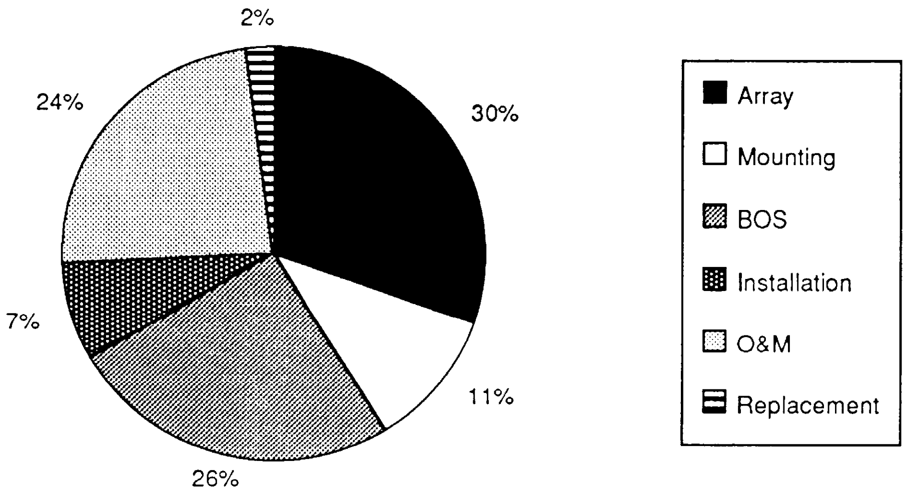
LIFE-CYCLE COST ANALYSIS
POINT DESIGN: DC DIRECT PUMP

Item	Dollar Amount ($)	Present Worth ($)	Percent Total LCC cost (%)
1. CAPITAL COSTS:			
Array	$936	$936	30.7
Mounting & Foundation	350	350	11.5
LCB/BOS Components/Tracker	800	800	26.3
Installation	250	250	8.2
A - SUBTOTAL (Equipment & installation)	2,336	2,336	76.7
2. OPERATION & MAINTENANCE			
B - Annual Inspection	**50**	**744**	**24.4**
3. REPLACEMENT: (YEAR)			
C - LCB 10	**100**	**75**	**2.4**
4. SALVAGE: (YEAR)			
D - 20% of Original 20	**(417)**	**(108)**	**(3.5)**
TOTAL LIFE-CYCLE COST (A + B + C - D)		**$3,047**	**100.0**

ECONOMIC NOTES:

1) Neither the cost of the pump, tank, or any pump/well maintenance are included in the LCC because they are site dependent. However, experience shows these to be major cost items and they should be considered by the owner for his specific application.

COST ELEMENTS AS A PERCENT OF LCC (%)



POINT DESIGN NO. 11

DEEP WELL JACK PUMP

This system is also used for livestock watering but the water level in southern New Mexico is 110 meters or more. A jack pump with a 75-volt dc motor is used. The array is connected to the motor through the maximum power point tracker. The water demand is 2,200 gallons per day in summer and the water is stored in a 15,000 gallon open metal tank on site. A generator can be connected to the motor if a major failure occurs so the system sizing is considered noncritical. The pump stroke is approximately 14 inches at 30 strokes per minute under full sun. A two-pole fused disconnect switch is mounted on the base of the array tracker support post. Summer thundershowers cause much lightning in the area so movistors or varistors are installed from the leads to ground in the disconnect switch box.

KEY DESIGN INFORMATION

APPLICATION:	Stock Watering
SITE:	Near Las Cruces, New Mexico
LOCATION/ELEVATION:	32° 20’ N 106° 40’ W 1670 m
ENVIRONMENT:	High Desert
TEMPERATURE RANGE (°C):	-5 to 45
MAXIMUM WIND SPEED (m/s):	30
AVAILABILITY REQUIRED:	Noncritical
DAYS OF STORAGE:	~ 7 (open tank)
SOURCE:	Cased Borehole 6”
DYNAMIC HEAD (m):	122
WATER REQUIRED (gpd):	2200 June-August

INSTALLATION

The array was mounted on a passive single-axis tracker tilted at 18° to maximize summertime production. The array tracker pedestal foundation was designed to withstand local windloading conditions. The tracker pedestal was located away from the jack pump and wellhead to allow the access needed for pump maintenance. The pump cylinder was 1 7/8 inches and installed in the well on 2 1/4 inch galvanized steel pipe. This allows the leathers to be changed without pulling the pipe and cylinder from the well. A fiberglass sucker rod was used to connect the jack pump to the pump cylinder. Wires from the linear current booster (LCB) to the motor mounted on the jack pump were enclosed in conduit and buried. The array frame and tracker were grounded to the well casing using No. 6 copper wire. The grounding conductor was run outside the conduit in the same trench as the power leads. Each series string of photovoltaic modules has a blocking diode to prevent damage to a failed string. An array safety switch was installed on the jackpump housing within easy reach of the motor. The site was fenced to prevent animal access to the array or jack pump.

WATER PUMPING WORKSHEET #1 WP

CALCULATE THE WATER PUMPING LOAD

NOTE: THE UNITS FOR WATER VOLUME AND HEAD ARE LITERS AND METERS RESPECTIVELY.

1P Source Capacity (L/HR)	2P Water Required per Day (L/DAY)	3P D Pumping Time Factor	4P Peak Sun (HRS/DAY)	5P Pumping Rate (L/HR)
2275	~ 8325	÷ 1.2	÷ 10	= 694

6P Static Level (M)	7P Drawdown Level (M)	8P Static Lift (M)	9P Discharge Head (M)	10P Static Head (M)	11P D Allowance For Friction (DECIMAL)	12P Static Head (M) 10P	13P Total Dynamic Head (M)
106	+ 8	+ 2	+ 0	= 116	x 0.05	+ 116	= 122

14P Water Required per Day (L/DAY) 2P	15P Total Dynamic Head (M) 13P	16P Conversion Factor	17P Hydraulic Energy (WH/DAY)	18P Pump System Efficiency (DECIMAL)	19P Array Energy (WH/DAY)	20P D Nominal System Voltage (V)	21P Amp-Hour Load (AH/DAY)
~ 8325	x 122	÷ 367	= 2747	÷ 0.45	= 6150	÷ 75	= 82.0

WATER PUMP AND MOTOR INFORMATION	
Make/Model	Solar Jack SJA 15-47
Pump Type	(Jack Pump) Volume Displacement
Motor Type	Permanent Magnet
Input Voltage (AC/DC)	75V DC
Optimum Current (A)	6
Pumping Subsystem Efficiency	0.45

22P Amp-Hour Load (AH/DAY) 21P	23P D Wire Loss Factor (DECIMAL)	24P D Battery Efficiency Factor (DECIMAL)	25P Corrected Amp-Hour Load (AH/DAY)
82.0	÷ 0.98	÷ 1.0	= 83.7

NOTE: IF THE WATER PUMPING SYSTEM HAS NO BATTERY ENTER 1.0 IN BLOCK 24.

DESIGN NOTES:

Peak Sun Hours are estimated from El Paso insolation data.

Nominal System Voltage is set by recommended motor input voltage.

JACK PUMP

WORKSHEET #2 DESIGN CURRENT AND ARRAY TILT

21					
System Location	Near Las Cruces, NM	Latitude	32° N	Longitude	106° 3' W
Insolation Location	El Paso, TX	Latitude	31° 8' N	Longitude	107° 7' W

MONTH	Tilt at Latitude -15°			Tilt at Latitude			Tilt at Latitude +15°		
	22A Corrected Load (AH/DAY) 20	23A Peak Sun (HRS/DAY)	24A Design Current (A)	22B Corrected Load (AH/DAY) 20	23B Peak Sun (HRS/DAY)	24B Design Current (A)	22C Corrected Load (AH/DAY) 20	23C Peak Sun (HRS/DAY)	24C Design Current (A)
J		÷	=		÷	=		÷	=
F		÷	=		÷	=		÷	=
M		÷	=		÷	=		÷	=
A		÷	=		÷	=		÷	=
M		÷	=		÷	=		÷	=
J	83.7	÷ 11.51	= 7.3	83.7	÷ 11.06	= 7.6	83.7	÷ 10.36	= 8.1
J	83.7	÷ 10.58	= 7.9	83.7	÷ 10.23	= 8.2	83.7	÷ 9.61	= 8.7
A	83.7	÷ 10.02	= 8.4	83.7	÷ 9.89	= 8.5	83.7	÷ 9.48	= 8.9
S		÷	=		÷	=		÷	=
O		÷	=		÷	=		÷	=
N		÷	=		÷	=		÷	=
D		÷	=		÷	=		÷	=

Select the largest design current and corresponding peak sun from each latitude and enter below

Latitude -15°	
25A Peak Sun (HRS/DAY)	26A Design Current (A)
10.02	8.4

Latitude	
25B Peak Sun (HRS/DAY)	26B Design Current (A)
9.89	8.5

Latitude +15°	
25C Peak Sun (HRS/DAY)	26C Design Current (A)
9.48	8.9

Now select the smallest design current and corresponding peak sun

27 Peak Sun (HRS/DAY	28 Design Current (A)
10.02	8.4
Tilt Angle =	17

NOTE: DO NOT MIX TRACKING AND FIXED ARRAY DATA ON THE SAME SHEET.

DESIGN NOTES:

A summer maximum of 8300 L/Day is required. August is found to be the design month.

1-axis Tracking data used.

WORKSHEET #4 CALCULATE SYSTEM ARRAY SIZE

46 Design Current (A) 28		47 Module Derate Factor (DECIMAL) D		48 Derated Design Current (A)		49 Rated Module Current (A) D		50 Modules in Parallel
8.4	÷	0.9	=	9.3	÷	3.1	=	3

		51 Nominal Battery Voltage 37		52 Batteries in Series 38	53 Voltage Required for Load (V)		54 Highest Temperature Module Voltage (V)		55 Modules in Series		56 Modules in Parallel 50		57 Total Modules
1.20	x	—	x	—	75	÷	15.5	=	5	x	3	=	15

NOTE: USE MANUFACTURER'S SPECIFICATIONS TO FILL IN PV MODULE INFORMATION BLOCK.

PV MODULE INFORMATION

Make/Model	Siemens M55			Nominal Volts	12
Length	51	Width	13	Thickness	2
Weight	13 lbs.			Bypass Diode	[✓ Y] N

Voltage (V)	At STC	Open Circuit	At Highest Expected Temperature
	17.4	21.7	15.5
Current (A)	At STC	Short Circuit	
	3.1	3.5	

NOTES: BLOCK 50 - ROUND UP FOR CONSERVATIVE DESIGN.

BLOCK 55 - ROUND UP OR SELECT ANOTHER MODULE WITH SUFFICIENT VOLTAGE TO CHARGE THE BATTERIES WHEN OPERATING AT THE HIGHEST EXPECTED TEMPERATURE.

58 Modules in Parallel 50		59 Rated Module Current (A)		60 Rated Array Current (A)
	x	3.1	=	9.3
		61 Module Short Circuit Current (A)		62 Array Short Circuit Current (A)
	x	3.5	=	10.5

63 Modules in Series 55		64 Rated Module Voltage (V)		65 Array Rated Voltage (V)
	x	17.4	=	87
		66 Open Circuit Module Voltage (V)		67 Array Open Circuit Voltage (V)
	x	21.7	=	108.5

DESIGN NOTES:

No battery subsystem for this direct-drive application.

Therefore, worksheet #3 is not used.

Module voltage operates near maximum because of peak power tracker.

JACK PUMP

WATER PUMPING WORKSHEET #2 WP

PUMPED WATER AND PUMPING RATE

26P	27P	28P	29P	30P	31P	32P	33P	34P
Modules in Parallel	**Rated Module Current (A)**	**Nominal System Voltage (V)**	**Pump System Efficiency (DECIMAL)**	**Conversion Factor**	**Peak Sun (HRS/DAY)**	**Module Derate Factor (DECIMAL)**	**Total Dynamic Head (M)**	**Pumped Water (L/DAY)**
50	49	20P	18P		4P	46	13P	
3	x 3.1	x 75	x 0.45	x **367**	x 10.0	x 0.9	÷ 122	= 8498

NOTE: MAKE SURE PUMPING RATE, BLOCK 38P, IS LESS THAN THE SOURCE CAPACITY, BLOCK 1P.

35P	36P	37P	38P
Pumped Water (L/DAY)	**Pumping Time Factor**	**Peak Sun (HRS/DAY)**	**Pumping Rate (L/HR)**
34P	3P	4P	
8498	÷ 1.2	÷ 10.0	= 708

DESIGN NOTES:

Pumping rate does not exceed source capacity.

CONTROLLER SPECIFICATION

DESIGN NOTES:

		A1 Array Short Circuit Current (A) 62		A2 Minimum Controller Current (A)		A3 Rated Controller Current) (A)		A4 Controllers in Parallel
1.25	X	10.5	=	13	÷	13	=	1

A5

(CONTROLLER)

Make/Model Bobier LCB-6HV Linear Current Booster

Rated Voltage 75 V adjustable

Rated Current ______

Features

Temperature Compensation ______

Reverse Current Protection ______

Adjustable Set Points)

High Voltage Disconnect ______

High Voltage Re-connect ______

Low Voltage Disconnect ______

Low Voltage Re-connect ______

Maximum Power Tracking ✓

Meters

Battery Voltage ______

Array Current ______

Load Current ______

PROTECTION COMPONENTS SPECIFICATION

Protected Circuit		Protection Device				Rated Current	Rated Voltage	Description
		Switch	Diode	Fuse	Movistor			
D1	Array output	✓				20amp	250V	DC switch
D2	LCB input				✓			Surge Protection
D3								
D4								
D5								
D6								
D7								
D8								
D9								
D10								
D11								
D12								
D13								
D14								

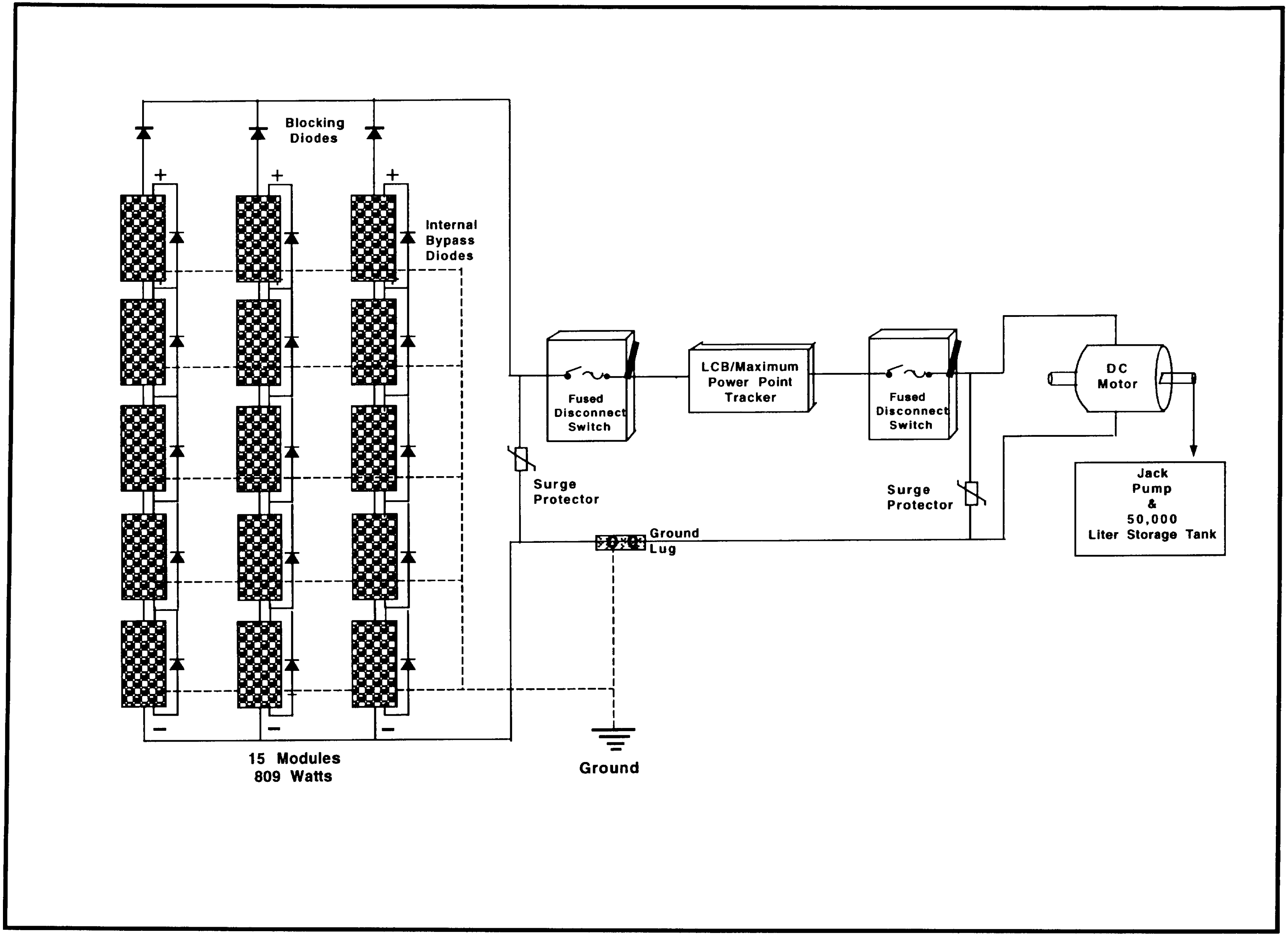
No fuses used because motor can withstand maximum array short circuit current.

DC WIRE SIZING SPECIFICATION

E1 Wire Runs	E2 System Voltage (V)	E3 Maximum Current (A)	E4 One Way Length (FT)	E5 Allowed Voltage Drop (%)	E6 Allowance for Temperature Derate	E7 AWG Number	E8 Wire Type
Array Circuit							
Module to Module	75	4	2	0	0	12	THHN
Array to Controller or Battery	75	12	8	2%	0	10	THHN
DC Circuits							
Battery to Battery							
Battery or Controller to DC Loads	75	12	25	2%	18%	6	THHN
Branch Circuits							
A							
B							
C							
D							
E							
Battery Charger to Batteries							
Battery to Inverter Or Converter							

System Grounding	Wire Type	AWG Number	Type of Earth Ground
E9 **Equipment Ground**	Bare Copper	6	Well Casing
E10 **System Ground**	Bare Copper	6	Well Casing

DESIGN NOTES:


Blocking Diodes
+
+
+
Internal Bypass Diodes
−
−
−
15 Modules
809 Watts
Fused Disconnect Switch
LCB/Maximum Power Point Tracker
Fused Disconnect Switch
DC Motor
Jack Pump & 50,000 Liter Storage Tank
Surge Protector
Surge Protector
Ground Lug
Ground

ECONOMICS ANALYSIS

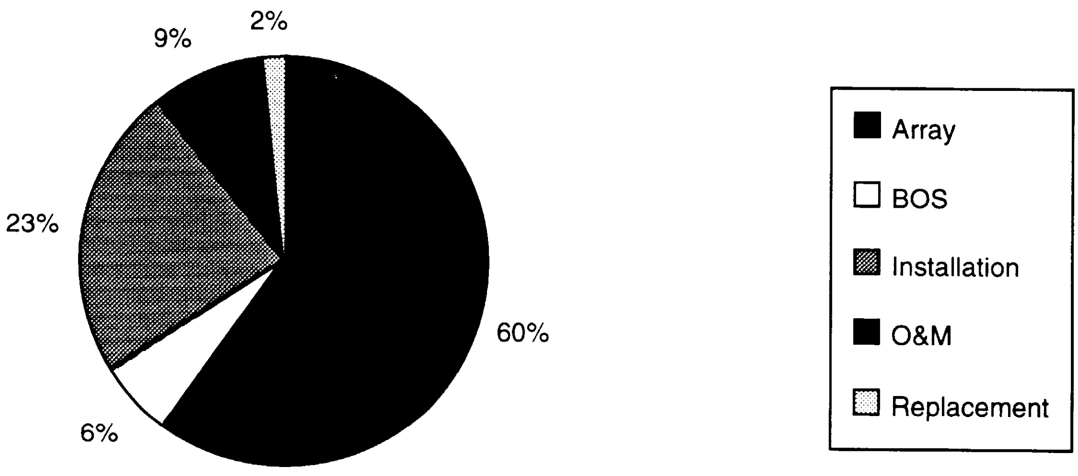
LIFE-CYCLE COST ANALYSIS
POINT DESIGN: DEEP WELL JACK PUMP

Item	Dollar Amount ($)	Present Worth ($)	Percent Total LCC cost (%)
1. CAPITAL COSTS:			
Array	$5,260	$5,260	63.5
BOS Hardware	500	500	6.0
Installation + Mounting Hardware	2,000	2,000	24.2
A - SUBTOTAL (Equipment & Installation)	**7,760**	**7,760**	**93.7**
2. OPERATION & MAINTENANCE			
B - Annual Inspection	**50**	**744**	**9.0**
3. REPLACEMENT: (YEAR)			
C - Control Unit 10	**200**	**149**	**1.8**
4. SALVAGE: (YEAR)			
D - 20% of Original 20	**(1452)**	**(375)**	**(4.5)**
TOTAL LIFE-CYCLE COST (A + B + C - D)		**$8,278**	**100.0**

ECONOMIC NOTES:

1) The cost of the pump, tank, and pump/well maintenance are not included in the LCC because they are site dependent. However, experience shows these to be major cost items and they should be considered by the owner for his specific application.

COST ELEMENTS AS A PERCENT OF LCC (%)



POINT DESIGN NO. 12

AC SUBMERSIBLE PUMP

A village on the island of Antigua requires 5,000 gallons per day of water for domestic use. The available well has an adequate water supply but many maintenance problems have occurred with the gasoline generator being used to drive the ac submersible pump. A direct-coupled pumping system was designed to replace the generator and a new pump with a 1,500 watt constant-voltage three-phase inverter as part of the pumping package was installed. The stainless steel multistage submersible pump system came with a three-phase 1.5-hp induction motor, system switch box, and heavy-duty submersible pump cable. The control electronics remain above ground for easy access.

KEY DESIGN INFORMATION

APPLICATION:	Community Water Supply
SITE:	Bendals, Antigua, West Indies
LOCATION/ELEVATION:	17°N 61°5’W 0m
ENVIRONMENT:	Tropical Island
TEMPERATURE RANGE (°C):	15 to 35
MAXIMUM WIND SPEED (m/s):	40
AVAILABILITY REQUIRED:	Critical
DAYS OF STORAGE:	N/A
SOURCE:	Cased Borehole 6”
DYNAMIC HEAD (m):	47
WATER REQUIRED (gpd):	~ 5000 (yearly average)

INSTALLATION

The tropical environment and proximity to the ocean were major considerations in the specification of the hardware. The tracking array support structure was made of corrosion resistant steel with anodized aluminum module frames and stainless steel hardware. Hurricane ties were placed on the tracker frame to stabilize it during tropical storms. The tracker pedestals were designed for storm conditions. The inverter and disconnect switch were mounted in an enclosure on the array tracker support post and strain relief connections and drip loops were used to prevent moisture penetration into the box. The pump was attached to 2-inch galvanized steel pipe and installed in the 6-inch borehole. The power cables were secured to the drop pipe to prevent them from abrading on the casing as the pump was lowered into the well. The submersible pump cable was run in conduit between the junction box at the array and the wellhead. The conduit was sized to accommodate three No. 6 wires with insulation jacket. A sanitary well seal was placed on the well casing to seal the drop pipe and conduit entries and prevent water contamination of the well.

WATER PUMPING WORKSHEET #1 WP

CALCULATE THE WATER PUMPING LOAD

NOTE: THE UNITS FOR WATER VOLUME AND HEAD ARE LITERS AND METERS RESPECTIVELY.

1P Source Capacity (L/HR)	2P Water Required per Day (L/DAY)		3P Pumping Time Factor D		4P Peak Sun (HRS/DAY)		5P Pumping Rate (L/HR)
5700	19,000	÷	1.2	÷	8*	=	1979

6P Static Level (M)		7P Drawdown Level (M)		8P Static Lift (M)		9P Discharge Head (M)		10P Static Head (M)		11P Allowance For Friction (DECIMAL) D		12P Static Head (M) 10P		13P Total Dynamic Head (M)
3	+	3	+	39	+	0	=	45	x	0.05	+	45	=	47

14P Water Required per Day (L/DAY) 2P		15P Total Dynamic Head (M) 13P		16P Conversion Factor		17P Hydraulic Energy (WH/DAY)		18P Pump System Efficiency (DECIMAL)		19P Array Energy (WH/DAY)		20P Nominal System Voltage (V) D		21P Amp-Hour Load (AH/DAY)
19,000	x	47	÷	367	=	2433	÷	0.3	=	8110	÷	105	=	77.2

WATER PUMP AND MOTOR INFORMATION	
Make/Model	Grundfos 1.5 hp
Pump Type	Multistage Submersible
Motor Type	Induction
Input Voltage (AC/DC)	105 Vdc
Optimum Current (A)	9
Pumping Subsystem Efficiency	0.3

22P Amp-Hour Load (AH/DAY) 21P		23P Wire Loss Factor (DECIMAL) D		24P Battery Efficiency Factor (DECIMAL) D		25P Corrected Amp-Hour Load (AH/DAY)
77.2	÷	1.0	÷	1.0	=	77.2

NOTE: IF THE WATER PUMPING SYSTEM HAS NO BATTERY ENTER 1.0 IN BLOCK 24.

DESIGN NOTES:

* with tracker

WORKSHEET #2 DESIGN CURRENT AND ARRAY TILT

21 System Location	Bendals, Antigua	Latitude	17° N	Longitude	61°5' W
Insolation Location	St. Johns, Antigua	Latitude		Longitude	

	Tilt at Latitude -15°			Tilt at Latitude			Tilt at Latitude +15°		
MONTH	22A Corrected Load (AH/DAY) 20	23A Peak Sun (HRS/DAY)	24A Design Current (A)	22B Corrected Load (AH/DAY) 20	23B Peak Sun (HRS/DAY)	24B Design Current (A)	22C Corrected Load (AH/DAY) 20	23C Peak Sun (HRS/DAY)	24C Design Current (A)
J		÷	=		÷	=		÷	=
F		÷	=		÷	=		÷	=
M		÷	=		÷	=		÷	=
A		÷	=		÷	=		÷	=
M		÷	=		÷	=		÷	=
J		÷	=	77.2	÷ 8.0	= 9.7		÷	=
J		÷	=		÷	=		÷	=
A		÷	=		÷	=		÷	=
S		÷	=		÷	=		÷	=
O		÷	=		÷	=		÷	=
N		÷	=		÷	=		÷	=
D		÷	=		÷	=		÷	=

Select the largest design current and corresponding peak sun from each latitude and enter below

Latitude -15°		Latitude		Latitude +15°	
25A Peak Sun (HRS/DAY)	26A Design Current (A)	25B Peak Sun (HRS/DAY)	26B Design Current (A)	25C Peak Sun (HRS/DAY)	26C Design Current (A)
N/A	N/A	8.0	9.7	N/A	N/A

Now select the smallest design current and corresponding peak sun

27 Peak Sun (HRS/DAY	28 Design Current (A)
8.0	9.7
Tilt Angle =	17°

NOTE: DO NOT MIX TRACKING AND FIXED ARRAY DATA ON THE SAME SHEET.

DESIGN NOTES:

Year round insolation average of 8 KWH/day for tracking array is used here.

A summer high of 25,800 litres per day (~6000 gallons per day) will be obtained when insolation reaches 10 KWH/day. This does not exceed source capacity.

Tilt selection at latitude optimizes yearly insolation.

WORKSHEET #4 CALCULATE SYSTEM ARRAY SIZE

46 Design Current (A) 28		47 Module Derate Factor (DECIMAL) D		48 Derated Design Current (A)		49 Rated Module Current (A) D		50 Modules in Parallel
9.7	÷	0.9	=	10.8	÷	3.6	=	3

		51 Nominal Battery Voltage 37		52 Batteries in Series 38	53 Voltage Required for Load (V)		54 Highest Temperature Module Voltage (V)		55 Modules in Series		56 Modules in Parallel 50		57 Total Modules
1.20	x		x		105	÷	15.4	=	7	x	3	=	21

58 Modules in Parallel 50		59 Rated Module Current (A)		60 Rated Array Current (A)
	x	3.6	=	10.8
		61 Module Short Circuit Current (A)		62 Array Short Circuit Current (A)
	x	3.9	=	11.7

63 Modules in Series 55		64 Rated Module Voltage (V)		65 Array Rated Voltage (V)
	x	17.5	=	105
		66 Open Circuit Module Voltage (V)		67 Array Open Circuit Voltage (V)
	x	21.4	=	128

NOTE: USE MANUFACTURER'S SPECIFICATIONS TO FILL IN PV MODULE INFORMATION BLOCK.

PV MODULE INFORMATION

Make/Model	Solarex MSX-64			Nominal Volts	12
Length	44	Width	20	Thickness	2
Weight	16 lbs.			Bypass Diode	[✓ Y] N
Voltage (V)	At STC	Open Circuit		At Highest Expected Temperature	
	17.5	21.4		15.4	
Current (A)	At STC	Short Circuit			
	3.6	3.9			

NOTES: BLOCK 50 - ROUND UP FOR CONSERVATIVE DESIGN.
BLOCK 55 - ROUND UP OR SELECT ANOTHER MODULE WITH SUFFICIENT VOLTAGE TO CHARGE THE BATTERIES WHEN OPERATING AT THE HIGHEST EXPECTED TEMPERATURE.

DESIGN NOTES:

No battery subsystem is used.

105 V DC recommended by pump manufacturer for input voltage.

Hybrid design not feasible.

WATER PUMPING WORKSHEET #2 WP

PUMPED WATER AND PUMPING RATE

26P Modules In Parallel 50		27P Rated Module Current (A) 49		28P Nominal System Voltage (V) 20P		29P Pump System Efficiency (DECIMAL) 18P		30P Conversion Factor		31P Peak Sun (HRS/DAY) 4P		32P Module Derate Factor (DECIMAL) 46		33P Total Dynamic Head (M) 13P		34P Pumped Water (L/DAY)
3	x	3.6	x	105	x	0.3	x	367	x	8.0	x	0.9	÷	47	=	19,126

NOTE: MAKE SURE THE PUMPING RATE IN BLOCK 38P IS LESS THAN THE SOURCE CAPACITY IN BLOCK 1P.

35P Pumped Water (L/DAY) 34P		36P Pumping Time Factor 3P		37P Peak Sun (HRS/DAY) 4P		38P Pumping Rate (L/HR)
19,126	÷	1.2	÷	8.0	=	~2000

DESIGN NOTES:

Pumping rate
does not
exceed source
capacity.

POWER CONDITIONING UNITS SPECIFICATION

Inverter

System Requirements

B1 Wave Form *N/A**

B2 DC System Voltage ______ (V)

B3 AC System Voltage ______ (V)

B4 Surge Capacity ______ (W)

B5 Total AC Watts ______ (W)

B6 Maximum Single AC Load ______ (W)

B7 Maximum Simultaneous AC Load ______ (W)

B8 Inverter Run Time at Maximum Simultaneous Load ______ (MIN)

B9 Inverter Continuous Duty Rating ______ (W)

B10 Required Inverter Efficiency at Load ______ (%)

B11 Inverter Specifications

Make *Grundfos*

Model *1500-5*

Wave Form *Modified Square*

Input Voltage (DC) *105* (V)

Output Voltage (AC) *105* (V)

Surge Capacity ______ (W)

FEATURES:

- Battery Charging ( )
- Voltmeter ( )
- Remote Control ( )
- Generator Start ( )
- Transfer Switch ( )
- Maximum Power Tracking (✓)

DESIGN NOTES:

* DC to AC inverter integrated with pump.

Converter

System Requirements

C1 Input DC Voltage ____ to ____ (V)

C2 Output DC Voltage ____ to ____ (V)

C3 Output Power ____ (W)

C4 Operating Temperature ____ to ____ (C°)

C5 Converter

Make ______

Model ______

Input Voltage ______ (V)

Output Voltage ______ (V)

Output Current ______ (A)

Operating Temperature ______ (C°)

FEATURES:

Adjustable Output Voltage ______ (V)

PROTECTION COMPONENTS SPECIFICATION

Protected Circuit	Protection Device				Rated Current	Rated Voltage	Description
	Switch	Diode	Fuse	Movistor			
D1 Array output	✓		✓				Fused Disconnect
D2 Controller to load	✓						*
D3							
D4							
D5							
D6							
D7							
D8							
D9							
D10							
D11							
D12							
D13							
D14							

* Input and output switches are included in switch box provided with pump system.

DC WIRE SIZING SPECIFICATION

E1 Wire Runs	E2 System Voltage (V)	E3 Maximum Current (A)	E4 One Way Length (FT)	E5 Allowed Voltage Drop (%)	E6 Allowance for Temperature Derate	E7 AWG Number	E8 Wire Type
Array Circuit							
Module to Module	105	3.6	3	0	0	12	USE
Array to Controller or Battery	105	14.6	75	3%	18%	10	USE
DC Circuits							
Battery to Battery							
Battery or Controller to DC Loads							
Branch Circuits							
A							
B							
C							
D							
E							
Battery Charger to Batteries							
Battery to Inverter Or Converter							

System Grounding	Wire Type	AWG Number	Type of Earth Ground
E9 **Equipment Ground**	Bare Copper	8	Well Casing
E10 **System Ground**	Bare Copper	8	Well Casing

DESIGN NOTES:

120 V DC wire size table used to determine necessary wire size.

AC WIRE SIZING SPECIFICATION

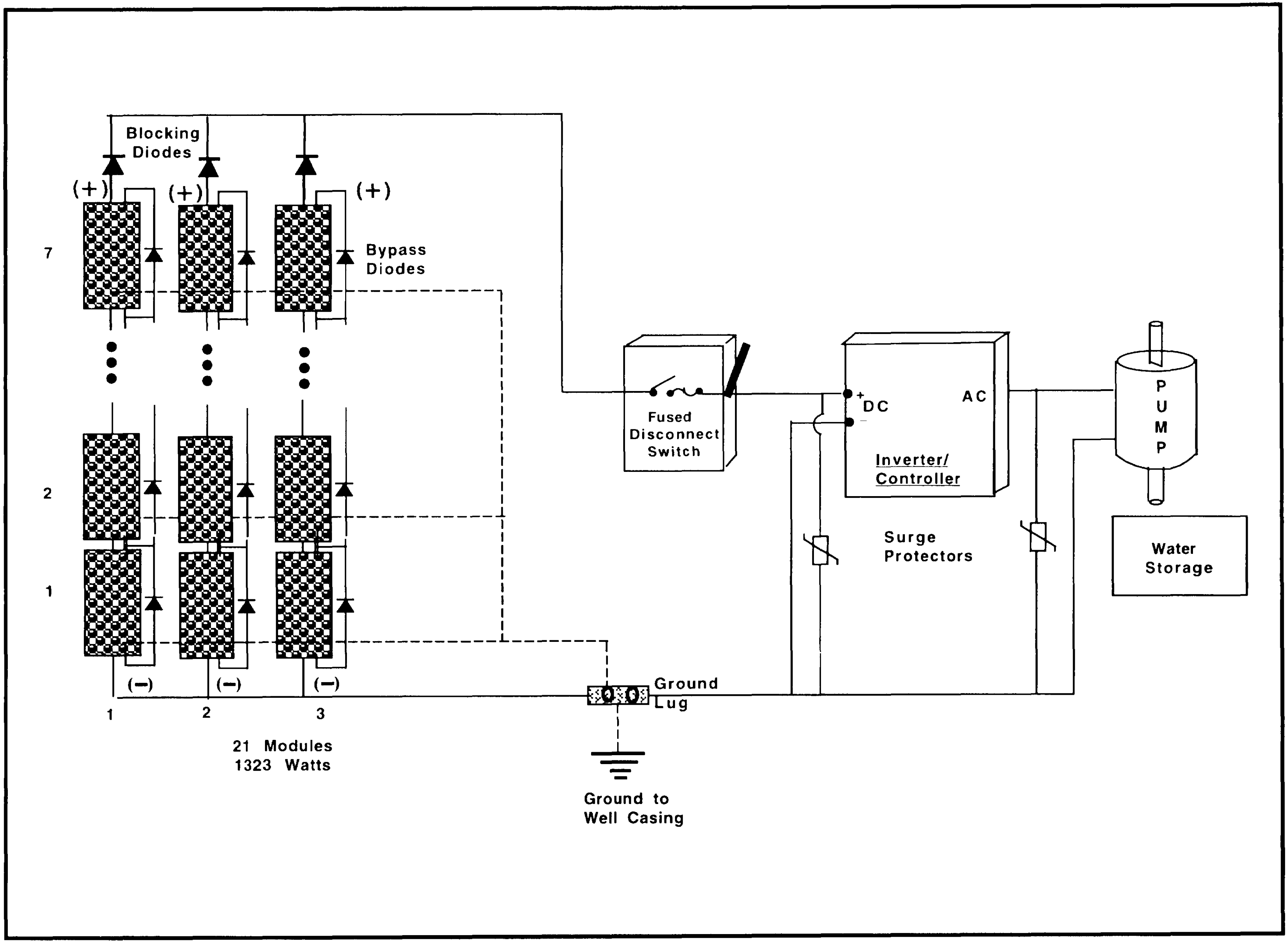
Wire Sizing And Specification (DC Side)

F1 Wire Runs	F2 System Voltage (V)	F3 Maximum Current (A)	F4 One Way Length (FT)	F5 Allowed Voltage Drop (%)	F6 Allowance for Temperature Derate	F7 AWG Number	F8 Wire Type
AC Circuits							
Inverter to AC Loads (Pump)	105	10	150	2.5%		8	*
Branch Circuits							
A							
B							
C							
D							
E							
F							
G							
Generator							
Generator to Battery Charger	N/A						
Generator to AC Load Center	N/A						

System Grounding	Wire Type	AWG Number	Type of Earth Ground
F9 Equipment Ground	Bare Copper	8	Well Casing
F10 System Ground	Bare Copper	8	Well Casing

DESIGN NOTES:

* Submersible pump cable supplied by pump dealer.


Blocking
Diodes
(+)
(+)
(+)
7
Bypass
Diodes
2
1
(−)
(−)
(−)
1
2
3
21 Modules
1323 Watts
Fused
Disconnect
Switch
+
DC
−
AC
Inverter/
Controller
P
U
M
P
Surge
Protectors
Water
Storage
Ground
Lug
Ground to
Well Casing

ECONOMICS ANALYSIS

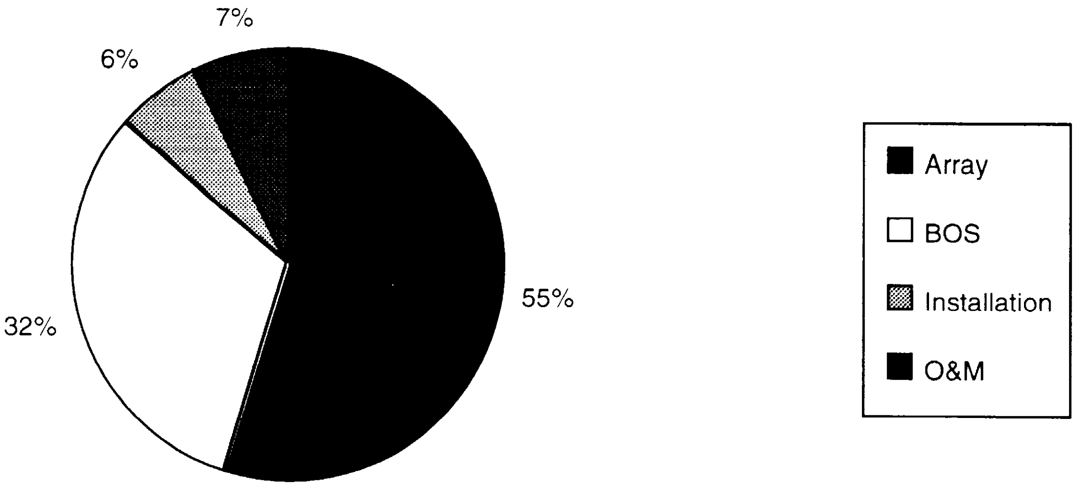
LIFE-CYCLE COST ANALYSIS
POINT DESIGN: AC SUBMERSIBLE PUMP

Item	Dollar Amount ($)	Present Worth ($)	Percent Total LCC cost (%)
1. CAPITAL COSTS:			
Array	$8,600	$8,600	57.7
BOS (Trackers + Hardware)	4,940	4,940	33.1
Installation	1,000	1,000	6.7
A - SUBTOTAL (Equip. & Installation)	**14,540**	**14,540**	**97.5**
2. OPERATION & MAINTENANCE			
B - Annual Inspection	**75**	**1,116**	**7.5**
3. REPLACEMENT: (YEAR)			
C - Power system should last for 20 years or more		**N/A**	
4. SALVAGE: (YEAR)			
D - 20% of Original 20	**(2908)**	**(750)**	**(5.0)**
TOTAL LIFE-CYCLE COST (A + B + C - D)		**$14,906**	**100.0**

ECONOMIC NOTES:

1) The pump, motor, inverter, and control switches are part of the pump system obtained from the dealer.
2) Neither the cost of the pump or any pump/well maintenance are included in the LCC because they are site dependent. However, experience shows these to be major cost items and they should be considered by the owner for his specific application.

COST ELEMENTS AS A PERCENT OF LCC (%)



POINT DESIGN NO. 13

SHALLOW WELL PUMP

This small pumping system was installed to provide domestic water for residents in a village in Bolivia. Water was pumped to a set of six 2,000 liter storage tanks located on a hill above the village. The water was then gravity fed to a faucet centrally located in the village. Because the replenishment rate of the source was low, it was decided to incorporate batteries into the system and allow pumping 24 hours a day. The pumping rate was decreased accordingly.

KEY DESIGN INFORMATION

SITE: Achacachi, Bolivia
LOCATION /ELEVATION: 17° 5' N 68° W 3903 m
ENVIRONMENT: La Paz, Bolivia
TEMPERATURE RANGE (°C): -12 to 30
MAXIMUM WIND SPEED (m/s): 75
AVAILABILITY REQUIRED: Noncritical
DAYS OF STORAGE: N/A
SOURCE: Cased Borehole 6"
DYNAMIC HEAD (m): 20
WATER REQUIRED (gpd): ~ 2000 (yearly average)

INSTALLATION

A fixed array was specified and ground mounted on concrete piers near the wellhead. The batteries were placed in a fiberglass box and buried near the well. A disconnect switch for the array was installed in a weatherproof enclosure on the back of the array support structure. The conductors between the array and the battery and wellhead were enclosed in conduit. The array was grounded to the well casing and the bare copper ground cable was buried in the same trench as the conduit. A sanitary well seal was used to cover the top of the well casing. The power conductors from the battery to the pump entered the well casing through a conduit connector attached to the well seal. The pump conductors were securely fastened to the drop pipe as it was lowered into the well. A safety rope was attached to the pump to prevent its loss if it became disengaged from the drop pipe during or after installation. The drop pipe was secured with an adaptor that allows the water to exit the well casing below ground level. This helps to protect the water delivery pipes against freezing.

WATER PUMPING WORKSHEET #1 WP

CALCULATE THE WATER PUMPING LOAD

NOTE: THE UNITS FOR WATER VOLUME AND HEAD ARE LITERS AND METERS RESPECTIVELY.

1P Source Capacity (L/HR)	2P Water Required per Day (L/DAY)	3P D Pumping Time Factor	4P Peak Sun (HRS/DAY)	5P Pumping Rate (L/HR)
~ 500	7500	÷ 3.2	÷ 5.7	= 411

6P Static Level (M)	7P Drawdown Level (M)	8P Static Lift (M)	9P Discharge Head (M)	10P Static Head (M)	11P D Allowance For Friction (DECIMAL)	12P Static Head (M) 10P	13P Total Dynamic Head (M)
2	+ 2	+ 15	+ 0	= 19	x 0.07	+ 19	= 20.3

14P Water Required per Day (L/DAY) 2P	15P Total Dynamic Head (M) 13P	16P Conversion Factor	17P Hydraulic Energy (WH/DAY)	18P Pump System Efficiency (DECIMAL)	19P Array Energy (WH/DAY)	20P D Nominal System Voltage (V)	21P Amp-Hour Load (AH/DAY)
7500	x 20.3	÷ **367**	= 415	÷ 0.4	= 1037	÷ 24	= 43.2

WATER PUMP AND MOTOR INFORMATION	
Make/Model	Flowlite Slow Pump
Pump Type	Diaphram
Motor Type	1/2 hp DC
Input Voltage (AC/DC)	24V DC
Optimum Current (A)	8.4A
Pumping Subsystem Efficiency	0.4

22P Amp-Hour Load (AH/DAY) 21P	23P D Wire Loss Factor (DECIMAL)	24P D Battery Efficiency Factor (DECIMAL)	25P Corrected Amp-Hour Load (AH/DAY)
43.2	÷ 0.99	÷ 0.85	= 51.4

NOTE: IF THE WATER PUMPING SYSTEM HAS NO BATTERY ENTER 1.0 IN BLOCK 24.

DESIGN NOTES:

Source capacity won't furnish required water unless pump time is over 15 hours/day. Batteries used to extend pumping time to 18 hours/day.

Determine peak sun hours for worst case month using worksheet #2.

Pump efficiency estimated at 40% for this head and flow rate.

WORKSHEET #2 DESIGN CURRENT AND ARRAY TILT

21	System Location	Achacachi, Bolivia	Latitude	17°5'S	Longitude	68°W
	Insolation Location	La Paz, Bolivia	Latitude	17°S	Longitude	68°W

MONTH	Tilt at Latitude -15°			Tilt at Latitude			Tilt at Latitude +15°		
	22A Corrected Load (AH/DAY) 20	23A Peak Sun (HRS/DAY)	24A Design Current (A)	22B Corrected Load (AH/DAY) 20	23B Peak Sun (HRS/DAY)	24B Design Current (A)	22C Corrected Load (AH/DAY) 20	23C Peak Sun (HRS/DAY)	24C Design Current (A)
J		÷	=		÷	=	51.4	÷ 5.93	= 8.7
F		÷	=		÷	=	51.4	÷ 5.84	= 8.8
M		÷	=		÷	=	51.4	÷ 5.87	= 8.8
A		÷	=		÷	=	51.4	÷ 7.28	= 7.1
M		÷	=		÷	=	51.4	÷ 5.80	= 8.9
J		÷	=		÷	=	51.4	÷ 5.71	= 9.0
J		÷	=		÷	=	51.4	÷ 5.95	= 8.6
A		÷	=		÷	=	51.4	÷ 5.80	= 8.9
S		÷	=		÷	=	51.4	÷ 6.13	= 8.4
O		÷	=		÷	=	51.4	÷ 6.06	= 8.5
N		÷	=		÷	=	51.4	÷ 6.05	= 8.5
D		÷	=		÷	=	51.4	÷ 5.81	= 8.8

Select the largest design current and corresponding peak sun from each latitude and enter below

Latitude -15°		Latitude		Latitude +15°	
25A Peak Sun (HRS/DAY)	26A Design Current (A)	25B Peak Sun (HRS/DAY)	26B Design Current (A)	25C Peak Sun (HRS/DAY)	26C Design Current (A)
				5.7	9.0

Now select the smallest design current and corresponding peak sun

27 Peak Sun (HRS/DAY	28 Design Current (A)
5.7	9.0
Tilt Angle =	~30°

NOTE: DO NOT MIX TRACKING AND FIXED ARRAY DATA ON THE SAME SHEET.

DESIGN NOTES:

June is the least insolation design month, as June is mid-winter in the southern hemisphere.

Since load is assumed constant, latitude +15° will maximize the design current during winter.

WORKSHEET #3 CALCULATE SYSTEM BATTERY SIZE

29 Corrected Amp-Hour Load (AH/DAY) 20		30 Storage Days D		31 Maximum Depth of Discharge (DECIMAL) D		32 Derate for Temperature (DECIMAL) D		33 Required Battery Capacity (AH)		34 Capacity of Selected Battery (AH)		35 Batteries in Parallel
51.4	X	3	÷	0.9	÷	0.9	=	190	÷	240	=	1

NOTE: BLOCK 35. ROUND UP FOR CONSERVATIVE DESIGN.

36 Nominal System Voltage (V) 9		37 Nominal Battery Voltage (V)		38 Batteries in Series		39 Batteries in Parallel 35		40 Total ~~Batteries~~ Cells
24	÷	1.2V/cell	=	20	X	1	=	20

BATTERY INFORMATION	
Make	SAB-NIFE
Model	240
Type	NiCad
Nominal Voltage (V)	1.2
Rated Capacity (AH)	240

41 Batteries in Parallel 35		42 Capacity of Selected Battery (AH) 34		43 System Battery Capacity (AH)		44 Maximum Depth of Discharge (DECIMAL) 31		45 Usable Battery Capacity (AH)
1	X	240	=	240	X	0.9	=	216

NOTE: USE MANUFACTURER'S DATA TO FILL IN BATTERY INFORMATION BLOCK

DESIGN NOTES:

WORKSHEET #4 CALCULATE SYSTEM ARRAY SIZE

46 Design Current (A) 28		47 Module Derate Factor (DECIMAL) D		48 Derated Design Current (A)		49 Rated Module Current (A) D		50 Modules in Parallel
9.0	÷	0.95	=	9.5	÷	3.0	=	3

		51 Nominal Battery Voltage 37		52 Batteries in Series 38	53 Voltage Required for Load (V)		54 Highest Temperature Module Voltage (V)		55 Modules in Series		56 Modules in Parallel 50		57 Total Modules
1.20	x	12	x	2	28.8	÷	15	=	2	x	3	=	6

NOTE: USE MANUFACTURER'S SPECIFICATIONS TO FILL IN PV MODULE INFORMATION BLOCK.

58 Modules in Parallel 50		59 Rated Module Current (A)		60 Rated Array Current (A)
	x	3	=	9
		61 Module Short Circuit Current (A)		62 Array Short Circuit Current (A)
	x	3.3	=	9.9

PV MODULE INFORMATION				
Make/Model	Solec S-50		**Nominal Volts**	12
Length	51	**Width** 13	**Thickness**	1.5
Weight	12.5 lbs.		**Bypass Diode**	Y [✓ N]
Voltage (V)	**At STC**	**Open Circuit**	**At Highest Expected Temperature**	
	16.6	20.3	15	
Current (A)	**At STC**	**Short Circuit**		
	3.0	3.3		

63 Modules in Series 55		64 Rated Module Voltage (V)		65 Array Rated Voltage (V)
	x	16.6	=	33.2
		66 Open Circuit Module Voltage (V)		67 Array Open Circuit Voltage (V)
	x	20.3	=	40.6

NOTES: BLOCK 50 - ROUND UP FOR CONSERVATIVE DESIGN.
BLOCK 55 - ROUND UP OR SELECT ANOTHER MODULE WITH SUFFICIENT VOLTAGE TO CHARGE THE BATTERIES WHEN OPERATING AT THE HIGHEST EXPECTED TEMPERATURE.

DESIGN NOTES:

Module derate of 0.95 used because the high elevation is a good environment for PV arrays.

WATER PUMPING WORKSHEET #2 WP

PUMPED WATER AND PUMPING RATE

26P Modules In Parallel 50	27P Rated Module Current (A) 49	28P Nominal System Voltage (V) 20P	29P Pump System Efficiency (DECIMAL) 18P	30P Conversion Factor	31P Peak Sun (HRS/DAY) 4P	32P Module Derate Factor (DECIMAL) 46	33P Total Dynamic Head (M) 13P	34P Pumped Water (L/DAY)
3	x 3.0	x 24	x 0.4	x **367**	x 5.7	x 0.95	÷ 20.3	= 8458

NOTE: MAKE SURE THE PUMPING RATE IN BLOCK 38P IS LESS THAN THE SOURCE CAPACITY IN BLOCK 1P.

35P Pumped Water (L/DAY) 34P	36P Pumping Time Factor 3P	37P Peak Sun (HRS/DAY) 4P	38P Pumping Rate (L/HR)
8458	÷ 3.0	÷ 5.7	= 495

DESIGN NOTES:

System should provide all water required by pumping 16-18 hours/day. Storage tanks fitted with level switch to shut off pump if tanks are full.

CONTROLLER SPECIFICATION

		A1 Array Short Circuit Current 62 (A)		A2 Minimum Controller Current (A)		A3 Rated Controller Current) (A)		A4 Controllers in Parallel
1.25	X	9.9	=	12	÷	12	=	1

A5

(CONTROLLER)

Make/Model Specialty Concepts ASC-24/12

Rated Voltage 24

Rated Current ____

Features

Temperature Compensation ____

Reverse Current Protection ✓

Adjustable Set Points)

High Voltage Disconnect ____

High Voltage Re-connect ____

Low Voltage Disconnect ____

Low Voltage Re-connect ____

Meters

Battery Voltage ____

Array Current indicator ✓

Load Current ____

DESIGN NOTES:

PROTECTION COMPONENTS SPECIFICATION

	Protected Circuit	Protection Device				Rated Current	Rated Voltage	Description
		Switch	Diode	Fuse	Movistor			
D1	Array output	✓				20 amp	250 V	DC switch
D2	Controller to load	✓				10 amp	125 V	DC switch
D3	Battery	✓		✓		15 amp	125 V	Fused switch
D4								
D5								
D6								
D7								
D8								
D9								
D10								
D11								
D12								
D13								
D14								

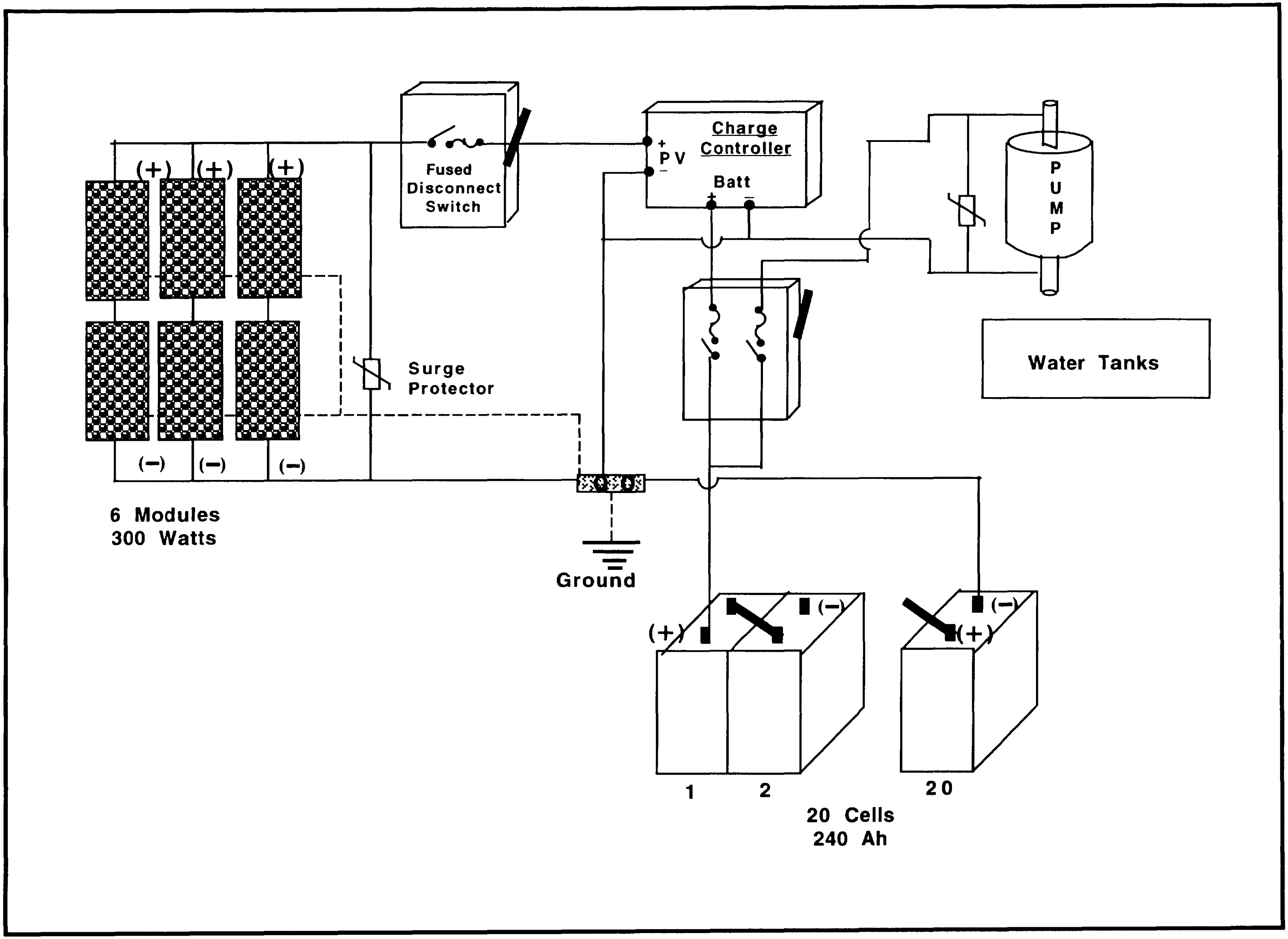
Controller provides reverse current protection.

DC WIRE SIZING SPECIFICATION

E1 Wire Runs	E2 System Voltage (V)	E3 Maximum Current (A)	E4 One Way Length (FT)	E5 Allowed Voltage Drop (%)	E6 Allowance for Temperature Derate	E7 AWG Number	E8 Wire Type
Array Circuit							
Module to Module							
Array to Controller or Battery	24	9	100	2.5%	—	6	USE in conduit
DC Circuits							
Battery to Battery							
Battery or Controller to DC Loads	24	4	60	3%	—	8	USE
Branch Circuits							
A	N/A						
B							
C							
D							
E							
Battery Charger to Batteries	N/A						
Battery to Inverter Or Converter	N/A						

System Grounding	Wire Type	AWG Number	Type of Earth Ground
E9 Equipment Ground	Bare Copper	8	Ground Rod
E10 System Ground	Bare Copper	8	Ground Rod

DESIGN NOTES:



(+)
(+)
(+)
(−)
(−)
(−)
6 Modules
300 Watts
Fused
Disconnect
Switch
Surge
Protector
+
PV
−
Charge
Controller
Batt
+
−
P
U
M
P
Water Tanks
Ground
(+)
(−)
(−)
(+)
1
2
20
20 Cells
240 Ah

ECONOMICS ANALYSIS

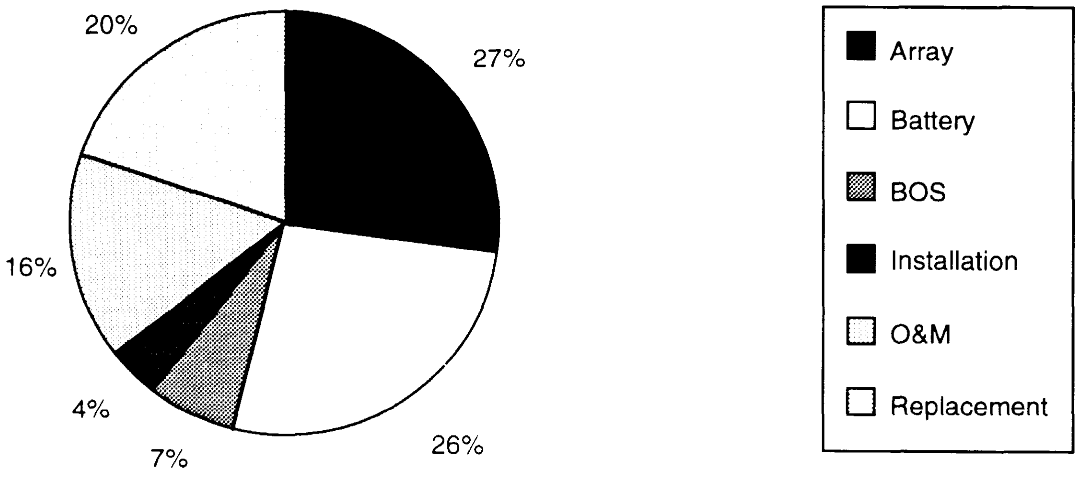
LIFE-CYCLE COST ANALYSIS
POINT DESIGN: SHALLOW WELL PUMP

Item		Dollar Amount ($)	Present Worth ($)	Percent Total LCC cost (%)
1. CAPITAL COSTS:				
Array		$1,950	$1,950	28.0
Battery		1,920	1,920	27.5
BOS + Hardware		550	550	6.9
Installation		250	250	3.6
A - SUBTOTAL (Equipment & Installation)		**4,670**	**4,670**	**67.0**
2. OPERATION & MAINTENANCE				
B - Annual Inspection		**75**	**1,116**	**16.0**
3. REPLACEMENT:	(YEAR)			
Battery	12	1,920	1,346	19.3
Controller	10	96	71	1.0
C - SUBTOTAL (Replacement)		**2,016**	**1,417**	**20.3**
4. SALVAGE:	(YEAR)			
D - 20% of Original	20	**(884)**	**(228)**	**(3.3)**
TOTAL LIFE-CYCLE COST (A + B + C - D)			**$6,975**	**100.0**

ECONOMIC NOTES:

1) NiCd batteries cost $8/ampere-hour orginally but will have to be replaced only once.
2) The water tanks are not included in the LCC because they would be necessary regardless of the pump power system installed.

COST ELEMENTS AS A PERCENT OF LCC (%)



REMOTE MONITORING STATIONS

Remote instrumentation and data communications equipment require reliable power to prevent interruption or loss of data. Photovoltaic power supplies are ideal for this application because the power requirements are usually low and many units are installed far from conventional power sources. Because of the reliability and simplicity of the PV power supply, these systems are even replacing ac powered units in areas served by utility companies. Systems should be placed in areas where potential shading and the vulnerability to vandalism are low. Antenna location is also a consideration if data transmission via radio frequency link is required. PV arrays are usually small and often mounted on a pole. The module frames should be grounded and a lightning rod may be required. Many data acquisition systems are susceptible to voltage surges which will cause loss of data–movistors should be considered.

APPLICATIONS

- Climate Monitoring
- Highway Conditions
- Structural Conditions
- Insect Trapping
- Seismic Recording
- Scientific Research
- Auto-Dial Alarms

LOAD

Almost all stand-alone PV powered monitoring systems operate at 12 volts dc. The load will vary with the number of sensors, sample rate, and data recording and transmittal requirements. If data transmission is not required, the load is usually quite small, sometimes only milliamperes per day and a battery will sometimes provide several weeks of backup.

ARRAY

Most monitor applications require only one PV module. Many systems use nonglass modules that are resistant to vandalism. All wiring should be tied to the array frame.

BATTERIES

Some data recorders include rechargeable nickel cadmium or lead acid gelled electrolyte batteries. Check the instrumentation specifications for allowable charging currents and operating voltage. The data acquisition equipment and batteries can be located in the same weather-resistant enclosure if sealed batteries are used. Burying the equipment box is sometimes done for protection and concealment.

CONTROL

Battery charge control may not be necessary if the load demand and array design current are less than one ampere. Some data recorders have a built-in charge regulator that may be large enough to control an external battery.

MOUNTING

The PV array is often pole mounted with the DAS and sensor package attached near the top of the pole before installation. If metal poles are used, they provided a good ground for the system. If the array is ground mounted, it should be protected from animals. The array should be installed in a protected location and securely anchored to prevent theft. Consider vegetation growth, possible shading, and snow coverage.

POINT DESIGN NO. 14

PIPELINE STATUS MONITOR

There are thousands of miles of pipelines carrying oil and gas to consumers across the United States. Measuring flowrate, pressure, and other parameters at stations along the pipeline provide an important indicator of status and a warning of impending problems. This system is an example of hundreds of PV powered system control and data acquisition (SCADA) units now installed. This system monitors and transmits status information to a local field office. Each station transmits information on a set schedule or each may be queried for current status.

KEY DESIGN INFORMATION

APPLICATION:	Pipeline Monitor
SITE:	Near Hugoton, Kansas
LOCATION/ELEVATION:	37.1° N 101.5° W 1000 m
ENVIRONMENT:	Rural
TEMPERATURE RANGE (°C):	-20 to 40
MAXIMUM WIND SPEED (m/s):	25
AVAILABILITY REQUIRED:	Noncritical
LOAD PROFILES:	Constant

INSTALLATION

The single PV module was mounted on pipes near the monitoring equipment. The pipes were anchored on concrete bases. The module was approximately 10 feet above the ground but there were no trees that would shade the module. The module was tilted at about 55° to maximize energy production in winter months. The battery was located in a locked box at ground level. A nickel-cadmium battery was used because the load was small and long-life under harsh conditions were important design criteria. The power wires were enclosed in conduit between the module and battery box. The transmitting antenna was located above the module where 360° field of view was available. No controller was used.

WORKSHEET #1 CALCULATE THE LOADS (FOR EACH MONTH OR SEASON AS REQUIRED)

DESIGN NOTES:

1 Load Description	2 QTY		3 Load Current (A)		4 Load Voltage (V)		5A DC Load Power (W)	5B AC Load Power (W)		6 Daily Duty Cycle (HRS/DAY)		7 Weekly Duty Cycle (DAYS/WK)		8 Power Conversion Efficiency (DECIMAL) D		9 Nominal System Voltage (V)		10 Amp-Hour Load (AH/DAY)
Datalogger DC	1	X	0.04	X	12	=	0.48	N/A	X	24	X	7 ÷7	÷	1.0	÷	12	=	0.96
Transmitter DC	1	X	1.0	X	12	=	12	N/A	X	0.7	X	7 ÷7	÷	1.0	÷	12	=	0.70
DC		X		X		=		N/A	X		X	÷7	÷		÷		=	
DC		X		X		=		N/A	X		X	÷7	÷		÷		=	
AC		X		X			N/A	=	X		X	÷7	÷		÷		=	
AC		X		X			N/A	=	X		X	÷7	÷		÷		=	
AC		X		X			N/A	=	X		X	÷7	÷		÷		=	
AC		X		X			N/A	=	X		X	÷7	÷		÷		=	
11 Total Load Power (W)				DC 11A			12.5	AC 11B					12 Total Amp-Hour Load (AH/DAY)					1.7

13 Total DC Load Power (W) 11A		14 Total AC Load Power (W) 11B		15 Nominal System Voltage (V) 9		16 Peak Current Draw (A)	17 Total Amp-Hour Load (AH/DAY) 12		18 Wire Efficiency Factor (DECIMAL) D		19 Battery Efficiency Factor (DECIMAL) D		20 Corrected Amp-Hour Load (AH/DAY)
12.5	+		÷	12	=	1.04	1.7	÷	0.99	÷	0.85	=	2.0

WORKSHEET #2 DESIGN CURRENT AND ARRAY TILT

21					
System Location	Hugoton, Kansas	Latitude	37.1° N	Longitude	101.5° W
Insolation Location	Oklahoma City	Latitude	35° N	Longitude	97.6° W

MONTH	Tilt at Latitude -15°			Tilt at Latitude			Tilt at Latitude +15°		
	22A Corrected Load (AH/DAY) 20	23A Peak Sun (HRS/DAY)	24A Design Current (A)	22B Corrected Load (AH/DAY) 20	23B Peak Sun (HRS/DAY)	24B Design Current (A)	22C Corrected Load (AH/DAY) 20	23C Peak Sun (HRS/DAY)	24C Design Current (A)
J		÷	=		÷	=		÷	=
F		÷	=		÷	=		÷	=
M		÷	=		÷	=		÷	=
A		÷	=		÷	=		÷	=
M		÷	=		÷	=		÷	=
J		÷	=		÷	=		÷	=
J		÷	=		÷	=		÷	=
A		÷	=		÷	=		÷	=
S		÷	=		÷	=		÷	=
O		÷	=		÷	=		÷	=
N		÷	=		÷	=		÷	=
D		÷	=		÷	=	2.0	÷ 3.94	= 0.51

Select the largest design current and corresponding peak sun from each latitude and enter below

Latitude -15°	
25A Peak Sun (HRS/DAY)	26A Design Current (A)

Latitude	
25B Peak Sun (HRS/DAY)	26B Design Current (A)

Latitude +15°	
25C Peak Sun (HRS/DAY)	26C Design Current (A)
3.94	0.51

Now select the smallest design current and corresponding peak sun

27 Peak Sun (HRS/DAY	28 Design Current (A)
3.94	0.51
Tilt Angle =	~55°

NOTE: DO NOT MIX TRACKING AND FIXED ARRAY DATA ON THE SAME SHEET.

DESIGN NOTES:

Latitude + 15° used to maximize winter energy production

December is lowest solar month

WORKSHEET #3 CALCULATE SYSTEM BATTERY SIZE

29 Corrected Amp-Hour Load (AH/DAY) 20		30 Storage Days D		31 Maximum Depth of Discharge (DECIMAL) D		32 Derate for Temperature (DECIMAL) D		33 Required Battery Capacity (AH)		34 Capacity of Selected Battery (AH)		35 Batteries in Parallel
2.0	X	5	÷	0.95	÷	1.0	=	10.5	÷	10	=	1

NOTE: BLOCK 35. ROUND UP FOR CONSERVATIVE DESIGN

36 Nominal System Voltage (V) 9		37 Nominal Battery Voltage (V)		38 Batteries in Series		39 Batteries in Parallel 35		40 Total Batteries
12	÷	1.2	=	10	X	1	=	10

BATTERY INFORMATION	
Make	Powersonic
Model	Electronics Battery
Type	NiCd
Nominal Voltage (V)	1.2
Rated Capacity (AH)	10

41 Batteries in Parallel 35		42 Capacity of Selected Battery (AH) 34		43 System Battery Capacity (AH)		44 Maximum Depth of Discharge (DECIMAL) 31		45 Usable Battery Capacity (AH)
1	X	10	=	10	X	0.95	=	9.5

NOTE: USE MANUFACTURER'S DATA TO FILL IN BATTERY INFORMATION BLOCK

DESIGN NOTES:

NiCd Battery Pack purchased from local electronics supplier – 10 NiCd cells in one package.

WORKSHEET #4 CALCULATE SYSTEM ARRAY SIZE

46 Design Current (A) 28		47 Module Derate Factor (DECIMAL) D		48 Derated Design Current (A)		49 Rated Module Current (A) D		50 Modules in Parallel
0.51	÷	0.9	=	0.57	÷	0.75	=	1

		51 Nominal Battery Voltage 37		52 Batteries in Series 38		53 Voltage Required for Load (V)		54 Highest Temperature Module Voltage (V)		55 Modules in Series		56 Modules in Parallel 50		57 Total Modules
1.20	x	1.2	x	10		12	÷	14	=	1	x	1	=	1

58 Modules in Parallel 50		59 Rated Module Current (A)		60 Rated Array Current (A)
	x	0.75	=	0.75
		61 Module Short Circuit Current (A)		62 Array Short Circuit Current (A)
	x	0.78	=	0.78

63 Modules in Series 55		64 Rated Module Voltage (V)		65 Array Rated Voltage (V)
	x	14.7	=	14.7
		66 Open Circuit Module Voltage (V)		67 Array Open Circuit Voltage (V)
	x	18.8	=	18.8

NOTE: USE MANUFACTURER'S DATA TO FILL IN PV MODULE INFORMATION BLOCK.

PV MODULE INFORMATION

Make/Model	Duravolt DV12		Nominal Volts	12
Length	15.1"	Width 14.1"	Thickness	1.5"
Weight	3.8 lbs		Bypass Diode	Y [✓ N]
Voltage (V)	At STC	Open Circuit	At Highest Expected Temperature	
	14.7	18.8	14	
Current (A)	At STC	Short Circuit		
	0.75	0.78		

NOTES: BLOCK 50 - ROUND UP FOR CONSERVATIVE DESIGN.
BLOCK 55 - ROUND UP OR SELECT ANOTHER MODULE WITH SUFFICIENT VOLTAGE TO CHARGE THE BATTERIES WHEN OPERATING AT THE HIGHEST EXPECTED TEMPERATURE.$_2$

DESIGN NOTES:

Used module with non-glass cover for protection against vandalism

SWITCHES & PROTECTION COMPONENTS

Circuit	Protection Device				Rated Current	Rated Voltage	Description
	Switch	Diode	Fuse	Surge			
D1 Module output		✓			5	25	Blocking diode
D2 Module output				✓		20	silicon oxide
D3 DAS input				✓		20	Varistors
D4							
D5							
D6							
D7							
D8							
D9							
D10							
D11							
D12							
D13							
D14							

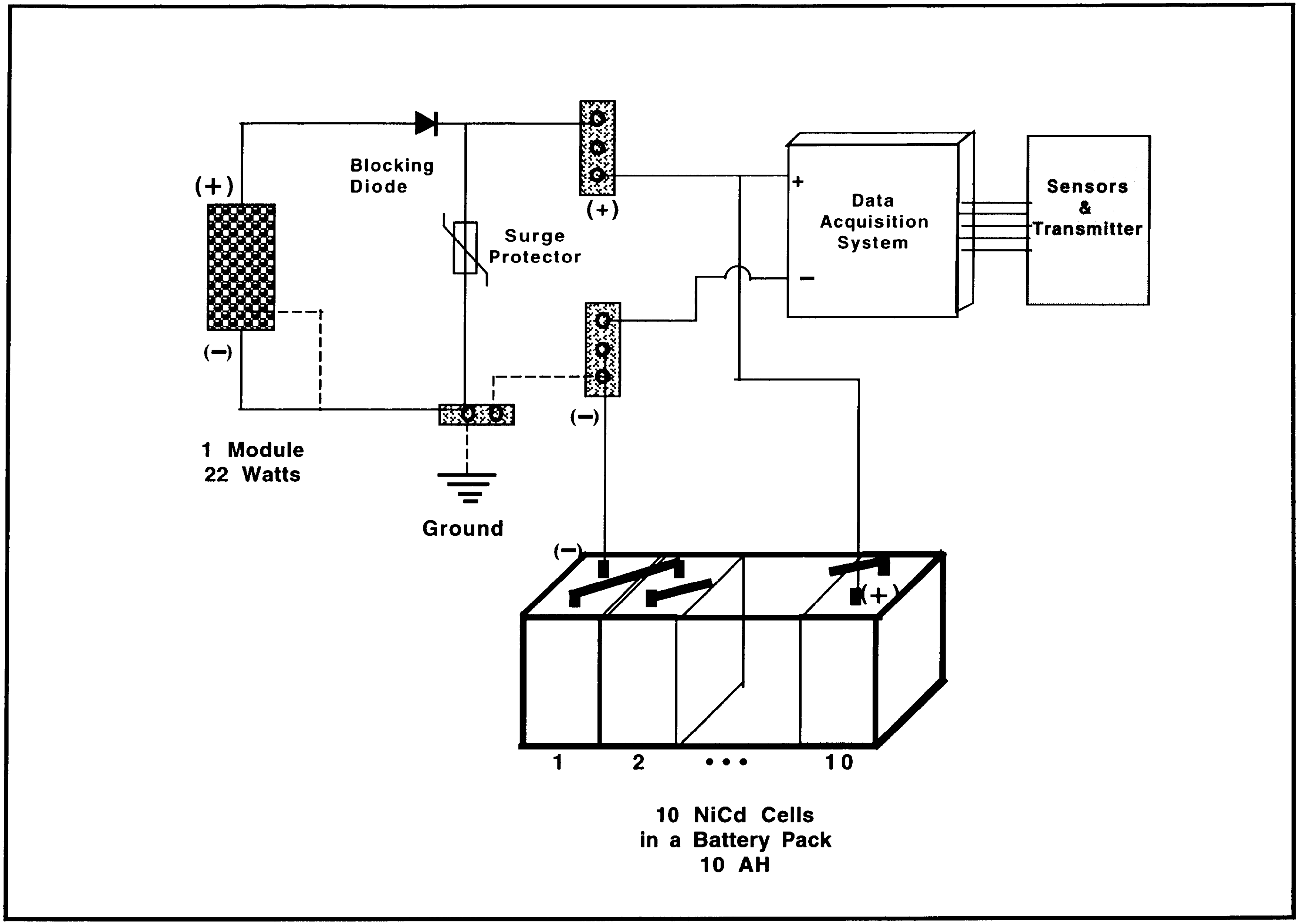
DC WIRE SIZING SPECIFICATION

E1 Wire Runs	E2 System Voltage (V)	E3 Maximum Current (A)	E4 One Way Length (FT)	E5 Allowed Voltage Drop (%)	E6 Allowance for Temperature Derate	E7 AWG Number	E8 Wire Type
Array Circuit							
Module to Module							
Array to Controller/ Battery	12	1.5	15	1%	—	14	THHN
DC Circuits							
Battery to Battery							
Battery to DC Loads	12	1.0	5	1%		14	THHN
Branch Circuits							
A							
B							
C							
D							
E							
Battery Charger to Batteries							
Battery to Inverter Or Converter							

System Grounding	Wire Type	AWG Number	Type of Earth Ground
E9 Equipment Ground	Bare Copper	10	Rod
E10 System	Bare Copper	10	Rod

DESIGN NOTES:

All wire in conduit


Blocking Diode
(+)
(−)
Surge Protector
(+)
Data Acquisition System
+
−
Sensors & Transmitter
(−)
1 Module 22 Watts
Ground
(−)
(+)
1
2
• • •
10
10 NiCd Cells in a Battery Pack 10 AH

ECONOMICS ANALYSIS

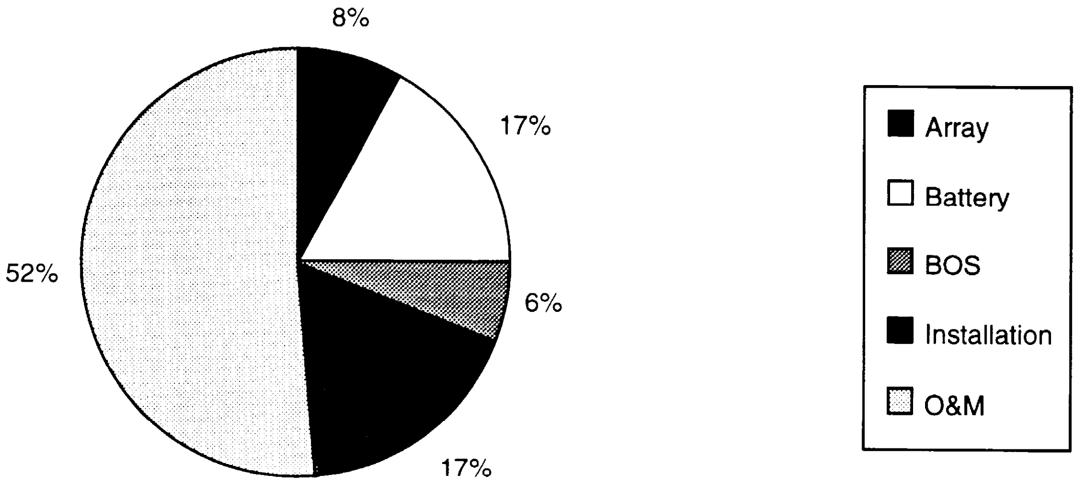
LIFE-CYCLE COST ANALYSIS
POINT DESIGN: PIPELINE STATUS MONITOR

Item	Dollar Amount ($)	Present Worth ($)	Percent Total LCC cost (%)
1. CAPITAL COSTS:			
Array	$120	$120	8.5
Battery	240	240	17.0
BOS	90	90	6.5
Installation	250	250	17.7
A - SUBTOTAL (Equipment & Installation)	**700**	**700**	**49.7**
2. OPERATION & MAINTENANCE			
B - Annual Inspection	**50**	**745**	**52.9**
3. REPLACEMENT: (YEAR)			
C - NONE			
4. SALVAGE: (YEAR)			
D - 20% of Original 20	**(140)**	**(36)**	**(2.6)**
TOTAL LIFE-CYCLE COST (A + B + C - D)		**$1,409**	**100.0**

ECONOMIC NOTES:

1) Capital cost does not include monitoring equipment or transmitter.
2) A nickel cadmium battery pack is used for this low power application for convenience and to eliminate the need for regulation. The cost is $24 per amphour.
3) Smaller modules cost more on a per watt basis.

COST ELEMENTS AS A PERCENT OF LCC (%)



DIRECT-DRIVE APPLICATIONS

Small dedicated loads that have a good correlation between power demand and solar intensity may be connected directly to a PV module. No controller or battery is used. The characteristic of the load dictates the operating point (voltage and current) of the PV module. Many complete packages including PV source and load are now available. Using one of these packages, even if it does not meet the requirements precisely, will probably be less expensive that designing a system to meet a specific load.

APPLICATIONS

- Ventilation Fans
- Portable Radios
- Toys
- Solar Tracking Devices
- Solar Collector Pumps

LOAD/ARRAY

The efficiency of most loads will vary with operating voltage. For maximum efficiency, the load should be operated near the peak power point of the selected module. The current provided to the load will then vary directly with solar irradiance. The load must be able to withstand the full range of PV module voltage and the highest-irradiance-current without being damaged.

BATTERIES

No batteries are used. Some direct-drive systems have product storage. This refers to heat storage or water storage that can be passively discharged after system shutdown.

CONTROL

No controller is required for these simple systems but some designers use a commercially available linear current booster to provide some matching between the module and load. For simple motor loads such as fans, a large capacitor may be used to add some stability to the operating point of the load. Thermostats are sometimes used to control the fan operation on hot air systems. A manual disconnect switch should be used if the operator needs to turn the load on and off frequently.

MOUNTING

The system may be portable and no mounting required. On some sites, the PV module is integrated into the equipment package and mounted as close to the load as possible. Some amorphous silicon modules are being used for these applications because of the low power required. Some of these modules are lightweight and flexible and some can be folded or rolled up for storage.

POINT DESIGN NO. 15

SOLAR COLLECTOR FAN

A ventilation fan was needed for a small washroom in a state park near Carbondale, Colorado. A direct-drive PV powered fan was installed because daytime ventilation would be sufficient. The park service engineers specified a required airflow of 225 cubic feet per minute (cfm) at full sun. A 12-volt dc fan was found that would deliver between 200 and 250 cfm with 1.5 amperes input and the fan manufacturer did not think a current of 2 amperes would damage the motor as long as it occurred only on rare occasions. Also, the fan motor would not be damaged by an open-circuit voltage of 25 volts.

KEY DESIGN INFORMATION

APPLICATION:	Solar Fan
SITE:	Carbondale, Colorado
LOCATION/ELEVATION:	39°2’ N 107° 1’ W 2500 m
ENVIRONMENT:	Mountains
TEMPERATURE RANGE (°C):	-25 to 33
MAXIMUM WIND SPEED (m/s):	40
AVAILABILITY REQUIRED:	Noncritical

INSTALLATION

The photovoltaic module was mounted on a frame attached to the roof of the washroom and in line with the roof angle. The tilt angle of the roof was 30°–near optimum for summertime energy generation. Also, the module was less likely to be noticed when lying in the plane of the roof. A manual cutoff switch was installed in the positive lead. The switch box was mounted high on the wall inside the building where access was limited and it would not be turned off inadvertently. The wiring was run from the module down the roof, through the wall to the switch, then along the ceiling to the fan. Conduit was used for all wire runs.

DIRECT DRIVE WORKSHEET #1DD

MATCH THE ARRAY CURRENT AND LOAD CURRENT

DESIGN NOTES:

1D DEVICE LOAD INFORMATION

Device	Ventilating Fan	▨	**Nominal**	**Maximum**
Model	FC 40-12HE	**Voltage (V)**	12	25
Make	Hartel	**Current (A)**	1.2	2.0

2D Nominal Device Current (A)		3D D Wire Efficiency Factor (DECIMAL)		4D Maximum Design Current (A)		5D D Module Derate Factor (DECIMAL)		6D Design Current (A)		7D Rated Module Current (A)		8D Modules in Parallel
1.2	÷	.99	=	1.2	÷	0.8	=	1.5	÷	1.4	=	1

9D Nominal Device Voltage 1D (V)		10D Nominal Module Voltage 1D (V)		11D Modules in Series		12D Modules in Parallel 8D		13D Total Modules
12	÷	12	=	1	X	1	=	1

		14D Rated Module Current 7D (A)		15D Modules in Parallel 8D		16D Maximum Current (A)
1.25	X	1.4	X	1	=	2.2

PV MODULE INFORMATION

Make/Model	UPM-880		**Nominal Volts**	12
Length	47	**Width** 14	**Thickness**	2
Weight	8 lbs		**Bypass Diode**	Y [✓ N]
Voltage (V)	**At STC**	**Open Circuit**	**At Highest Expected Temperature**	
	15.6	22	15.0	
Current (A)	**At STC**	**Short Circuit**		
	1.4	1.5		

DIRECT DRIVE WIRING AND PROTECTION HARDWARE SPECIFICATION

DESIGN NOTES:

WIRE SIZING AND SPECIFICATION (DC SIDE)

17D Wire Runs	18D System Voltage (V)	19D Maximum Current (A)	20D One Way Length (FT)	21D Allowed Voltage Drop (%)	22D Allowance for Temperature Derate	23D AWG Number	24D Wire Type
Array to Load	12	2.0	15	2%	None	#12	USE Sunlight Resistant

25D ARRAY TO LOAD DISCONNECT

Type DC Switch

Current Rating 10 (A)

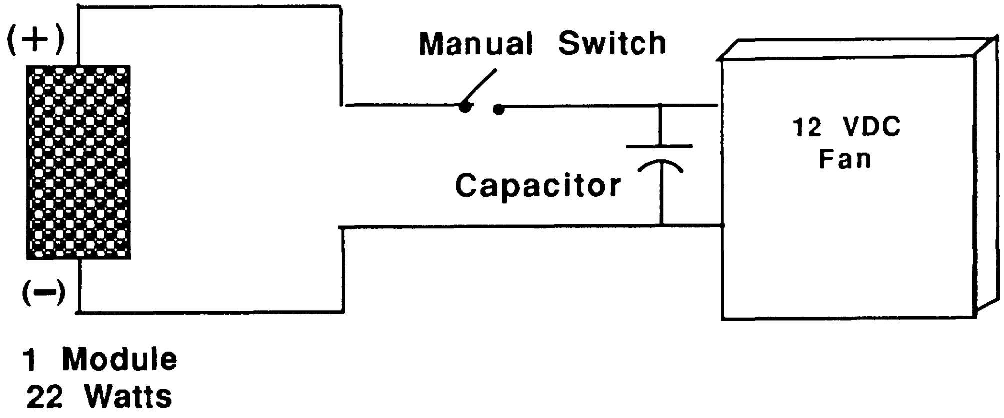
Voltage Rating 125 (V)

26D OVERCURRENT PROTECTION

Type

Current Rating None (A)

Enclosure Type


(+)
(−)
1 Module
22 Watts
Manual Switch
Capacitor
12 VDC
Fan

ECONOMICS ANALYSIS

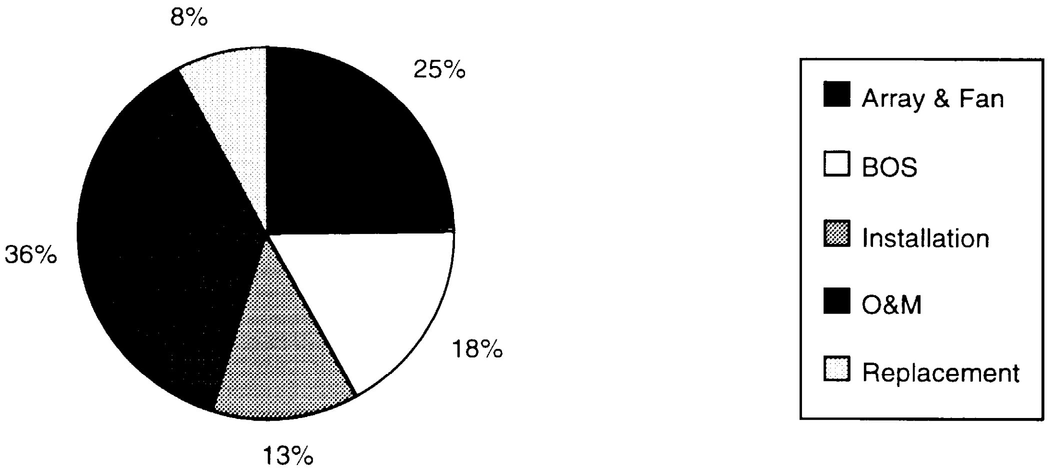
LIFE-CYCLE COST ANALYSIS
POINT DESIGN: DIRECT FAN

Item	Dollar Amount ($)	Present Worth ($)	Percent Total LCC cost (%)
1. CAPITAL COSTS:			
Array	$243	$243	25.1
BOS	175	175	18.1
Installation	125	125	12.9
A - SUBTOTAL (Equipment & Installation)	**543**	**543**	**56.1**
2. OPERATION 8. MAINTENANCE			
B - Annual Inspection	**25**	**372**	**38.4**
3. REPLACEMENT: (YEAR)			
Fan 10	100	75	7.7
4. SALVAGE: (YEAR)			
D - 20% of Original 20	**(84)**	**(22)**	**(2.2)**
TOTAL LIFE-CYCLE COST (A + B + C - D)		**$968**	**100.0**

ECONOMIC NOTES:

1) The fan is included in this LCC analysis because a package system that included PV module, starting circuit, and fan was obtained for a cost of $243.00

COST ELEMENTS AS A PERCENT OF LCC (%)



CATHODIC PROTECTION

Federal regulations in the United States require any underground metal storage tanks holding toxic materials or petrochemicals to have cathodic protection. In addition, there are thousands of miles of pipelines and thousands of well casings that are corrosion protected using cathodic protection. PV systems have been used successfully for this application, particularly in instances where the current requirements are small and there is no ready access to utility power grids. The use of PV for this application will increase as the effectiveness of metal coatings decrease current demand, and as the advantages of PV are better understood by the corrosion protection engineering community. Determining the amount of current required to protect a metal structure is not straightforward and is a challenge for experienced corrosion engineers. The simplified method presented here demonstrates one method of determining the required protection current for a small cathodic protection system. It is not intended as specific guidance for corrosion protection systems. After the amount of current has been determined, PV sizing is similar to that of other applications.

APPLICATIONS

- Corrosion Control

LOAD

Metals corrode because of ion loss to an electrolyte. When metals are buried, the water and acids in the soil serve as an electrolyte and provide a medium for electron flow. Cathodic protection is achieved by causing a current to flow to the metal to be protected. This can be done by burying a sacrificial anode or by using an external power source to impress a current on the metal to be protected. Only the impressed current method is considered here. The load is the amount of current required to overcome the potential between the metal (anode) and the surrounding electrolyte.

ARRAY

For systems that are to protect a structure like a tank, the PV array will likely be installed near the tank. For pipelines or distributed structures, the PV array may be installed near the buried anodes (multiple anodes are needed for distributed systems.) In either case, the array should be installed where the probability of theft or vandalism is diminished. Pole mounting may decrease vandalism but increases the length of wire runs. The array should be mounted as close to the load as practical. If the application is in a coastal area, the modules should be capable of operating for 20+ years in a salt spray environment. Wiring should be heavy-duty USE or UF type cable with all connections in water-tight junction boxes with strain relief connectors. All module to module wiring should be laced and attached to the support structure with wire ties. The array should be grounded and the structure to be protected can often serve as the ground point.

BATTERIES

Batteries are used for almost all PV powered cathodic protection systems. This may change in the future if it is determined that diurnal impression of current will provide a sufficient level of protection for some structures. If batteries are used, deep cycle lead acid or nickel cadmium types are recommended. Lead-calcium batteries that are intended for float applications are not acceptable. Batteries should be located in a weather-resistant enclosure. Nonmetallic enclosures are recommended, particularly in a marine environment. A fused disconnect switch in the battery-load circuit makes maintenance easier and the fuse is sized to protect the wiring.

CONTROL

For systems installed in remote areas, the reliability of a charge controller is critical. Load currents are less than 3 amperes for most CP applications that use PV power. Install the controller in a weather resistant box near the batteries. Some small CP systems are wired direct with no controller. In these cases, the battery must be large enough to accept charging current over an extended period of good weather.

MOUNTING

PV arrays may be ground mounted or pole mounted. If mounted on the ground, they should be fenced to prevent access by animals or unauthorized persons. Elevating the array above the structure may decrease the possibility of vandalism. Array structures should be anodized aluminum, galvanized, or stainless steel designed for maximum anticipated wind velocities. Stainless steel fasteners with lockwashers, nylock, or pel nuts are advised. Locate all subsystems adjacent to the load to keep wire runs to a minimum.

POINT DESIGN NO. 16

This point design illustrates a simple system that might be installed without the aid of an experienced corrosion engineer. A small business operator wants to provide some corrosion protection for a metal tank he uses periodically to store non-hazardous chemicals. The tank may not be used for several months at a time but when it is needed, the owner wants to be assured that it will not leak. He plans to design and install the cathodic protection system himself but he gets the tank supplier to coat the tank and then estimate the current required to protect it when buried in that area.

KEY DESIGN INFORMATION

APPLICATION:	Protection for a metal tank
SITE:	Doyline, Louisiana
LOCATION/ELEVATION:	30°50’ N 94° W 55 m
ENVIRONMENT:	Framland; damp loam soil
TEMPERATURE RANGE (°C):	-5 to 37
MAXIMUM WIND SPEED (m/s):	40
AVAILABILITY REQUIRED:	Non-critical

INSTALLATION

The array, control box, and battery container were installed on a 10’ steel pole supported by a concrete foundation. The wiring from the array to the control box was installed in conduit. A pole mounting hardware kit was supplied by the manufacturer of the photovoltaic module. A non-glass module was chosen because it is resistant to vandalism. The control box and battery container were made of heavy gauge steel with padlocks. The conductors from the battery/control box were installed in conduit and run down the pole. Once underground, the cable is buried without conduit since its insulation is suitable for underground placement. Sealed batteries were specified in this design to reduce the amount of service required.

CATHODIC PROTECTION WORKSHEET #1 CP

LOAD CURRENT DETERMINATION

		1C Metal Coating Efficiency (DECIMAL) D		2C Total Metal Surface Area (FT^2)		3C Bare Metal Surface Area (FT^2)		4C Metal Protection Current Density (A/FT^2) D		5C Estimated Protection Current (A)	6C Measured Protection Current (A)
1.0	−		x		=		x		=		0.25

NOTES:
1) USE 5C TO ESTIMATE LOAD CURRENT IF ACTUAL FIELD MEASUREMENTS ARE NOT AVAILABLE.
2) CC IS THE ABBREVIATION FOR CUBIC CENTIMETER.
3) ENTER 1.0 IN BLOCK IF ONLY ONE ANODE IS USED.

7C Required Protection Current 5C or 6C		8C Rated Anode Current (A) D		9C Number of Anodes
0.25	÷	2	=	1

10C Soil Resistivity (OHM/CC) D		11C Conversion Factor		12C Single Anode Resistance to Earth (OHMS) D		13C Multiple Anode Factor D		14C Anode(s) Resistance to Earth (OHMS)		15C Required Protection Current 7C		16C Required System Voltage
12,500	÷	1000	x	3.5	x	1	=	43.8	x	0.25	=	10.9

17C Required Protection Current 7C		18C Daily Duty Cycle (HRS/DAY) D		19C Amp Hour Load (AH/DAY)		20C Wire Efficiency Factor (DECIMAL) D		21C Battery Efficiency Factor (DECIMAL) D		22C Corrected Amp-Hour Load (AH/DAY)
0.25	x	24	=	6	÷	1	÷	.9	=	6.7

DESIGN NOTES:

Used single 5ft. graphite anode 6" diameter.

WORKSHEET #2 DESIGN CURRENT AND ARRAY TILT

DESIGN NOTES:

21	System Location	Doyline, LA	Latitude	32°5'N	Longitude	94°W
	Insolation Location	New Orleans, LA	Latitude	29°59'N	Longitude	90°15'W

MONTH	Tilt at Latitude -15°					Tilt at Latitude					Tilt at Latitude +15°				
	22A Corrected Load (AH/DAY) 20		23A Peak Sun (HRS/DAY)		24A Design Current (A)	22B Corrected Load (AH/DAY) 20		23B Peak Sun (HRS/DAY)		24B Design Current (A)	22C Corrected Load (AH/DAY) 20		23C Peak Sun (HRS/DAY)		24C Design Current (A)
J	6.7	÷	3.14	=	2.1	6.7	÷	3.56	=	1.9	6.7	÷	3.79	=	1.8
F		÷		=			÷		=			÷		=	
M		÷		=			÷		=			÷		=	
A		÷		=			÷		=			÷		=	
M		÷		=			÷		=			÷		=	
J		÷		=			÷		=			÷		=	
J		÷		=			÷		=			÷		=	
A		÷		=			÷		=			÷		=	
S		÷		=			÷		=			÷		=	
O		÷		=			÷		=			÷		=	
N		÷		=			÷		=			÷		=	
D	6.7	÷	3.14	=	2.1	6.7	÷	3.60	=	1.9	6.7	÷	3.88	=	1.7

Select the largest design current and corresponding peak sun from each latitude and enter below

Latitude -15°	
25A Peak Sun (HRS/DAY)	26A Design Current (A)
3.14	2.1

Latitude	
25B Peak Sun (HRS/DAY)	26B Design Current (A)
3.56	1.9

Latitude +15°	
25C Peak Sun (HRS/DAY)	26C Design Current (A)
3.79	1.8

Now select the smallest design current and corresponding peak sun

27 Peak Sun (HRS/DAY	28 Design Current (A)
3.79	1.8
Tilt Angle =	48°

NOTE: DO NOT MIX TRACKING AND FIXED ARRAY DATA ON THE SAME SHEET.

WORKSHEET #3 CALCULATE SYSTEM BATTERY SIZE

DESIGN NOTES:

29 Corrected Amp-Hour Load (AH/DAY) 20		30 Storage Days D		31 Maximum Depth of Discharge (DECIMAL) D		32 Derate for Temperature (DECIMAL) D		33 Required Battery Capacity (AH)		34 Capacity of Selected Battery (AH)		35 Batteries in Parallel
6.7	X	6	÷	0.7	÷	1	=	57.4	÷	55	=	1

NOTE: BLOCK 35. ROUND UP FOR CONSERVATIVE DESIGN.

36 Nominal System Voltage (V) 9		37 Nominal Battery Voltage (V)		38 Batteries in Series		39 Batteries in Parallel 35		40 Total Batteries
12	÷	12	=	1	X	1	=	1

BATTERY INFORMATION	
Make	Johnson Controls
Model	GC12550B
Type	Sealed Lead Acid
Nominal Voltage (V)	12
Rated Capacity (AH)	55

41 Batteries in Parallel 35		42 Capacity of Selected Battery (AH) 34		43 System Battery Capacity (AH)		44 Maximum Depth of Discharge (DECIMAL) 31		45 Usable Battery Capacity (AH)
1	X	55	=	55	X	0.7	=	38.5

NOTE: USE MANUFACTURER'S DATA TO FILL IN BATTERY INFORMATION BLOCK

WORKSHEET #4 CALCULATE SYSTEM ARRAY SIZE

DESIGN NOTES:

46 Design Current (A) 28		47 Module Derate Factor (DECIMAL) D		48 Derated Design Current (A)		49 Rated Module Current (A) D		50 Modules in Parallel
1.8	÷	0.9	=	2.0	÷	1.75	=	1

		51 Nominal Battery Voltage 37		52 Batteries in Series 38	53 Voltage Required for Load (V)		54 Highest Temperature Module Voltage (V)		55 Modules in Series		56 Modules in Parallel 50		57 Total Modules
1.20	X	12	X	1	14.4	÷	15	=	1	X	1	=	1

NOTE: USE MANUFACTURER'S SPECIFICATIONS TO FILL IN PV MODULE INFORMATION BLOCK.

58 Modules in Parallel 50		59 Rated Module Current (A)		60 Rated Array Current (A)
	X	1.75	=	1.75
		61 Module Short Circuit Current (A)		62 Array Short Circuit Current (A)
	X	1.9	=	1.9

63 Modules in Series 55		64 Rated Module Voltage (V)		65 Array Rated Voltage (V)
	X	17.1	=	17.1
		66 Open Circuit Module Voltage (V)		67 Array Open Circuit Voltage (V)
	X	22	=	22

PV MODULE INFORMATION

Make/Model	MSX 30L		Nominal Volts	12
Length	24	Width 20	Thickness	0.4
Weight	5 lbs.		Bypass Diode	Y [✓ N]
Voltage (V)	At STC	Open Circuit	At Highest Expected Temperature	
	17.1	22	15	
Current (A)	At STC	Short Circuit		
	1.75	1.9		

NOTES: BLOCK 50 - ROUND UP FOR CONSERVATIVE DESIGN.

BLOCK 55 - ROUND UP OR SELECT ANOTHER MODULE WITH SUFFICIENT VOLTAGE TO CHARGE THE BATTERIES WHEN OPERATING AT THE HIGHEST EXPECTED TEMPERATURE.

A hybrid system is not reasonable for this small demand application.

CONTROLLER SPECIFICATION

DESIGN NOTES:

		A1 Array Short Circuit Current (A) 62		A2 Minimum Controller Current (A)		A3 Rated Controller Current (A)		A4 Controllers in Parallel
1.25	x	1.9	=	2.4	÷	4	=	1

A5 **(CONTROLLER)**

Make/Model Bobier M-2

Rated Voltage 12.0

Rated Current 4

Features

Temperature Compensation ____

Reverse Current Protection ____

Adjustable Set Points (X)

High Voltage Disconnect ____

High Voltage Re-connect ____

Low Voltage Disconnect ____

Low Voltage Re-connect ____

Meters

Battery Voltage ____

Array Current ____

Load Current ____

PROTECTION COMPONENTS SPECIFICATION

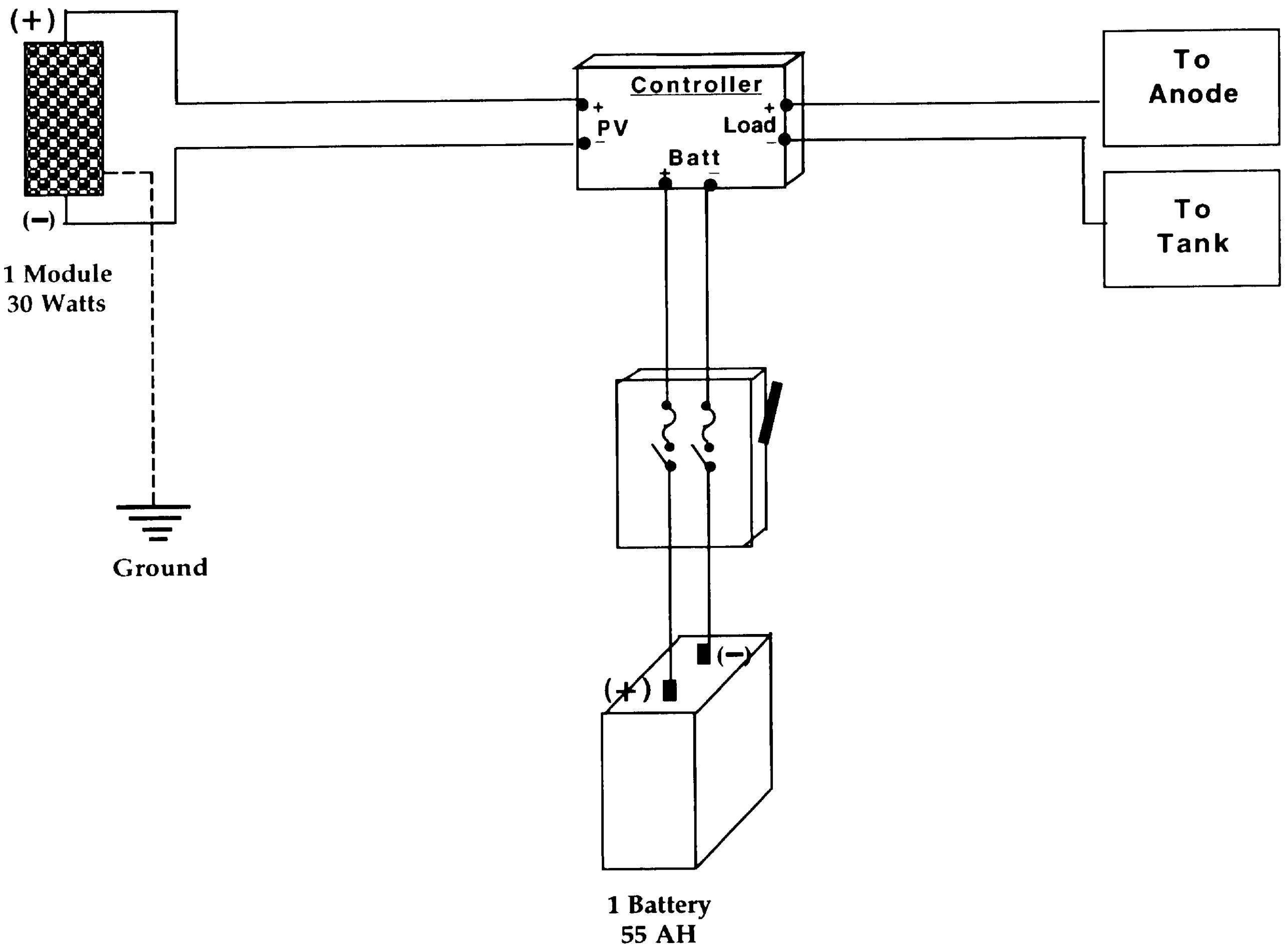
Protected Circuit	Protection Device				Rated Current	Rated Voltage	Description
	Switch	Diode	Fuse	Movistor			
D1 Battery Output	✓		✓		3	120	Fused Disconnect
D2							
D3							
D4							
D5							
D6							
D7							
D8							
D9							
D10							
D11							
D12							
D13							
D14							

DC WIRE SIZING SPECIFICATION

E1 Wire Runs	E2 System Voltage (V)	E3 Maximum Current (A)	E4 One Way Length (FT)	E5 Allowed Voltage Drop (%)	E6 Allowance for Temperature Derate	E7 AWG Number	E8 Wire Type
Array Circuit							
Module to Module							
Array to Controller or Battery	12	2.4	15	2%	20%	#14	THHN
DC Circuits							
Battery to Battery							
Battery to DC Loads	12	0.3	50	2%	20%	#14	THHN - nylon jacket for damp locations
Branch Circuits							
A ______							
B ______							
C ______							
D ______							
E ______							
Battery Charger to Batteries							
Battery to Inverter Or Converter							

System Grounding	Wire Type	AWG Number	Type of Earth Ground
E9 Equipment Ground	Bare Copper	#6	To buried pipe
E10 System Ground	Bare Copper	#6	To buried pipe

DESIGN NOTES:


(+)
(−)
1 Module
30 Watts
Ground
Controller
+
PV
−
+
Load
−
Batt
+
−
To
Anode
To
Tank
(+)
(−)
1 Battery
55 AH

ECONOMICS ANALYSIS

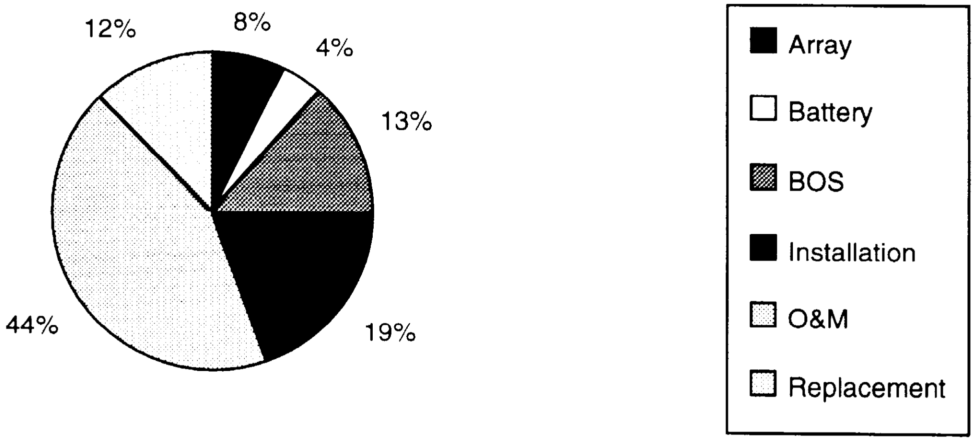
LIFE-CYCLE COST ANALYSIS
POINT DESIGN: CATHODIC PROTECTION

Item	Dollar Amount ($)	Present Worth ($)	Percent Total LCC cost (%)
1. CAPITAL COSTS:			
Array	$195	$195	7.6
Battery	110	110	4.3
BOS + Hardware	345	345	13.5
Installation	500	500	19.6
A - SUBTOTAL (Equipment & Installation)	**1,150**	**1,150**	**45.0**
2. OPERATION & MAINTENANCE			
B - Annual Inspection	**75**	**1,116**	**43.7**
3. REPLACEMENT: (YEAR)			
Battery 5	110	95	3.7
Battery 10	110	82	3.2
Battery 15	110	71	2.8
Controller 10	96	71	2.8
C - SUBTOTAL (Replacement)	**426**	**319**	**12.5**
4. SALVAGE: (YEAR)			
D - 20% of Original 20	**(130)**	**(34)**	**(1.2)**
TOTAL LIFE-CYCLE COST (A + B + C - D)		**$2,551**	**100.0**

ECONOMIC NOTES:

1) Anodes not included in the LCC figures.
2) Initial power system costs are only 12% of total life cycle costs.

COST ELEMENTS AS A PERCENT OF LCC (%)



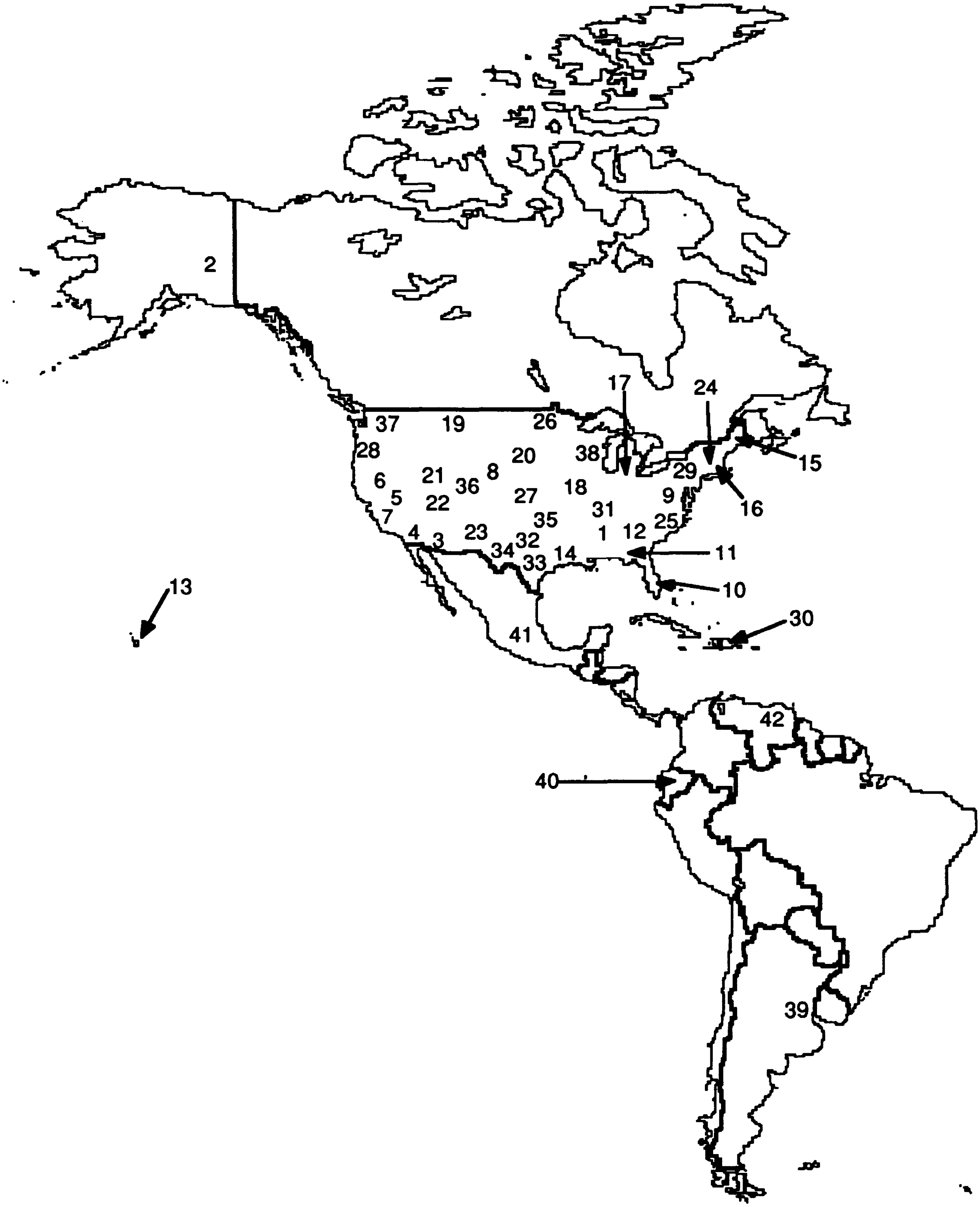
APPENDIX A
INSOLATION DATA

Obtain insolation data from local sources if possible. Airports, meteorological stations, universities, government ministries, or other sources in the country should be contacted to determine if they have accurate data for specific locations. The following data for selected cities plus the 12 world maps are included for use when local insolation data are not available.

The data for the cities in the United States were processed by the Photovoltaic Design Assistance Center at Sandia National Laboratories in Albuquerque, New Mexico. The data for the worldwide cities were processed by the Southwest Technology Development Institute using a modified clear sky model to predict daily solar insolation values for different array orientations and tilt angles.

The world maps indicate seasonal data. These maps are published in Water Pumping: The Solar Alternative (See Recommended Reading, page 86). The seasons mentioned in the titles for each chart (spring, summer, autumn and winter) are for the northern hemisphere. The tilt angle is referenced to horizontal.

Data in a compatible format for 239 sites in the United States and its territories is available in Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors (See Recommended Reading, page 86).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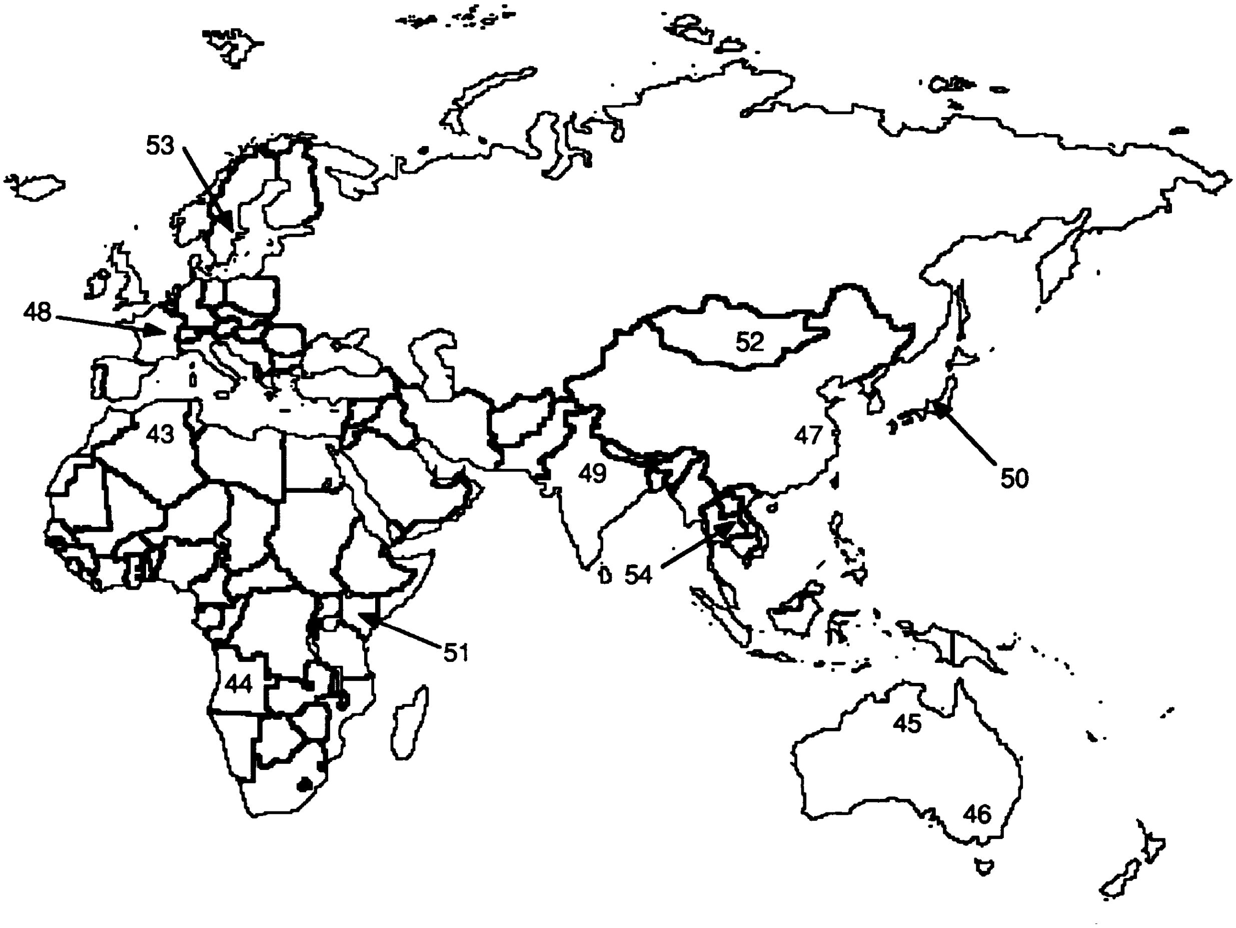
39

INSOLATION INDEX

(In alphabetical order by state)

1 Birmingham, Alabama
2 Fairbanks, Alaska
3 Phoenix, Arizona
4 Daggett, California
5 Fresno, California
6 Sacramento, California
7 San Diego, California
8 Denver, Colorado
9 Washington, D. C.
10 Miami, Florida
11 Orlando, Florida
12 Atlanta, Georgia
13 Honolulu, Hawaii
14 New Orleans, Louisiana
15 Caribou, Maine
16 Boston, Massachusetts
17 Detroit, Michigan
18 Columbia, Missouri
19 Great Falls, Montana
20 Omaha, Nebraska
21 Elko, Nevada
22 Las Vegas, Nevada
23 Albuquerque, New Mexico
24 Syracuse, New York
25 Raleigh-Durham, N. Carolina
26 Bismarck, North Dakota
27 Oklahoma City, Oklahoma
28 Medford, Oregon
29 Pittsburgh, Pennsylvania
30 San Juan, Puerto Rico
31 Nashville, Tennessee
32 Austin, Texas
33 Brownsville, Texas
34 El Paso, Texas
35 Fort Worth, Texas
36 Bryce Canyon, Utah
37 Seattle, Washington
38 Madison, Wisconsin
39 Buenos Aires, Argentina
40 Quito, Ecuador
41 Mexico D. F., Mexico
42 Caracas, Venezuela



INSOLATION INDEX

(In alphabetical order by country)

43	Biskra, Algeria	49	New Delhi, India
44	Luanda, Angola	50	Tokyo, Japan
45	Darwin, Australia	51	Nairobi, Kenya
46	Melbourne, Australia	52	Ulan-Bator, Mongolia
47	Shanghai, China	53	Stockholm, Sweden
48	Paris-St. Maur, France	54	Bangkok, Thailand

BIRMINGHAM, ALABAMA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M^2)

LOCATION: 33° 34' N, 86° 45' W, 192 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	2.91	3.62	4.57	5.48	6.07	5.75	5.60	5.42	5.18	4.69	3.46	2.74	4.63
1-Axis North South Tracking Array	3.64	4.57	6.17	7.33	7.92	7.31	7.00	6.80	6.66	6.00	4.41	3.48	5.95
LATITUDE TILT (°)													
Fixed Array	3.29	3.96	4.75	5.44	5.78	5.36	5.27	5.29	5.31	5.11	3.92	3.17	4.72
1-Axis North South Tracking Array	3.94	4.82	6.30	7.31	7.72	7.03	6.76	6.70	6.75	6.32	4.76	3.81	6.03
LATITUDE TILT +15 (°)													
Fixed Array	3.51	4.09	4.69	5.13	5.21	4.73	4.70	4.91	5.17	5.26	4.18	3.43	4.59
1-Axis North South Tracking Array	4.10	4.92	6.25	7.08	7.33	6.60	6.37	6.42	6.63	6.43	4.95	4.02	5.93
TWO AXIS TRACKING	4.15	4.92	6.30	7.36	7.99	7.44	7.10	6.82	6.75	6.43	4.99	4.08	6.20

FAIRBANKS, ALASKA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 64° 49' N, 147° 52' W, 138 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	0.31	2.30	4.94	5.75	5.76	5.38	5.25	4.10	3.62	2.50	0.84	0.00	3.40
1-Axis North South Tracking Array	0.32	2.58	6.42	8.49	8.95	8.40	7.89	5.74	4.81	2.94	0.90	0.00	4.80
LATITUDE TILT (°)													
Fixed Array	0.35	2.54	5.19	5.68	5.43	4.97	4.88	3.93	3.68	2.69	0.95	0.00	3.36
1-Axis North South Tracking Array	0.36	2.79	6.62	8.46	8.77	8.19	7.69	5.64	4.86	3.11	0.99	0.00	4.80
LATITUDE TILT +15 (°)													
Fixed Array	0.37	2.62	5.13	5.29	4.83	4.34	4.30	3.57	3.54	2.73	0.99	0.00	3.14
1-Axis North South Tracking Array	0.38	2.86	6.56	8.18	8.40	7.84	7.34	5.40	4.75	3.14	1.03	0.00	4.66
TWO AXIS TRACKING	0.38	2.87	6.62	8.52	9.13	8.73	8.12	5.79	4.87	3.15	1.04	0.00	4.94

PHOENIX, ARIZONA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 33° 26’ N, 112° 01’ W, 339 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	4.52	5.70	6.85	7.87	8.50	8.21	7.60	7.52	7.28	6.18	5.23	4.15	6.64
1-Axis North South Tracking Array	5.92	7.63	9.53	11.22	12.54	11.91	10.01	10.25	9.94	8.27	6.74	5.38	9.11
LATITUDE TILT (°)													
Fixed Array	5.31	6.42	7.28	7.84	8.00	7.54	7.11	7.32	7.55	6.82	6.07	4.94	6.85
1-Axis North South Tracking Array	6.53	8.17	9.85	11.21	12.23	11.47	9.66	10.12	10.14	8.75	7.40	5.99	9.29
LATITUDE TILT +15 (°)													
Fixed Array	5.79	6.76	7.30	7.37	7.07	6.47	6.25	6.73	7.39	7.07	6.56	5.43	6.68
1-Axis North South Tracking Array	6.90	8.42	9.84	10.88	11.62	10.78	9.06	9.70	10.01	8.92	7.78	6.38	9.19
TWO AXIS TRACKING	6.99	8.41	9.87	11.28	12.69	12.20	10.13	10.29	10.13	8.90	7.84	6.50	9.60

DAGGETT, CALIFORNIA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 34° 52’ N, 116° 47’W, 588 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	4.35	5.45	6.60	7.75	8.26	8.34	8.17	7.86	7.33	6.16	4.76	3.96	6.59
1-Axis North South Tracking Array	5.47	7.18	9.05	11.20	12.13	12.48	11.93	11.04	10.21	8.18	6.13	4.89	9.17
LATITUDE TILT (°)													
Fixed Array	5.07	6.13	7.01	7.72	7.79	7.65	7.59	7.66	7.60	6.80	5.52	4.67	6.77
1-Axis North South Tracking Array	6.05	7.70	9.36	11.20	11.83	12.04	11.56	10.92	10.41	8.66	6.72	5.47	9.33
LATITUDE TILT +15 (°)													
Fixed Array	5.51	6.45	7.03	7.26	6.90	6.54	6.60	7.03	7.44	7.05	5.95	5.11	6.57
1-Axis North South Tracking Array	6.40	7.93	9.35	10.88	11.25	11.35	10.92	10.49	10.27	8.84	7.06	5.83	9.22
TWO AXIS TRACKING	6.47	7.92	9.38	11.26	12.27	12.80	12.15	11.09	10.39	8.81	7.11	5.93	9.64

FRESNO, CALIFORNIA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 36° 46’ N, 119° 43’ W, 100 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	2.89	4.27	6.04	7.31	7.93	8.29	8.38	8.01	7.54	6.04	4.11	2.45	6.11
1-Axis North South Tracking Array	3.44	5.41	8.26	10.29	11.73	12.28	12.60	11.45	10.57	7.90	5.20	2.85	8.51
LATITUDE TILT (°)													
Fixed Array	3.28	4.71	6.37	7.29	7.47	7.62	7.78	7.80	7.82	6.66	4.71	2.78	6.20
1-Axis North South Tracking Array	3.75	5.75	8.51	10.30	11.44	11.85	12.22	11.32	10.79	8.38	5.67	3.13	8.60
LATITUDE TILT +15 (°)													
Fixed Array	3.48	4.89	6.34	6.88	6.63	6.54	6.77	7.15	7.66	6.89	5.04	2.97	5.94
1-Axis North South Tracking Array	3.92	5.88	8.47	10.00	10.89	11.16	11.57	10.88	10.65	8.54	5.93	3.29	8.44
TWO AXIS TRACKING	3.96	5.87	8.51	10.35	11.87	12.58	12.84	11.49	10.77	8.51	5.96	3.33	8.85

SACRAMENTO, CALIFORNIA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 38° 31' N, 121° 30' W, 8 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	2.84	3.83	5.63	7.01	7.63	8.13	8.39	8.08	7.31	5.55	3.89	2.47	5.91
1-Axis North South Tracking Array	3.33	4.85	7.57	9.98	11.29	12.27	12.43	11.57	10.18	7.27	4.90	2.87	8.22
LATITUDE TILT (°)													
Fixed Array	3.22	4.23	5.93	6.97	7.20	7.47	7.80	7.86	7.58	6.10	4.47	2.83	5.98
1-Axis North South Tracking Array	3.65	5.16	7.79	9.97	11.02	11.85	12.05	11.44	10.38	7.69	5.35	3.17	8.31
LATITUDE TILT +15 (°)													
Fixed Array	3.43	4.40	5.91	6.55	6.39	6.41	6.78	7.21	7.41	6.30	4.79	3.03	5.72
1-Axis North South Tracking Array	3.83	5.28	7.76	9.67	10.50	11.20	11.40	10.99	10.24	7.82	5.61	3.35	8.15
TWO AXIS TRACKING	3.87	5.29	7.80	10.03	11.42	12.58	12.65	11.61	10.36	7.81	5.64	3.40	8.55

SAN DIEGO, CALIFORNIA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 32° 44’ N, 117° 10’ W, 9 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	4.06	5.07	5.87	6.45	6.33	6.18	6.85	6.94	5.93	5.33	4.41	3.85	5.61
1-Axis North South Tracking Array	5.28	6.58	7.93	8.57	8.10	7.77	8.83	8.91	7.46	6.80	5.60	4.90	7.23
LATITUDE TILT (°)													
Fixed Array	4.73	5.66	6.21	6.42	6.02	5.76	6.43	6.80	6.10	5.84	5.06	4.54	5.80
1-Axis North South Tracking Array	5.79	7.03	8.18	8.55	7.89	7.48	8.54	8.81	7.59	7.20	6.11	5.45	7.39
LATITUDE TILT +15 (°)													
Fixed Array	5.12	5.93	6.21	6.06	5.42	5.07	5.70	6.29	5.94	6.03	5.43	4.98	5.68
1-Axis North South Tracking Array	6.09	7.23	8.16	8.28	7.47	6.99	8.02	8.44	7.46	7.33	6.39	5.79	7.31
TWO AXIS TRACKING	6.16	7.22	8.20	8.61	8.16	7.92	8.94	8.94	7.59	7.32	6.43	5.90	7.62

DENVER, COLORADO
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 39° 45’ N, 104° 52’ W, 1625 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	4.32	4.94	6.42	6.69	7.07	7.22	7.32	6.84	6.78	5.92	4.37	4.05	6.00
1-Axis North South Tracking Array	5.49	6.55	8.92	9.37	10.10	10.27	10.30	9.39	9.43	7.94	5.64	5.06	8.21
LATITUDE TILT (°)													
Fixed Array	5.07	5.54	6.80	6.65	6.69	6.67	6.84	6.66	7.02	6.53	5.05	4.81	6.20
1-Axis North South Tracking Array	6.08	7.00	9.20	9.36	9.86	9.91	9.99	9.29	9.61	8.40	6.17	5.67	8.39
LATITUDE TILT +15 (°)													
Fixed Array	5.51	5.81	6.80	6.24	5.97	5.78	6.01	6.13	6.85	6.75	5.43	5.28	6.05
1-Axis North South Tracking Array	6.43	7.19	9.18	9.07	9.39	9.34	9.45	8.92	9.48	8.55	6.46	6.06	8.30
TWO AXIS TRACKING	6.50	7.19	9.21	9.41	10.22	10.50	10.47	9.43	9.60	8.53	6.50	6.16	8.65

WASHINGTON, D.C.
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M^2)

LOCATION: 38° 57’ N, 77° 27’ W, 88 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	2.83	3.45	4.48	5.11	5.46	5.87	5.39	5.65	4.78	4.03	3.07	2.29	4.37
1-Axis North South Tracking Array	3.43	4.31	5.83	6.77	7.27	7.64	6.83	7.34	5.99	5.00	3.84	2.68	5.58
LATITUDE TILT (°)													
Fixed Array	3.24	3.78	4.68	5.07	5.18	5.48	5.06	5.49	4.87	4.37	3.47	2.64	4.45
1-Axis North South Tracking Array	3.77	4.57	5.98	6.75	7.08	7.37	6.61	7.23	6.07	5.26	4.16	2.97	5.66
LATITUDE TILT +15 (°)													
Fixed Array	3.47	3.92	4.63	4.77	4.65	4.83	4.51	5.07	4.72	4.47	3.68	2.83	4.30
1-Axis North South Tracking Array	3.95	4.67	5.93	6.53	6.72	6.92	6.23	6.92	5.95	5.33	4.32	3.14	5.56
TWO AXIS TRACKING	3.99	4.67	5.99	6.80	7.35	7.79	6.93	7.37	6.07	5.33	4.34	3.18	5.82

MIAMI, FLORIDA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 25° 48’ N, 80° 16’ W, 2 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	3.77	4.71	5.38	6.15	5.61	5.18	5.43	5.39	4.92	4.40	4.27	3.79	4.92
1-Axis North South Tracking Array	4.79	6.04	7.19	8.00	7.14	6.24	6.74	6.47	6.03	5.66	5.52	4.94	6.23
LATITUDE TILT (°)													
Fixed Array	4.31	5.21	5.67	6.12	5.34	4.86	5.12	5.27	5.03	4.75	4.87	4.41	5.08
1-Axis North South Tracking Array	5.19	6.42	7.40	7.98	6.95	6.00	6.52	6.38	6.10	5.91	5.97	5.40	6.35
LATITUDE TILT +15 (°)													
Fixed Array	4.62	5.45	5.67	5.79	4.83	4.33	4.59	4.90	4.90	4.85	5.20	4.81	4.99
1-Axis North South Tracking Array	5.43	6.59	7.38	7.72	6.59	5.62	6.14	6.09	5.99	5.97	6.22	5.70	6.28
TWO AXIS TRACKING	5.49	6.59	7.42	8.04	7.20	6.35	6.83	6.49	6.11	5.98	6.27	5.80	6.55

ORLANDO, FLORIDA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 28° 33' N, 81° 20' W, 36 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	3.83	4.57	5.42	6.25	6.31	5.60	5.59	5.35	4.91	4.67	4.26	3.50	5.02
1-Axis North South Tracking Array	4.89	5.83	7.41	8.56	8.29	6.90	6.82	6.58	6.02	5.87	5.51	4.42	6.43
LATITUDE TILT (°)													
Fixed Array	4.39	5.05	5.70	6.19	5.98	5.25	5.27	5.21	4.99	5.04	4.87	4.05	5.17
1-Axis North South Tracking Array	5.32	6.18	7.61	8.53	8.07	6.64	6.59	6.48	6.07	6.15	5.97	4.84	6.54
LATITUDE TILT +15 (°)													
Fixed Array	4.72	5.25	5.68	5.83	5.38	4.67	4.73	4.84	4.83	5.16	5.21	4.39	5.06
1-Axis North South Tracking Array	5.56	6.33	7.57	8.26	7.64	6.23	6.19	6.20	5.94	6.23	6.22	5.10	6.46
TWO AXIS TRACKING	5.63	6.34	7.62	8.59	8.37	7.02	6.90	6.60	6.08	6.24	6.27	5.19	6.74

ATLANTA, GEORGIA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 33° 39' N, 84° 36' W, 315 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	2.87	3.61	4.77	5.56	6.26	5.84	5.90	5.83	4.69	4.84	3.69	2.95	4.74
1-Axis North South Tracking Array	3.68	4.57	6.45	7.55	8.32	7.46	7.54	7.45	5.87	6.17	4.76	3.80	6.14
LATITUDE TILT (°)													
Fixed Array	3.27	3.96	4.98	5.52	5.95	5.44	5.54	5.69	4.79	5.29	4.21	3.43	4.84
1-Axis North South Tracking Array	3.98	4.83	6.61	7.52	8.11	7.18	7.29	7.34	5.95	6.51	5.15	4.16	6.23
LATITUDE TILT +15 (°)													
Fixed Array	3.49	4.10	4.94	5.20	5.34	4.79	4.93	5.27	4.66	5.44	4.50	3.72	4.70
1-Axis North South Tracking Array	4.15	4.94	6.56	7.29	7.69	6.74	6.87	7.04	5.84	6.62	5.37	4.38	6.13
TWO AXIS TRACKING	4.19	4.95	6.61	7.58	8.40	7.60	7.64	7.47	5.96	6.62	5.41	4.46	6.42

HONOLULU, HAWAII
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 21° 20’ N, 157° 55’ W, 5 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	3.97	4.63	5.30	5.74	6.20	6.10	6.29	6.31	5.94	5.02	4.20	3.84	5.30
1-Axis North South Tracking Array	4.97	5.84	6.80	7.40	7.91	7.63	8.18	8.25	7.74	6.45	5.36	4.81	6.78
LATITUDE TILT (°)													
Fixed Array	4.51	5.09	5.54	5.71	5.91	5.70	5.91	6.16	6.10	5.43	4.76	4.44	5.44
1-Axis North South Tracking Array	5.38	6.18	6.96	7.37	7.70	7.33	7.90	8.13	7.85	6.75	5.78	5.27	6.89
LATITUDE TILT +15 (°)													
Fixed Array	4.83	5.29	5.51	5.41	5.34	5.05	5.26	5.70	5.96	5.57	5.08	4.80	5.32
1-Axis North South Tracking Array	5.63	6.32	6.92	7.13	7.28	6.86	7.44	7.79	7.72	6.84	6.01	5.55	6.79
TWO AXIS TRACKING	5.68	6.33	6.98	7.43	7.99	7.77	8.30	8.28	7.85	6.85	6.06	5.64	7.10

NEW ORLEANS, LOUISIANA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 29° 59' N, 90° 15' W, 3 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	3.14	3.97	4.95	5.60	6.16	5.84	5.55	5.59	5.24	5.04	3.66	3.14	4.83
1-Axis North South Tracking Array	3.90	4.92	6.66	7.39	8.08	7.44	6.94	7.04	6.62	6.48	4.68	3.88	6.17
LATITUDE TILT (°)													
Fixed Array	3.56	4.35	5.19	5.58	5.86	5.45	5.23	5.47	5.39	5.50	4.16	3.60	4.95
1-Axis North South Tracking Array	4.22	5.22	6.83	7.37	7.86	7.16	6.71	6.95	6.73	6.82	5.05	4.24	6.27
LATITUDE TILT +15 (°)													
Fixed Array	3.79	4.50	5.16	5.28	5.27	4.80	4.67	5.08	5.26	5.66	4.44	3.88	4.82
1-Axis North South Tracking Array	4.40	5.33	6.79	7.14	7.45	6.71	6.31	6.67	6.62	6.93	5.26	4.46	6.18
TWO AXIS TRACKING	4.45	5.34	6.84	7.42	8.15	7.58	7.03	7.07	6.73	6.93	5.31	4.52	6.45

CARIBOU, MAINE
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 46° 52' N, 68° 01' W, 190 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	2.33	3.78	5.06	5.26	5.24	5.60	5.53	5.05	4.10	3.16	1.92	1.80	4.07
1-Axis North South Tracking Array	2.73	4.71	6.61	7.03	7.29	7.73	7.62	6.86	5.11	3.98	2.18	2.08	5.33
LATITUDE TILT (°)													
Fixed Array	2.65	4.17	5.31	5.22	4.95	5.19	5.17	4.88	4.19	3.40	2.13	2.07	4.11
1-Axis North South Tracking Array	3.00	5.03	6.80	7.01	7.10	7.46	7.38	6.75	5.18	4.16	2.37	2.31	5.38
LATITUDE TILT +15 (°)													
Fixed Array	2.83	4.32	5.27	4.91	4.42	4.54	4.56	4.47	4.05	3.45	2.23	2.22	3.94
1-Axis North South Tracking Array	3.15	5.14	6.76	6.79	6.75	7.04	6.99	6.47	5.07	4.19	2.45	2.44	5.27
TWO AXIS TRACKING	3.17	5.14	6.82	7.07	7.38	7.92	7.75	6.89	5.18	4.20	2.47	2.47	5.54

BOSTON, MASSACHUSETTS
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 41° 40’ N, 71° 10’ W, 10 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	2.24	3.12	4.07	4.49	5.17	5.87	5.48	4.95	4.90	3.58	2.41	2.01	4.03
1-Axis North South Tracking Array	2.60	3.92	5.25	5.80	7.27	8.29	7.06	6.39	6.54	4.47	2.90	2.34	5.24
LATITUDE TILT (°)													
Fixed Array	2.54	3.44	4.25	4.43	4.88	5.43	5.14	4.79	5.01	3.85	2.71	2.31	4.07
1-Axis North South Tracking Array	2.85	4.17	5.38	5.77	7.08	8.02	6.83	6.28	6.63	4.68	3.14	2.60	5.29
LATITUDE TILT +15 (°)													
Fixed Array	2.71	3.57	4.19	4.16	4.36	4.75	4.57	4.41	4.86	3.92	2.86	2.49	3.90
1-Axis North South Tracking Array	2.99	4.27	5.33	5.57	6.74	7.58	6.44	6.01	6.50	4.72	3.26	2.75	5.18
TWO AXIS TRACKING	3.02	4.27	5.38	5.82	7.36	8.49	7.16	6.41	6.62	4.73	3.28	2.79	5.45

DETROIT, MICHIGAN
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 42° 25’ N, 83° 01’ W, 191 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	2.04	3.07	3.76	4.87	5.60	5.92	6.01	5.30	4.87	3.78	2.19	1.58	4.08
1-Axis North South Tracking Array	2.38	3.94	4.97	6.44	7.35	7.78	7.87	6.76	6.19	4.70	2.53	1.78	5.23
LATITUDE TILT (°)													
Fixed Array	2.30	3.35	3.90	4.81	5.31	5.50	5.63	5.16	4.96	4.07	2.41	1.76	4.10
1-Axis North South Tracking Array	2.59	4.15	5.07	6.42	7.16	7.51	7.61	6.67	6.26	4.92	2.71	1.94	5.26
LATITUDE TILT +15 (°)													
Fixed Array	2.44	3.46	3.84	4.53	4.79	4.84	4.99	4.77	4.80	4.13	2.51	1.86	3.91
1-Axis North South Tracking Array	2.71	4.22	5.02	6.21	6.79	7.07	7.19	6.39	6.13	4.96	2.79	2.02	5.13
TWO AXIS TRACKING	2.74	4.23	5.08	6.47	7.42	7.94	7.98	6.78	6.26	4.97	2.80	2.05	5.40

COLUMBIA, MISSOURI
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 38° 49’ N, 92° 13’ W, 270 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	2.18	2.85	3.96	5.05	6.16	6.02	6.44	5.91	4.83	3.82	2.53	1.80	4.31
1-Axis North South Tracking Array	2.34	3.24	4.82	6.90	8.51	8.94	9.14	8.23	6.26	4.60	2.81	1.88	5.65
LATITUDE TILT (°)													
Fixed Array	2.36	3.05	4.12	5.02	5.82	5.54	6.00	5.73	4.93	4.07	2.74	1.94	4.28
1-Axis North South Tracking Array	2.50	3.41	4.94	6.88	8.29	8.64	8.86	8.12	6.33	4.79	2.99	2.01	5.66
LATITUDE TILT +15 (°)													
Fixed Array	2.44	3.11	4.08	4.73	5.20	4.81	5.27	5.25	4.79	4.11	2.82	2.00	4.06
1-Axis North South Tracking Array	2.58	3.46	4.90	6.67	7.87	8.18	8.39	7.79	6.21	4.83	3.06	2.07	5.51
TWO AXIS TRACKING	2.59	3.47	4.96	6.93	8.61	9.19	9.31	8.27	6.34	4.84	3.07	2.08	5.82

GREAT FALLS, MONTANA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 47° 29' N, 111° 22' W, 1116 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	2.51	3.69	5.17	5.60	6.00	6.61	7.62	6.86	5.61	4.54	2.92	2.27	4.96
1-Axis North South Tracking Array	2.96	4.56	6.93	7.54	7.96	9.03	11.25	9.79	7.62	5.93	3.47	2.66	6.66
LATITUDE TILT (°)													
Fixed Array	2.88	4.08	5.46	5.55	5.69	6.14	7.12	6.67	5.77	4.95	3.31	2.63	5.03
1-Axis North South Tracking Array	3.26	4.86	7.15	7.51	7.76	8.72	10.93	9.68	7.74	6.24	3.80	2.96	6.73
LATITUDE TILT +15 (°)													
Fixed Array	3.07	4.23	5.44	5.21	5.11	5.36	6.24	6.12	5.61	5.08	3.52	2.84	4.82
1-Axis North South Tracking Array	3.43	4.98	7.12	7.26	7.36	8.20	10.37	9.30	7.61	6.32	3.97	3.14	6.60
TWO AXIS TRACKING	3.46	4.98	7.16	7.57	8.04	9.21	11.44	9.83	7.74	6.32	3.99	3.19	6.92

OMAHA, NEBRASKA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 41° 25’ N, 26° 5’ W, 320 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	3.41	4.33	4.74	5.35	6.40	6.73	6.52	6.35	5.25	4.48	3.35	2.77	4.98
1-Axis North South Tracking Array	4.22	5.68	6.26	7.08	9.30	9.55	9.00	8.91	7.13	5.83	4.12	3.29	6.70
LATITUDE TILT (°)													
Fixed Array	3.95	4.82	4.99	5.32	6.04	6.24	6.10	6.18	5.36	4.91	3.81	3.23	5.08
1-Axis North South Tracking Array	4.65	6.06	6.45	7.07	9.08	9.23	8.73	8.81	7.23	6.16	4.49	3.67	6.81
LATITUDE TILT +15 (°)													
Fixed Array	4.26	5.04	4.97	5.02	5.38	5.44	5.38	5.68	5.20	5.06	4.06	3.49	4.91
1-Axis North South Tracking Array	4.90	6.21	6.42	6.85	8.65	8.72	8.25	8.47	7.09	6.26	4.69	3.90	6.70
TWO AXIS TRACKING	4.95	6.21	6.47	7.12	9.42	9.76	9.14	8.95	7.22	6.25	4.72	3.96	7.02

ELKO, NEVADA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 40° 50’ N, 115° 47’ W, 1547 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	3.73	5.26	5.76	6.62	7.33	7.89	8.16	8.10	7.47	5.89	3.97	3.34	6.13
1-Axis North South Tracking Array	4.59	6.96	7.86	9.40	10.97	11.88	12.06	11.54	10.58	7.82	5.00	4.08	8.57
LATITUDE TILT (°)													
Fixed Array	4.33	5.90	6.09	6.55	6.93	7.27	7.59	7.89	7.74	6.48	4.54	3.93	6.27
1-Axis North South Tracking Array	5.07	7.44	8.10	9.36	10.73	11.49	11.70	11.42	10.78	8.27	5.45	4.56	8.70
LATITUDE TILT +15 (°)													
Fixed Array	4.67	6.19	6.09	6.14	6.18	6.27	6.62	7.24	7.56	6.70	4.85	4.28	6.06
1-Axis North South Tracking Array	5.35	7.65	8.08	9.07	10.24	10.87	11.09	10.98	10.63	8.42	5.70	4.85	8.58
TWO AXIS TRACKING	5.41	7.65	8.13	9.43	11.12	12.19	12.28	11.59	10.76	8.41	5.73	4.92	8.97

LAS VEGAS, NEVADA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 36° 05' N, 115° 10' W, 664 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	4.79	6.09	7.26	8.25	8.38	8.47	7.92	7.91	7.64	6.27	5.05	4.14	6.85
1-Axis North South Tracking Array	6.19	8.21	10.29	11.94	12.47	12.51	11.33	11.11	10.78	8.46	6.58	5.15	9.59
LATITUDE TILT (°)													
Fixed Array	5.64	6.89	7.72	8.22	7.90	7.77	7.35	7.71	7.93	6.92	5.87	4.91	7.07
1-Axis North South Tracking Array	6.86	8.81	10.63	11.95	12.18	12.06	10.96	10.99	11.00	8.94	7.21	5.78	9.78
LATITUDE TILT +15 (°)													
Fixed Array	6.16	7.28	7.74	7.73	6.99	6.65	6.40	7.08	7.77	7.17	6.34	5.39	6.89
1-Axis North South Tracking Array	7.27	9.09	10.62	11.60	11.59	11.36	10.35	10.55	10.86	9.10	7.58	6.17	9.68
TWO AXIS TRACKING	7.35	9.08	10.64	12.00	12.63	12.81	11.52	11.15	10.98	9.08	7.63	6.27	10.10

ALBUQUERQUE, NEW MEXICO
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M^2)

LOCATION: 35° 03' N, 106° 37' W, 1619 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	4.49	5.61	6.53	7.85	8.18	8.06	7.78	7.61	7.09	6.46	5.31	4.44	6.62
1-Axis North South Tracking Array	5.87	7.44	8.84	10.85	11.62	11.88	10.45	10.33	9.84	8.60	7.05	5.71	9.04
LATITUDE TILT (°)													
Fixed Array	5.27	6.31	6.91	7.84	7.75	7.40	7.27	7.42	7.35	7.13	6.19	5.28	6.84
1-Axis North South Tracking Array	6.47	7.97	9.13	10.85	11.33	11.45	10.10	10.21	10.03	9.11	7.73	6.37	9.23
LATITUDE TILT +15 (°)													
Fixed Array	5.74	6.65	6.91	7.39	6.90	6.37	6.38	6.83	7.19	7.39	6.70	5.81	6.69
1-Axis North South Tracking Array	6.84	8.22	9.11	10.52	10.76	10.79	9.48	9.78	9.90	9.29	8.11	6.79	9.13
TWO AXIS TRACKING	6.92	8.22	9.15	10.90	11.74	12.18	10.60	10.37	10.02	9.26	8.18	6.91	9.54

SYRACUSE, NEW YORK
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 43° 07' N, 76° 07' W, 124 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	1.75	2.27	3.35	4.69	5.06	5.41	5.58	5.28	4.33	3.07	1.75	1.32	3.66
1-Axis North South Tracking Array	2.00	2.80	4.29	6.29	6.53	7.03	7.09	6.62	5.41	3.74	1.98	1.49	4.61
LATITUDE TILT (°)													
Fixed Array	1.94	2.44	3.46	4.62	4.79	5.03	5.24	5.13	4.43	3.27	1.92	1.47	3.65
1-Axis North South Tracking Array	2.16	2.93	4.37	6.25	6.35	6.78	6.86	6.51	5.48	3.89	2.11	1.61	4.62
LATITUDE TILT +15 (°)													
Fixed Array	2.04	2.50	3.40	4.32	4.31	4.44	4.67	4.74	4.29	3.30	1.98	1.53	3.46
1-Axis North South Tracking Array	2.24	2.97	4.32	6.03	6.02	6.38	6.46	6.22	5.37	3.91	2.17	1.67	4.49
TWO AXIS TRACKING	2.26	2.98	4.38	6.31	6.60	7.18	7.19	6.64	5.49	3.93	2.19	1.69	4.74

RALEIGH-DURHAM, NORTH CAROLINA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 35° 52’ N, 78° 47’ W, 134 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	2.81	3.85	4.69	5.61	5.58	5.78	5.75	5.53	4.80	4.29	3.69	2.79	4.60
1-Axis North South Tracking Array	3.48	4.95	6.27	7.71	7.16	7.30	7.18	7.02	5.98	5.37	4.66	3.36	5.87
LATITUDE TILT (°)													
Fixed Array	3.20	4.25	4.94	5.56	5.30	5.39	5.41	5.40	4.90	4.64	4.20	3.22	4.70
1-Axis North South Tracking Array	3.79	5.26	6.45	7.68	6.97	7.03	6.94	6.93	6.06	5.64	5.06	3.71	5.96
LATITUDE TILT +15 (°)													
Fixed Array	3.41	4.43	4.92	5.23	4.78	4.77	4.83	5.01	4.76	4.75	4.49	3.48	4.57
1-Axis North South Tracking Array	3.96	5.38	6.42	7.44	6.60	6.59	6.53	6.64	5.94	5.71	5.28	3.92	5.87
TWO AXIS TRACKING	4.00	5.39	6.47	7.74	7.22	7.43	7.27	7.04	6.07	5.72	5.31	3.97	6.14

BISMARCK, NORTH DAKOTA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 46° 46’ N, 100° 45’ W, 502 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	2.80	4.13	4.89	5.37	6.14	6.50	7.06	6.69	5.44	4.23	2.82	2.59	4.89
1-Axis North South Tracking Array	3.32	5.26	6.54	7.25	8.70	9.08	9.83	9.53	7.36	5.34	3.39	3.09	6.57
LATITUDE TILT (°)													
Fixed Array	3.21	4.60	5.14	5.33	5.82	6.03	6.62	6.51	5.61	4.59	3.20	3.03	4.98
1-Axis North South Tracking Array	3.66	5.62	6.73	7.24	8.50	8.77	9.54	9.43	7.49	5.62	3.69	3.45	6.65
LATITUDE TILT +15 (°)													
Fixed Array	3.44	4.80	5.12	5.02	5.21	5.26	5.84	5.98	5.47	4.69	3.39	3.29	4.79
1-Axis North South Tracking Array	3.85	5.77	6.70	7.01	8.09	8.26	9.01	9.06	7.38	5.69	3.85	3.67	6.53
TWO AXIS TRACKING	3.89	5.77	6.74	7.29	8.80	9.27	9.97	9.57	7.49	5.69	3.08	3.73	6.85

OKLAHOMA CITY, OKLAHOMA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 35° 24’ N, 97° 36’ W, 397 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	3.69	4.13	5.05	6.07	5.92	6.53	6.64	6.65	5.74	5.05	4.05	3.12	5.23
1-Axis North South Tracking Array	4.91	5.38	6.84	8.37	7.94	8.77	8.79	8.93	7.61	6.59	5.36	3.85	6.95
LATITUDE TILT (°)													
Fixed Array	4.31	4.57	5.32	6.04	5.61	6.06	6.22	6.50	5.89	5.53	4.68	3.63	5.37
1-Axis North South Tracking Array	5.38	5.71	7.03	8.36	7.73	8.45	8.51	8.82	7.73	6.95	5.83	4.26	7.07
LATITUDE TILT +15 (°)													
Fixed Array	4.68	4.76	5.30	5.71	5.02	5.31	5.50	6.01	5.74	5.70	5.04	3.94	5.23
1-Axis North South Tracking Array	5.65	5.84	7.00	8.11	7.34	7.95	8.02	8.47	7.60	7.06	6.10	4.51	6.98
TWO AXIS TRACKING	5.72	5.85	7.05	8.41	8.02	8.95	8.92	8.96	7.72	7.06	6.15	4.58	7.29

MEDFORD, OREGON
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 42° 22' N, 122° 52' W, 396 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	1.78	3.16	4.55	5.59	6.62	7.22	8.03	7.40	6.26	4.26	2.33	1.27	4.88
1-Axis North South Tracking Array	1.98	3.77	5.77	7.38	8.95	10.20	11.65	10.31	8.40	5.33	2.69	1.38	6.50
LATITUDE TILT (°)													
Fixed Array	1.96	3.44	4.77	5.53	6.29	6.69	7.50	7.22	6.45	4.61	2.58	1.39	4.88
1-Axis North South Tracking Array	2.14	4.00	5.95	7.34	8.73	9.85	11.31	10.20	8.55	5.60	2.89	1.49	6.52
LATITUDE TILT +15 (°)													
Fixed Array	2.05	3.54	4.73	5.19	5.63	5.81	6.57	6.65	6.29	4.70	2.68	1.45	4.61
1-Axis North South Tracking Array	2.22	4.08	5.91	7.10	8.28	9.28	10.71	9.80	8.42	5.67	2.99	1.55	6.34
TWO AXIS TRACKING	2.23	4.10	5.97	7.41	9.04	10.42	11.83	10.35	8.54	5.67	3.00	1.56	6.69

PITTSBURGH, PENNSYLVANIA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 40° 30' N, 80° 13' W, 373 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	2.02	2.38	3.30	4.69	5.18	5.44	5.59	5.18	4.50	3.56	2.22	1.43	3.80
1-Axis North South Tracking Array	2.36	2.84	4.12	6.05	6.72	6.90	7.04	6.43	5.59	4.37	2.58	1.60	4.73
LATITUDE TILT (°)													
Fixed Array	2.26	2.55	3.38	4.61	4.91	5.07	5.25	5.05	4.58	3.81	2.43	1.58	3.80
1-Axis North South Tracking Array	2.56	2.97	4.19	6.00	6.54	6.64	6.81	6.34	5.65	4.57	2.75	1.73	4.74
LATITUDE TILT +15 (°)													
Fixed Array	2.38	2.59	3.31	4.33	4.41	4.49	4.69	4.68	4.43	3.87	2.52	1.65	3.62
1-Axis North South Tracking Array	2.67	3.00	4.13	5.79	6.20	6.25	6.42	6.06	5.53	4.61	2.82	1.79	4.61
TWO AXIS TRACKING	2.69	3.02	4.20	6.07	6.79	7.03	7.14	6.45	5.65	4.63	2.83	1.80	4.87

SAN JUAN, PUERTO RICO
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 18° 26’ N, 66° 00’ W, 19 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	4.34	4.89	5.75	6.14	5.55	5.89	5.92	5.88	5.40	4.91	4.49	4.13	5.28
1-Axis North South Tracking Array	5.55	6.29	7.52	7.87	6.83	7.51	7.50	7.47	6.91	6.30	5.74	5.28	6.73
LATITUDE TILT (°)													
Fixed Array	4.97	5.39	6.04	6.10	5.29	5.50	5.58	5.74	5.52	5.31	5.08	4.79	5.44
1-Axis North South Tracking Array	6.02	6.66	7.73	7.83	6.64	7.22	7.24	7.35	6.99	6.58	6.18	5.77	6.85
LATITUDE TILT +15 (°)													
Fixed Array	5.35	5.63	6.02	5.76	4.80	4.85	4.98	5.33	5.38	5.44	5.42	5.20	5.35
1-Axis North South Tracking Array	6.31	6.83	7.69	7.57	6.27	6.76	6.80	7.04	6.87	6.66	6.43	6.09	6.78
TWO AXIS TRACKING	6.38	6.84	7.75	7.90	6.89	7.66	7.61	7.49	7.00	6.67	6.47	6.19	7.07

NASHVILLE, TENNESSEE
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 36° 07' N, 86° 41' W, 180 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	2.37	3.19	4.32	5.30	5.53	6.31	6.02	5.81	5.07	4.21	2.96	2.22	4.45
1-Axis North South Tracking Array	2.83	3.94	5.58	6.68	6.86	8.04	7.69	7.09	6.63	5.31	3.60	2.62	5.58
LATITUDE TILT (°)													
Fixed Array	2.69	3.48	4.50	5.26	5.29	5.89	5.66	5.68	5.18	4.57	3.34	2.56	4.51
1-Axis North South Tracking Array	3.09	4.16	5.72	6.66	6.68	7.74	7.44	6.99	6.72	5.59	3.91	2.89	5.64
LATITUDE TILT +15 (°)													
Fixed Array	2.86	3.58	4.44	4.96	4.79	5.21	5.05	5.26	5.03	4.69	3.54	2.75	4.35
1-Axis North South Tracking Array	3.24	4.23	5.67	6.43	6.31	7.26	7.01	6.67	6.59	5.67	4.07	3.06	5.52
TWO AXIS TRACKING	3.27	4.24	5.72	6.71	6.90	8.18	7.79	7.11	6.72	5.67	4.10	3.10	5.80

AUSTIN, TEXAS
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 30° 18’ N, 97° 42’ W, 189 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	3.56	4.14	5.20	5.09	5.80	6.39	6.63	6.20	5.48	4.91	4.00	3.58	5.09
1-Axis North South Tracking Array	4.66	5.38	7.06	6.63	7.46	8.35	8.77	8.09	7.11	6.44	5.25	4.71	6.67
LATITUDE TILT (°)													
Fixed Array	4.13	4.58	5.45	5.04	5.51	5.94	6.22	6.03	5.63	5.35	4.57	4.20	5.23
1-Axis North South Tracking Array	5.08	5.71	7.24	6.61	7.26	8.04	8.48	7.98	7.22	6.77	5.68	5.17	6.78
LATITUDE TILT +15 (°)													
Fixed Array	4.47	4.78	5.42	4.76	4.96	5.21	5.51	5.57	5.49	5.51	4.89	4.59	5.10
1-Axis North South Tracking Array	5.34	5.85	7.20	6.40	6.87	7.54	7.99	7.64	7.10	6.87	5.92	5.47	6.69
TWO AXIS TRACKING	5.42	5.86	7.25	6.66	7.52	8.51	8.89	8.12	7.22	6.87	5.96	5.57	7.00

BROWNSVILLE, TEXAS
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 25° 54' N, 97° 26' W, 6 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	3.30	4.07	5.02	6.15	5.98	6.38	6.80	6.74	5.66	4.79	3.71	3.16	5.15
1-Axis North South Tracking Array	4.06	5.16	6.59	7.84	7.38	8.58	9.24	9.07	7.18	6.19	4.81	3.90	6.67
LATITUDE TILT (°)													
Fixed Array	3.74	4.48	5.24	6.13	5.71	5.91	6.35	6.57	5.82	5.19	4.20	3.62	5.25
1-Axis North South Tracking Array	4.41	5.47	6.76	7.83	7.18	8.25	8.93	8.95	7.29	6.49	5.17	4.26	6.75
LATITUDE TILT +15 (°)													
Fixed Array	4.00	4.65	5.21	5.80	5.18	5.16	5.58	6.06	5.68	5.32	4.48	3.90	5.09
1-Axis North South Tracking Array	4.61	5.59	6.71	7.57	6.78	7.75	8.41	8.57	7.17	6.57	5.38	4.48	6.64
TWO AXIS TRACKING	4.66	5.60	6.77	7.88	7.44	8.76	9.39	9.11	7.29	6.57	5.41	4.55	6.96

EL PASO, TEXAS
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 31° 45' N, 106° 20' W, 1200 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	4.69	6.07	6.92	7.80	8.25	8.22	7.70	7.35	6.79	6.50	5.24	4.55	6.67
1-Axis North South Tracking Array	6.26	8.10	9.48	10.99	11.77	11.51	10.58	10.02	9.31	8.88	7.00	6.03	9.16
LATITUDE TILT (°)													
Fixed Array	5.51	6.85	7.35	7.78	7.78	7.56	7.18	7.15	7.01	7.18	6.10	5.43	6.91
1-Axis North South Tracking Array	6.88	8.69	9.80	10.99	11.46	11.06	10.23	9.89	9.48	9.39	7.66	6.71	9.35
LATITUDE TILT +15 (°)													
Fixed Array	6.01	7.24	7.36	7.32	6.89	6.51	6.28	6.56	6.85	7.45	6.61	5.99	6.75
1-Axis North South Tracking Array	7.26	8.97	9.79	10.66	10.87	10.36	9.61	9.48	9.34	9.57	8.04	7.15	9.26
TWO AXIS TRACKING	7.36	8.96	9.82	11.04	11.90	11.77	10.75	10.06	9.47	9.55	8.10	7.28	9.67

FORT WORTH, TEXAS
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 32° 50’ N, 90° 20’ W, 225 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	3.26	4.14	5.31	5.13	5.87	6.69	6.86	6.64	5.92	4.87	3.97	3.29	5.17
1-Axis North South Tracking Array	4.11	5.25	6.97	6.80	7.74	9.06	9.58	8.99	7.98	6.32	5.15	4.15	6.85
LATITUDE TILT (°)													
Fixed Array	3.76	4.60	5.61	5.13	5.57	6.20	6.42	6.47	6.10	5.34	4.57	3.87	5.31
1-Axis North South Tracking Array	4.50	5.61	7.20	6.80	7.54	8.73	9.28	8.88	8.11	6.68	5.60	4.60	6.97
LATITUDE TILT +15 (°)													
Fixed Array	4.05	4.81	5.61	4.86	5.01	5.41	5.67	5.97	5.95	5.52	4.90	4.22	5.17
1-Axis North South Tracking Array	4.73	5.77	7.18	6.61	7.14	8.20	8.77	8.52	7.98	6.80	5.86	4.89	6.88
TWO AXIS TRACKING	4.79	5.77	7.21	6.84	7.82	9.25	9.75	9.02	8.11	6.80	5.90	4.97	7.19

BRYCE CANYON, UTAH
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 37° 42’ N, 112° 09’ W, 2313 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	4.52	5.51	6.58	7.66	7.70	7.92	7.52	7.27	7.31	6.21	4.91	4.29	6.45
1-Axis North South Tracking Array	5.77	7.46	9.20	10.91	11.66	12.01	10.93	10.38	10.40	8.28	6.45	5.34	9.07
LATITUDE TILT (°)													
Fixed Array	5.30	6.19	6.98	7.63	7.27	7.27	6.98	7.05	7.57	6.84	5.70	5.11	6.66
1-Axis North South Tracking Array	6.39	7.96	9.50	10.91	11.39	11.60	10.59	10.25	10.59	8.76	7.06	6.00	9.25
LATITUDE TILT +15 (°)													
Fixed Array	5.77	6.51	6.98	7.18	6.46	6.25	6.09	6.46	7.39	7.08	6.14	5.61	6.49
1-Axis North South Tracking Array	6.76	8.19	9.48	10.60	10.88	10.98	10.02	9.85	10.44	8.92	7.40	6.42	9.16
TWO AXIS TRACKING	6.84	8.19	9.52	10.97	11.81	12.32	11.13	10.42	10.57	8.89	7.45	6.53	9.56

SEATTLE, WASHINGTON
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 47° 27' N, 122° 18' W, 122 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	1.28	2.08	3.73	4.64	5.40	5.53	6.46	5.92	4.60	2.88	1.52	1.04	3.77
1-Axis North South Tracking Array	1.41	2.36	4.73	6.09	7.16	7.25	8.92	7.97	5.91	3.46	1.70	1.16	4.86
LATITUDE TILT (°)													
Fixed Array	1.39	2.22	3.87	4.56	5.12	5.14	6.06	5.75	4.69	3.07	1.65	1.16	3.73
1-Axis North South Tracking Array	1.51	2.48	4.84	6.04	6.97	6.99	8.66	7.87	5.99	3.61	1.81	1.26	4.85
LATITUDE TILT +15 (°)													
Fixed Array	1.44	2.25	3.80	4.26	4.58	4.53	5.36	5.29	4.53	3.10	1.70	1.22	3.51
1-Axis North South Tracking Array	1.55	2.51	4.79	5.82	6.61	6.57	8.19	7.54	5.86	3.63	1.85	1.32	4.70
TWO AXIS TRACKING	1.56	2.52	4.85	6.11	7.24	7.40	9.05	8.00	5.99	3.65	1.86	1.33	4.98

MADISON, WISCONSIN
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 43° 08’ N, 89° 20’ W, 262 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	2.73	3.73	4.98	4.89	5.47	5.83	6.10	6.03	5.18	3.80	2.55	1.96	4.44
1-Axis North South Tracking Array	3.23	4.61	6.43	6.43	7.48	7.73	7.96	7.96	6.70	4.70	3.13	2.17	5.72
LATITUDE TILT (°)													
Fixed Array	3.14	4.10	5.25	4.85	5.17	5.43	5.72	5.86	5.33	4.10	2.88	2.25	4.51
1-Axis North South Tracking Array	3.57	4.91	6.64	6.40	7.29	7.46	7.70	7.85	6.81	4.94	3.39	2.42	5.79
LATITUDE TILT +15 (°)													
Fixed Array	3.36	4.24	5.22	4.56	4.63	4.78	5.07	5.40	5.18	4.18	3.05	2.40	4.34
1-Axis North South Tracking Array	3.76	5.02	6.61	6.19	6.92	7.02	7.26	7.52	6.69	5.00	3.53	2.57	5.68
TWO AXIS TRACKING	3.79	5.02	6.65	6.46	7.57	7.89	8.08	7.98	6.81	5.00	3.55	2.60	5.95

BUENOS AIRES, ARGENTINA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M^2)

LOCATION: 34° 58' S, 58° 48'O, 25 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	7.13	6.49	5.45	4.46	3.57	2.93	3.24	4.11	5.07	5.90	6.47	7.12	5.16
1-Axis North South Tracking Array	9.80	8.72	7.02	5.50	4.07	3.13	3.57	4.98	6.38	7.86	8.90	9.85	6.65
LATITUDE TILT (°)													
Fixed Array	6.58	6.19	5.47	4.75	4.02	3.39	3.70	4.48	5.19	5.71	6.02	6.51	5.17
1-Axis North South Tracking Array	9.24	8.52	7.20	5.97	4.64	3.67	4.14	5.51	6.68	7.80	8.46	9.18	6.75
LATITUDE TILT +15 (°)													
Fixed Array	5.77	5.62	5.21	4.80	4.25	3.65	3.95	4.60	5.06	5.27	5.33	5.65	4.93
1-Axis North South Tracking Array	8.05	7.74	6.89	6.03	4.90	3.96	4.42	5.66	6.52	7.21	7.44	7.88	6.39
TWO AXIS TRACKING	9.85	8.74	7.22	6.07	4.91	4.01	4.45	5.67	6.70	7.91	8.92	9.94	7.03

QUITO, ECUADOR
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 0° 28' S, 78° 53' O, 2851 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	5.38	5.21	4.09	4.10	3.82	3.91	4.23	5.30	4.47	4.88	5.12	5.14	4.64
1-Axis North South Tracking Array	6.84	6.76	5.49	5.37	4.85	4.84	5.27	6.71	5.89	6.40	6.59	6.55	5.96
LATITUDE TILT (°)													
Fixed Array	5.06	5.06	4.14	4.33	4.18	4.38	4.71	5.74	4.60	4.81	4.87	4.81	4.72
1-Axis North South Tracking Array	6.45	6.59	5.61	5.77	5.46	5.59	6.01	7.34	6.13	6.33	6.26	6.11	6.13
LATITUDE TILT +15 (°)													
Fixed Array	4.51	4.68	4.02	4.38	4.39	4.71	5.03	5.95	4.53	4.52	4.39	4.24	4.61
1-Axis North South Tracking Array	5.61	5.98	5.36	5.83	5.76	6.03	6.42	7.54	5.98	5.85	5.50	5.23	5.92
TWO AXIS TRACKING	6.89	6.77	5.62	5.86	5.78	6.09	6.46	7.56	6.14	6.43	6.61	6.62	6.40

MEXICO D. F., MEXICO
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 19° 33’ N, 99° 18’ O, 2268 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	4.32	6.24	7.71	6.22	5.93	4.94	4.92	5.43	5.00	4.45	4.50	4.51	5.36
1-Axis North South Tracking Array	5.06	7.39	9.51	8.07	7.84	6.66	6.64	7.19	6.51	5.67	5.29	5.54	6.78
LATITUDE TILT (°)													
Fixed Array	4.90	6.86	7.99	6.07	5.57	4.58	4.60	5.22	5.04	4.82	5.06	5.23	5.50
1-Axis North South Tracking Array	5.85	8.17	9.96	8.02	7.45	6.20	6.24	7.02	6.69	6.15	6.04	6.49	7.04
LATITUDE TILT +15 (°)													
Fixed Array	5.23	7.11	7.86	5.64	4.97	4.06	4.10	4.78	4.84	4.87	5.36	5.68	5.38
1-Axis North South Tracking Array	6.23	8.40	9.74	7.41	6.56	5.32	5.42	6.37	6.41	6.22	6.38	6.99	6.79
TWO AXIS TRACKING	6.27	8.41	9.99	8.13	7.86	6.72	6.67	7.20	6.70	6.26	6.40	7.07	7.31

CARACAS, VENEZUELA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 10° 50’ N, 66° 88’ O, 862 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	5.00	5.95	6.12	5.99	5.02	5.23	5.58	5.84	5.70	4.92	4.54	4.69	5.38
1-Axis North South Tracking Array	5.98	7.29	7.75	7.73	6.62	6.82	7.24	7.56	7.32	6.21	5.53	5.55	6.80
LATITUDE TILT (°)													
Fixed Array	5.64	6.47	6.31	5.87	4.76	4.87	5.22	5.68	5.76	5.22	5.04	5.35	5.51
1-Axis North South Tracking Array	6.82	8.00	8.08	7.68	6.30	6.37	6.82	7.39	7.50	6.69	6.24	6.42	7.03
LATITUDE TILT +15 (°)													
Fixed Array	6.06	6.71	6.21	5.48	4.30	4.30	4.63	5.17	5.55	5.30	5.33	5.80	5.40
1-Axis North South Tracking Array	7.27	8.22	7.91	7.11	5.56	5.47	5.93	6.71	7.19	6.78	6.60	6.92	6.81
TWO AXIS TRACKING	7.32	8.23	8.11	7.78	6.64	6.90	7.29	7.58	7.51	6.81	6.62	7.00	7.32

BISKRA, ALGERIA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 34.85° N, 5.73° W, 124 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	4.21	4.98	5.64	6.01	6.36	6.63	6.79	6.60	5.69	4.86	4.05	3.79	5.47
1-Axis North South Tracking Array	4.87	6.29	7.05	7.97	8.74	9.21	9.36	8.83	7.25	6.07	4.69	4.20	7.04
LATITUDE TILT (°)													
Fixed Array	4.86	5.47	5.82	5.84	5.93	6.07	6.27	6.30	5.74	5.22	4.60	4.43	5.55
1-Axis North South Tracking Array	5.64	6.97	7.40	7.93	8.33	8.60	8.82	8.63	7.46	6.61	5.37	4.94	7.22
LATITUDE TILT +15 (°)													
Fixed Array	5.23	5.66	5.70	5.39	5.26	5.28	5.49	5.72	5.49	5.30	4.89	4.82	5.35
1-Axis North South Tracking Array	6.02	7.18	7.26	7.35	7.35	7.40	7.69	7.85	7.16	6.70	5.68	5.33	6.91
TWO AXIS TRACKING	6.07	7.19	7.43	8.03	8.76	9.29	9.40	8.85	7.47	6.73	5.70	5.40	7.35

LUANDA, ANGOLA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 8.82° N, 13.22° W, 42 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	5.92	6.07	5.43	4.89	4.60	4.18	3.36	3.70	4.57	5.06	5.60	6.16	4.96
1-Axis North South Tracking Array	7.62	7.83	7.02	6.19	5.61	5.01	4.17	4.75	5.96	6.66	7.27	7.87	6.33
LATITUDE TILT (°)													
Fixed Array	5.56	5.87	5.49	5.19	5.11	4.75	3.71	3.95	4.68	4.97	5.31	5.72	5.03
1-Axis North South Tracking Array	7.20	7.66	7.19	6.68	6.34	5.80	4.78	5.21	6.21	6.60	6.93	7.36	6.50
LATITUDE TILT +15 (°)													
Fixed Array	4.94	5.40	5.30	5.27	5.42	5.14	3.93	4.04	4.60	4.66	4.77	5.02	4.87
1-Axis North South Tracking Array	6.28	6.96	6.89	6.76	6.70	6.27	5.11	5.36	6.08	6.11	6.11	6.33	6.25
TWO AXIS TRACKING	7.67	7.84	7.20	6.79	6.73	6.34	5.14	5.37	6.23	6.69	7.30	7.95	6.77

DARWIN, AUSTRALIA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 12.43° N, 30.87° W, 27 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	5.17	5.33	5.57	5.05	5.14	4.96	5.25	6.14	6.41	6.52	6.22	5.68	5.62
1-Axis North South Tracking Array	6.83	7.02	7.18	6.34	6.15	5.79	6.19	7.46	8.09	8.38	8.06	7.41	7.08
LATITUDE TILT (°)													
Fixed Array	4.87	5.15	5.61	5.35	5.75	5.71	5.98	6.69	6.60	6.37	5.86	5.28	5.77
1-Axis North South Tracking Array	6.45	6.85	7.34	6.82	6.93	6.69	7.07	8.17	8.42	8.30	7.67	6.91	7.30
LATITUDE TILT +15 (°)													
Fixed Array	4.36	4.75	5.40	5.42	6.12	6.23	6.46	6.95	6.48	5.92	5.23	4.65	5.66
1 -Axis North South Tracking Array	5.61	6.22	7.02	6.89	7.31	7.22	7.54	8.40	8.22	7.67	6.74	5.93	7.06
TWO AXIS TRACKING	6.88	7.03	7.36	6.93	7.34	7.30	7.59	8.41	8.44	8.42	8.09	7.49	7.61

MELBOURNE, AUSTRALIA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 37.82° N, 44.97° W, 35 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	7.15	6.37	3.96	4.14	3.51	3.13	3.31	3.72	4.61	5.36	5.37	5.93	4.71
1-Axis North South Tracking Array	9.95	8.63	5.38	5.06	3.93	3.32	3.61	4.37	5.89	7.27	7.62	8.45	6.21
LATITUDE TILT (°)													
Fixed Array	6.60	6.07	3.94	4.41	3.96	3.65	3.80	4.05	4.72	5.18	5.01	5.45	4.74
1-Axis North South Tracking Array	9.39	8.44	5.53	5.49	4.49	3.90	4.19	4.85	6.17	7.22	7.25	7.88	6.23
LATITUDE TILT +15 (°)													
Fixed Array	5.78	5.51	3.74	4.45	4.20	3.96	4.08	4.17	4.59	4.77	4.45	4.77	4.54
1-Axis North South Tracking Array	8.19	7.68	5.30	5.55	4.74	4.22	4.48	4.99	6.04	6.68	6.39	6.78	5.92
TWO AXIS TRACKING	9.99	8.65	5.54	5.58	4.76	4.27	4.51	4.99	6.19	7.32	7.63	8.51	6.50

SHANGHAI, CHINA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M^2)

LOCATION: 31.28° N, 21.47° W, 3 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	3.38	3.07	4.27	4.85	5.34	4.69	5.82	5.99	5.20	4.38	3.47	3.11	4.46
1-Axis North South Tracking Array	3.74	3.55	5.54	6.58	7.38	6.63	8.01	8.04	6.72	5.37	3.90	3.35	5.73
LATITUDE TILT (°)													
Fixed Array	3.82	3.28	4.35	4.70	4.99	4.33	5.38	5.72	5.22	4.66	3.88	3.57	4.49
1-Axis North South Tracking Array	4.31	3.92	5.80	6.53	7.02	6.17	7.53	7.84	6.90	5.83	4.45	3.92	5.85
LATITUDE TILT +15 (°)													
Fixed Array	4.06	3.33	4.23	4.34	4.45	3.83	4.74	5.20	4.98	4.71	4.08	3.84	4.32
1-Axis North South Tracking Array	4.59	4.02	5.67	6.04	6.17	5.29	6.54	7.11	6.61	5.89	4.70	4.22	5.57
TWO AXIS TRACKING	4.62	4.03	5.82	6.62	7.40	6.69	8.06	8.05	6.91	5.93	4.72	4.27	6.09

PARIS-ST. MAUR, FRANCE
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 48.82° N, 2.50° W, 50 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	1.77	2.47	3.75	4.32	5.01	5.37	5.14	4.59	3.95	2.74	1.71	1.56	3.53
1-Axis North South Tracking Array	1.77	2.54	4.56	6.02	7.39	8.04	7.66	6.60	5.04	3.01	1.71	1.56	4.66
LATITUDE TILT (°)													
Fixed Array	2.06	2.75	3.90	4.25	4.78	5.05	4.87	4.45	4.02	2.95	1.95	1.83	3.57
1-Axis North South Tracking Array	2.06	2.82	4.79	5.99	7.05	7.50	7.21	6.46	5.19	3.27	1.95	1.83	4.68
LATITUDE TILT +15 (°)													
Fixed Array	2.24	2.91	3.88	4.04	4.41	4.61	4.47	4.18	3.93	3.02	2.11	2.02	3.49
1-Axis North South Tracking Array	2.24	2.94	4.69	5.54	6.22	6.45	6.28	5.87	4.98	3.31	2.11	2.02	4.39
TWO AXIS TRACKING	2.24	2.94	4.81	6.06	7.41	8.10	7.69	6.62	5.20	3.33	2.11	2.02	4.88

NEW DELHI, INDIA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 28.58° N, 77.20° W, 210 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	5.04	6.37	7.05	7.12	7.38	6.76	4.50	5.53	5.66	6.09	5.62	4.87	6.00
1-Axis North South Tracking Array	6.38	8.09	8.60	9.23	9.83	9.15	6.31	7.44	7.23	7.34	7.49	6.06	7.76
LATITUDE TILT (°)													
Fixed Array	5.83	7.04	7.31	6.94	6.87	6.19	4.20	5.30	5.70	6.57	6.43	5.73	6.18
1-Axis North South Tracking Array	7.38	8.97	9.02	9.17	9.36	8.53	5.94	7.27	7.44	7.99	8.56	7.11	8.06
LATITUDE TILT +15 (°)													
Fixed Array	6.28	7.31	7.18	6.42	6.08	5.38	3.75	4.83	5.46	6.69	6.88	6.26	6.04
1-Axis North South Tracking Array	7.87	9.23	8.83	8.50	8.25	7.32	5.17	6.60	7.13	8.09	9.05	7.68	7.81
IVV0 AXIS TRACKING	7.92	9.24	9.05	9.30	9.86	9.23	6.34	7.46	7.45	8.13	9.08	7.77	8.40

TOKYO, JAPAN
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 35.68° N, 39.77° W, 4 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	2.95	3.22	3.42	3.63	3.81	3.32	3.68	3.80	2.99	2.56	2.63	2.68	3.22
1-Axis North South Tracking Array	3.14	3.64	4.52	5.21	5.61	5.03	5.47	5.49	4.28	2.98	2.79	2.76	4.24
LATITUDE TILT (°)													
Fixed Array	3.34	3.47	3.47	3.50	3.58	3.09	3.43	3.62	2.96	2.67	2.92	3.08	3.26
1-Axis North South Tracking Array	3.63	4.03	4.74	5.18	5.34	4.69	5.15	5.37	4.40	3.24	3.19	3.24	4.35
LATITUDE TILT +15 (°)													
Fixed Array	3.55	3.53	3.35	3.23	3.21	2.76	3.07	3.30	2.80	2.65	3.06	3.31	3.15
1-Axis North South Tracking Array	3.87	4.14	4.64	4.80	4.71	4.03	4.48	4.88	4.23	3.27	3.37	3.50	4.16
TWO AXIS TRACKING	3.90	4.15	4.76	5.25	5.62	5.08	5.49	5.50	4.41	3.29	3.39	3.54	4.53

NAIROBI, KENYA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 1.30° N, 36.75° W, 1799 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	6.93	7.14	6.41	5.32	4.40	4.13	3.46	4.02	5.26	5.80	5.93	6.52	5.44
1-Axis North South Tracking Array	8.57	8.95	8.17	6.78	5.51	5.09	4.37	5.19	6.80	7.44	7.49	8.06	6.87
LATITUDE TILT (°)													
Fixed Array	6.46	6.89	6.49	5.65	4.86	4.66	3.81	4.30	5.42	5.69	5.60	6.03	5.49
1-Axis North South Tracking Array	8.08	8.73	8.35	7.29	6.21	5.88	4.98	5.68	7.08	7.37	7.12	7.52	7.02
LATITUDE TILT +15 (°)													
Fixed Array	5.67	6.29	6.26	5.75	5.13	5.02	4.02	4.42	5.33	5.32	5.01	5.24	5.29
1-Axis North South Tracking Array	7.02	7.92	7.98	7.36	6.55	6.34	5.32	5.83	6.91	6.81	6.26	6.44	6.73
TWO AXIS TRACKING	8.62	8.96	8.37	7.40	6.57	6.41	5.35	5.84	7.09	7.48	7.52	8.15	7.31

ULAN-BATOR, MONGOLIA
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

LOCATION: 47.85° N, 6.75° W, ---- Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	4.06	4.97	5.81	5.61	6.65	6.06	5.74	5.57	4.98	4.50	3.44	3.21	5.05
1-Axis North South Tracking Array	4.12	5.68	7.83	7.63	9.41	8.90	8.39	7.74	6.59	5.32	3.48	3.21	6.53
LATITUDE TILT (°)													
Fixed Array	4.81	5.64	6.12	5.55	6.33	5.69	5.43	5.42	5.10	4.92	4.01	3.85	5.24
1-Axis North South Tracking Array	4.83	6.29	8.22	7.60	8.97	8.30	7.91	7.57	6.78	5.79	4.03	3.85	6.68
LATITUDE TILT +15 (°)													
Fixed Array	5.31	6.04	6.13	5.27	5.82	5.18	4.97	5.08	4.99	5.10	4.38	4.28	4.77
1-Axis North South Tracking Array	5.31	6.47	8.05	7.04	7.92	7.14	6.88	6.88	6.51	5.86	4.38	4.28	6.39
TWO AXIS TRACKING	5.31	6.48	8.24	7.69	9.43	8.97	8.43	7.75	6.80	5.89	4.38	4.28	6.97

STOCKHOLM, SWEDEN
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M^2)

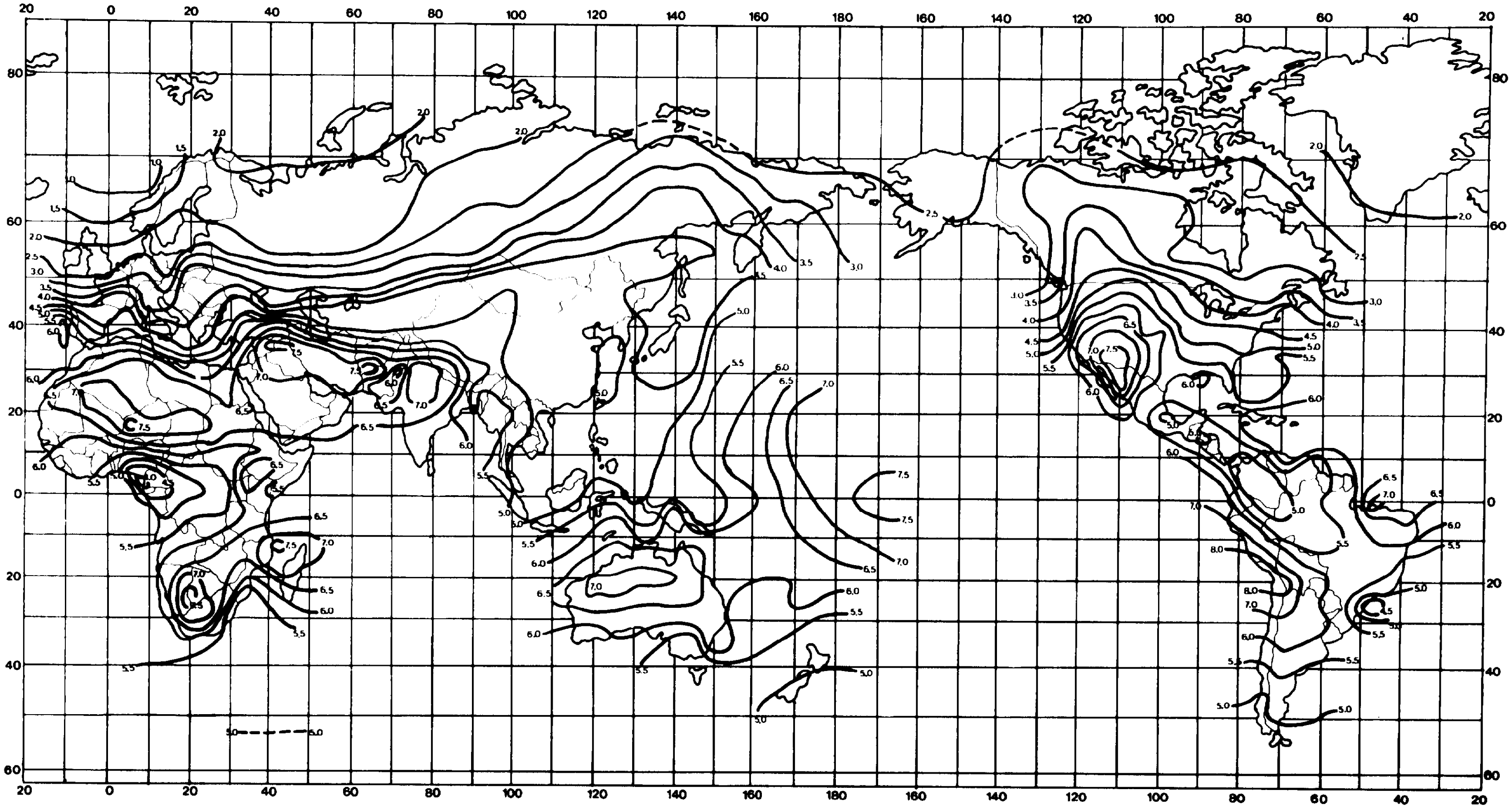
LOCATION: 59.35° N, 17.95° W, 43 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	1.43	2.46	3.85	4.12	5.17	5.45	5.27	4.57	3.46	2.09	1.09	1.05	3.33
1-Axis North South Tracking Array	1.43	2.47	4.63	5.82	8.16	8.94	8.51	6.79	4.42	2.20	1.09	1.05	4.63
LATITUDE TILT (°)													
Fixed Array	1.67	2.76	4.02	4.05	4.91	5.12	4.98	4.42	3.52	2.25	1.25	1.24	3.35
1-Axis North South Tracking Array	1.67	2.76	4.85	5.77	7.76	8.33	8.00	6.62	4.53	2.38	1.25	1.24	4.60
LATITUDE TILT +15 (°)													
Fixed Array	1.81	2.91	3.99	3.82	4.52	4.67	4.56	4.13	3.42	2.30	1.34	1.35	3.24
1-Axis North South Tracking Array	1.81	2.91	4.74	5.34	6.83	7.14	6.95	6.00	4.34	2.41	1.34	1.35	4.26
TWO AXIS TRACKING	1.81	2.91	4.86	5.86	8.18	9.03	8.56	6.80	4.54	2.43	1.34	1.35	4.81

BANGKOK, THAILAND
AVERAGE DAILY INSOLATION AVAILABILITY
(KWH/M²)

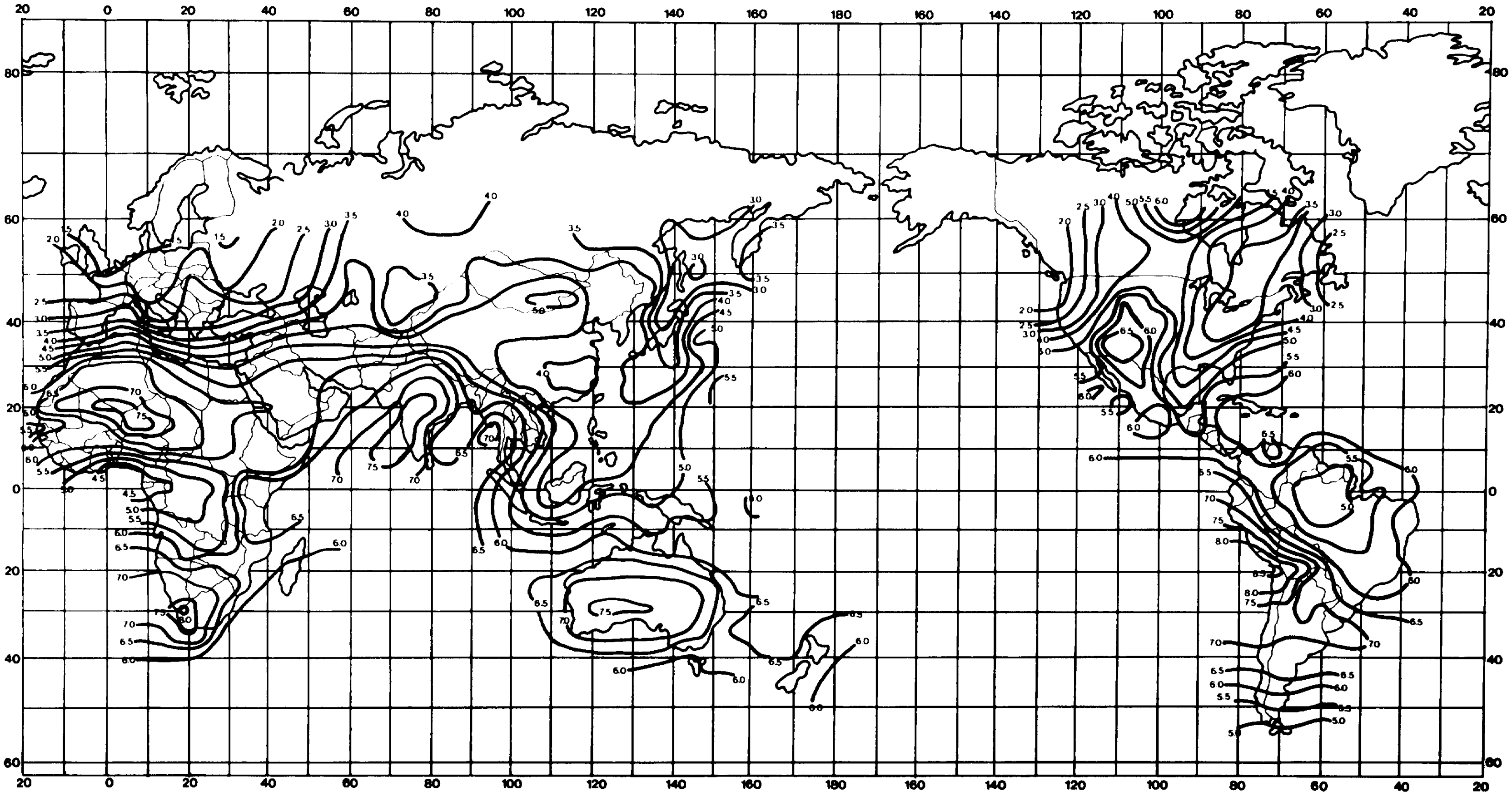
LOCATION: 13.73° N, 0.50° W, 20 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR
LATITUDE TILT -15 (°)													
Fixed Array	4.95	5.62	5.23	5.62	5.63	5.30	4.53	4.67	4.32	4.36	5.21	4.99	5.04
1-Axis North South Tracking Array	5.84	6.85	6.69	7.33	7.37	6.97	6.09	6.24	5.73	5.54	6.19	5.79	6.39
LATITUDE TILT (°)													
Fixed Array	5.60	6.10	5.37	5.51	5.32	4.93	4.27	4.52	4.35	4.61	5.84	5.74	5.18
1-Axis North South Tracking Array	6.67	7.51	6.99	7.28	7.03	6.52	5.74	6.10	5.87	5.98	7.00	6.71	6.62
LATITUDE TILT +15 (°)													
Fixed Array	6.01	6.32	5.27	5.14	4.77	4.36	3.84	4.18	4.19	4.66	6.23	6.25	5.10
1-Axis North South Tracking Array	7.12	7.73	6.85	6.75	6.20	5.60	5.00	5.55	5.64	6.06	7.41	7.24	6.43
TWO AXIS TRACKING	7.17	7.74	7.01	7.37	7.39	7.05	6.12	6.25	5.88	6.09	7.44	7.33	6.90



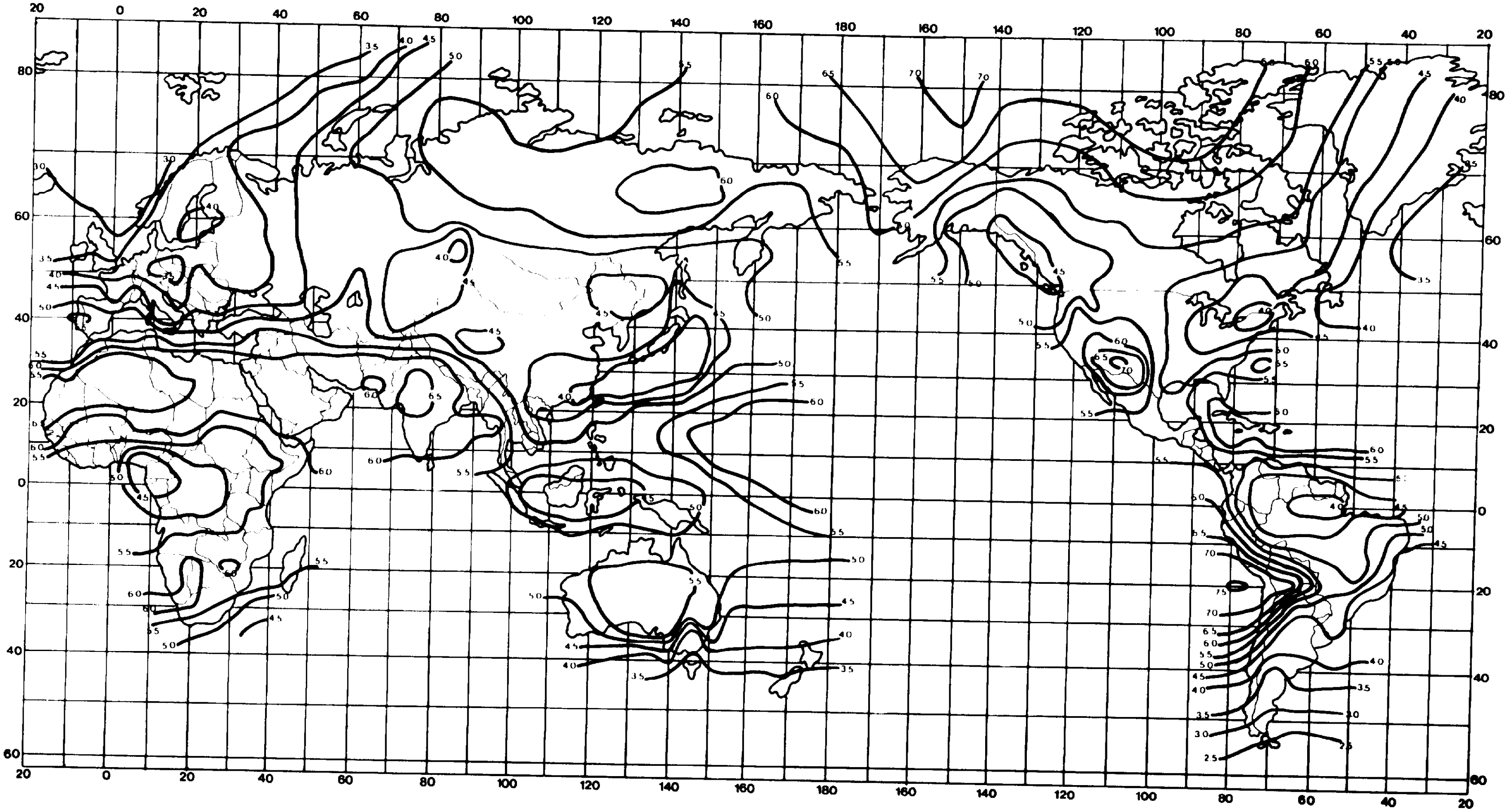
AUTUMN - Tilt angle equals the latitude angle +15°

Daily total solar radiation incident on a tilted surface in kWh/m²/day



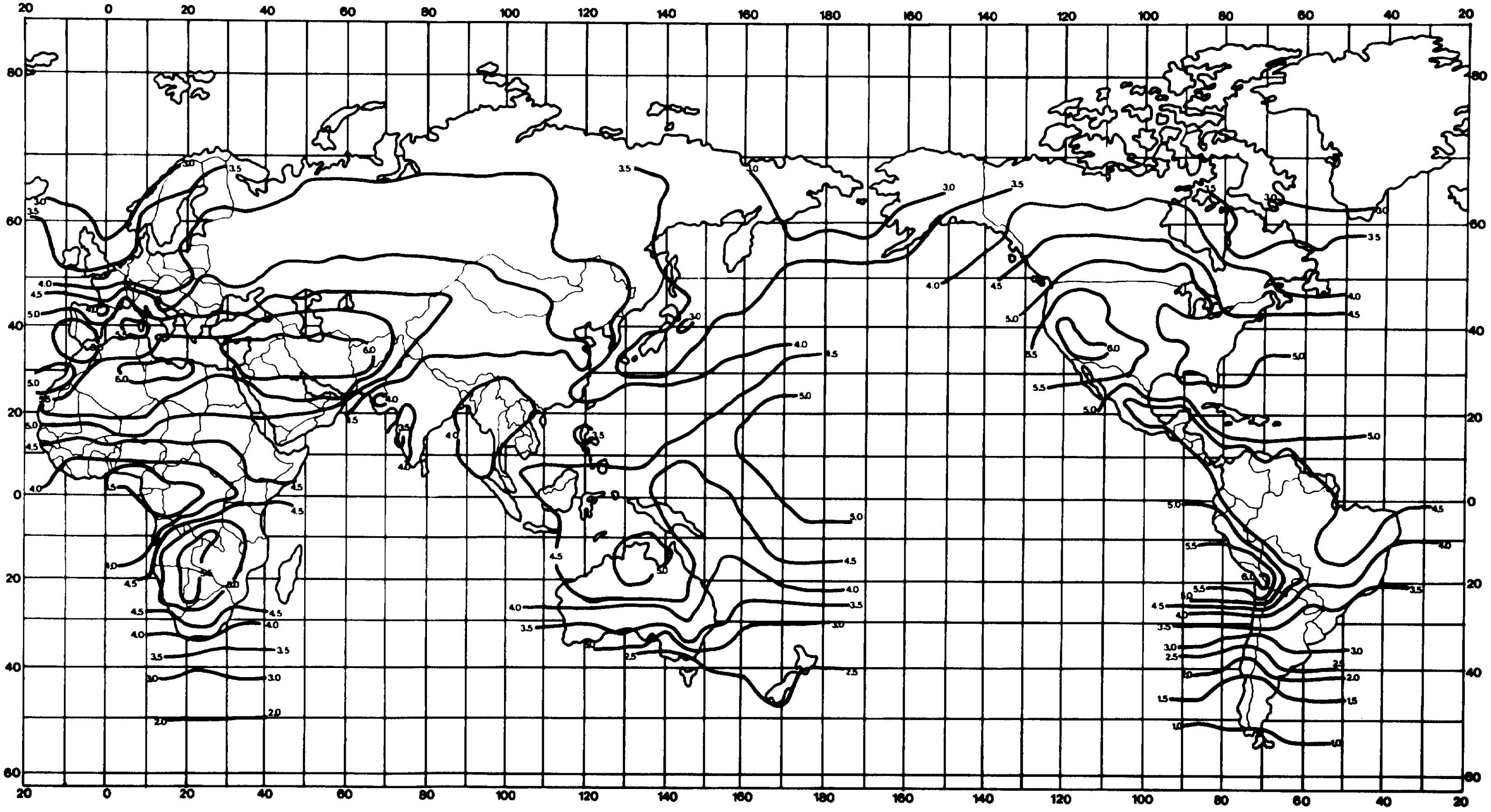
WINTER - Tilt angle equals the latitude angle +15°

Daily total solar radiation incident on a tilted surface in kWh/m²/day



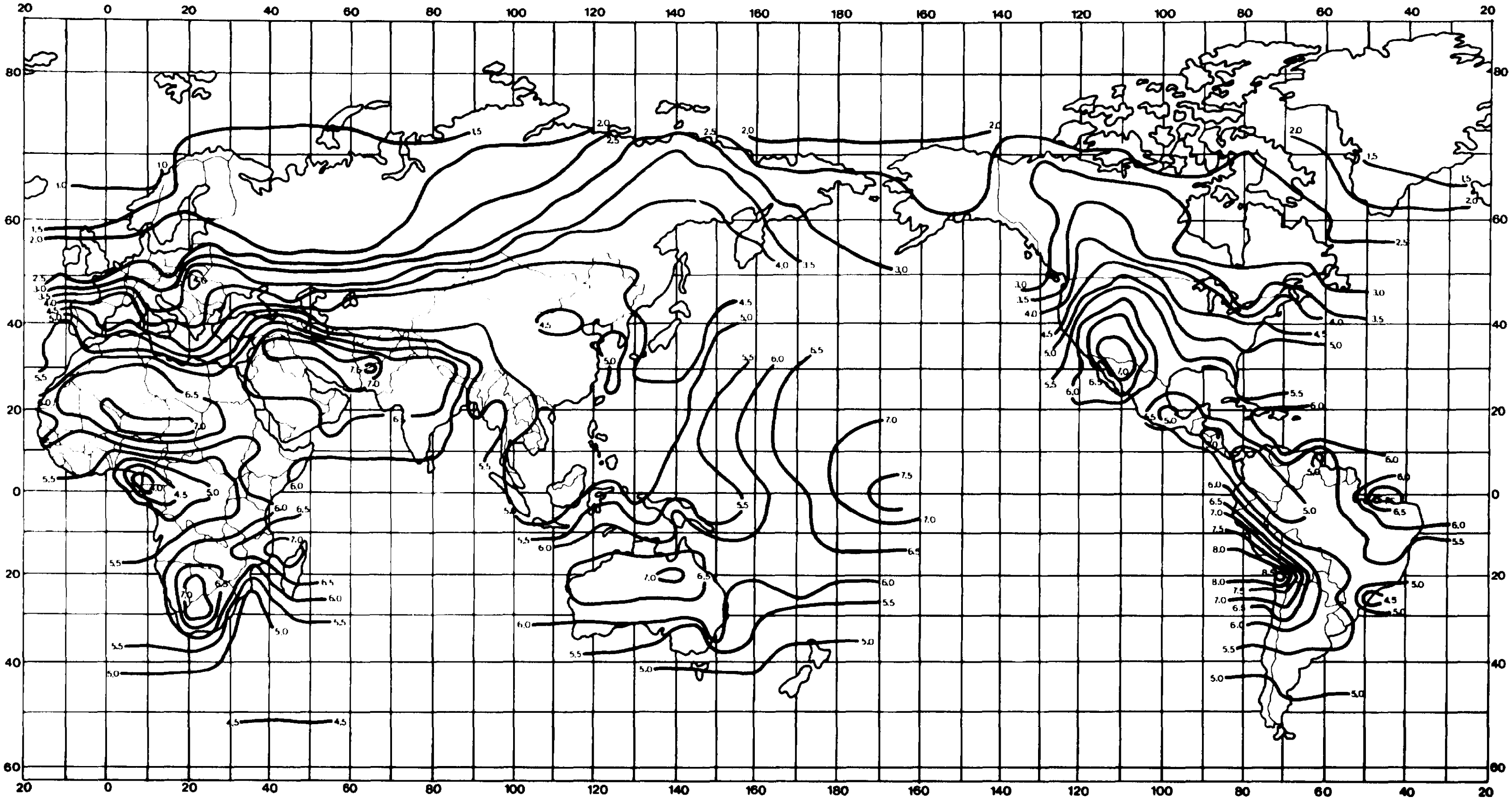
SPRING - Tilt angle equals the latitude angle +15°

Daily total solar radiation incident on a tilted surface in kWh/m²/day



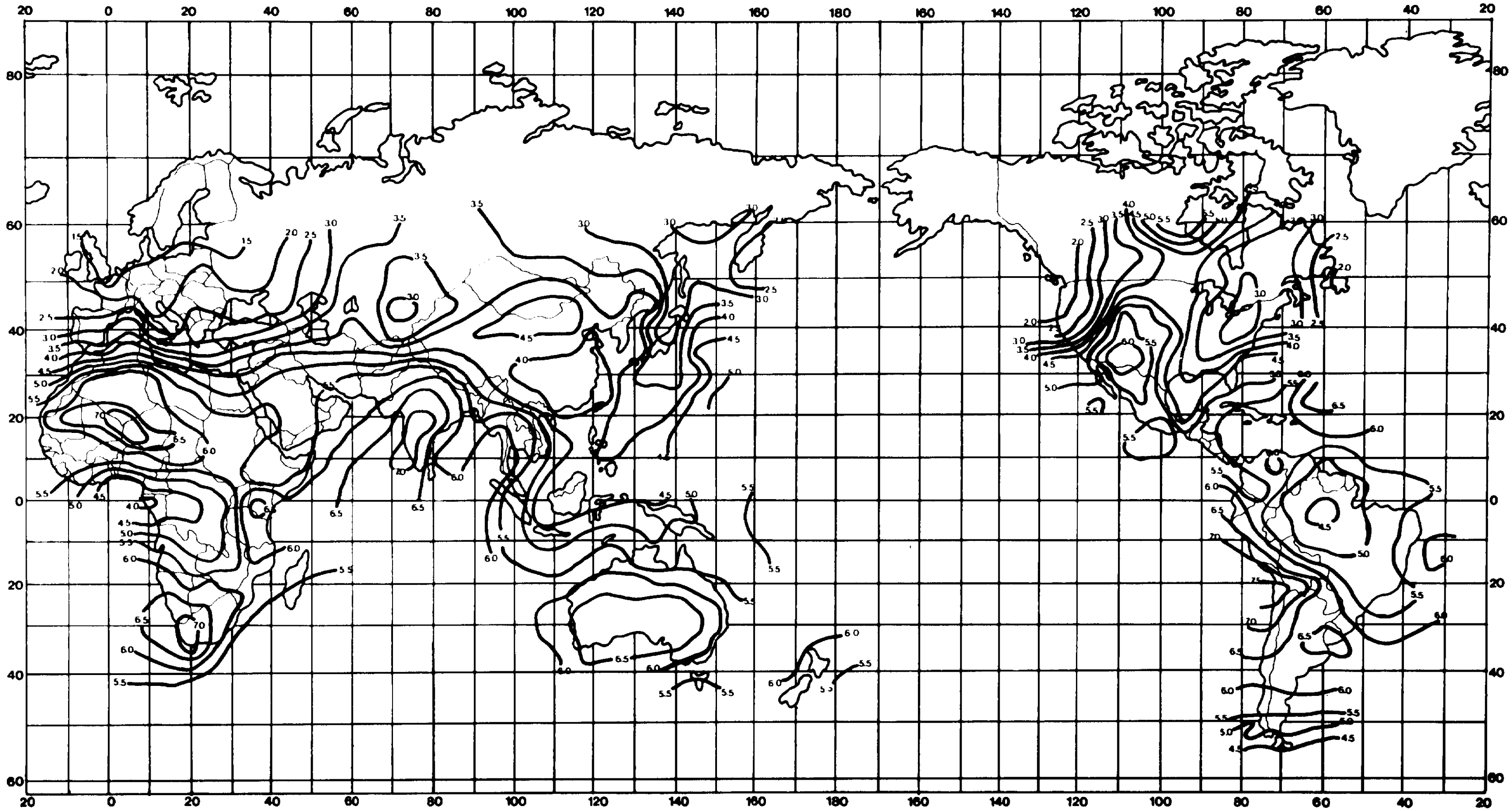
SUMMER - Tilt angle equals the latitude angle +15°

Daily total solar radiation incident on a tilted surface in kWh/m^2/day



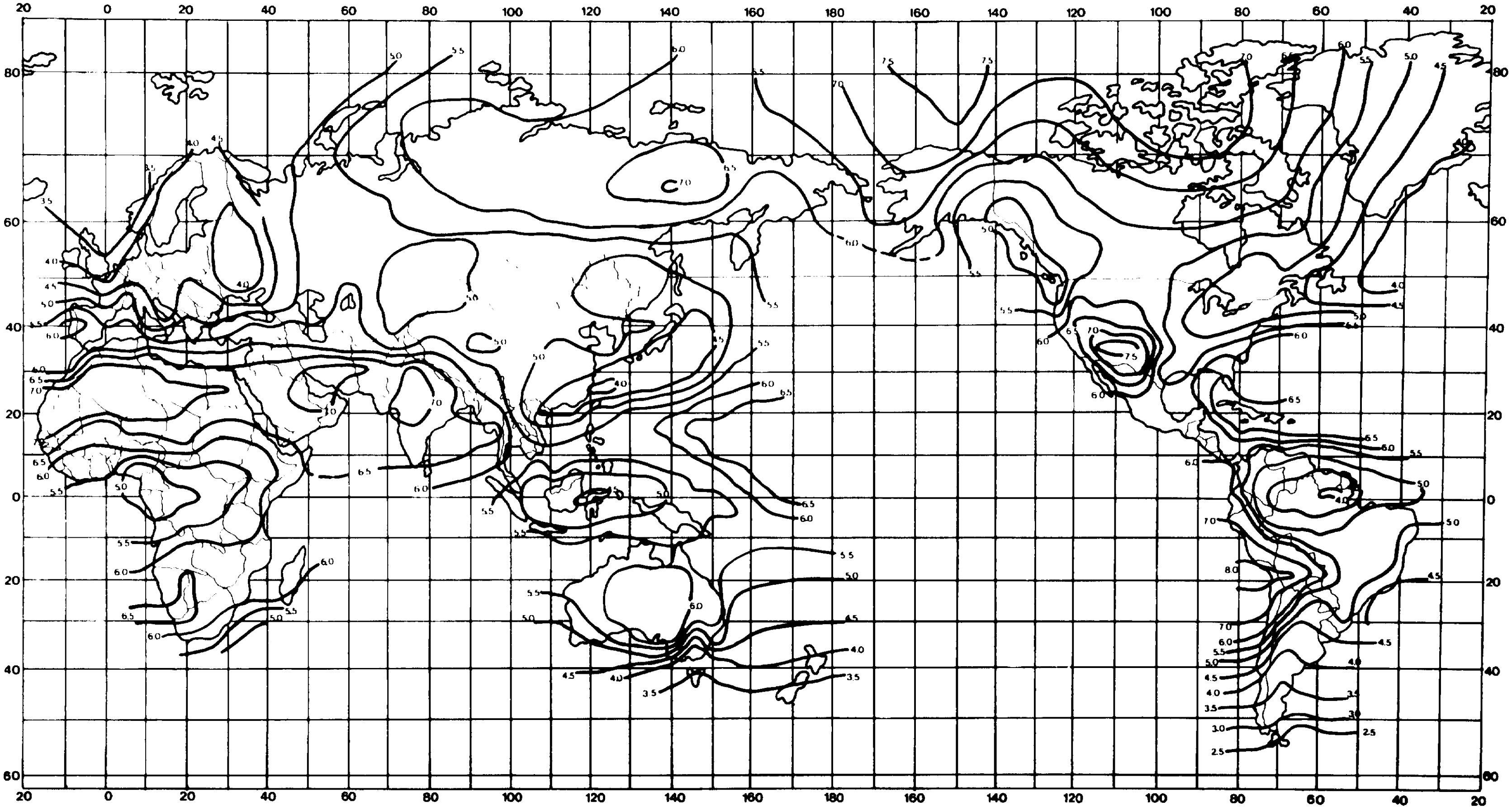
AUTUMN - Tilt angle equals the latitude angle

Daily total solar radiation incident on a tilted surface in kWh/m²/day



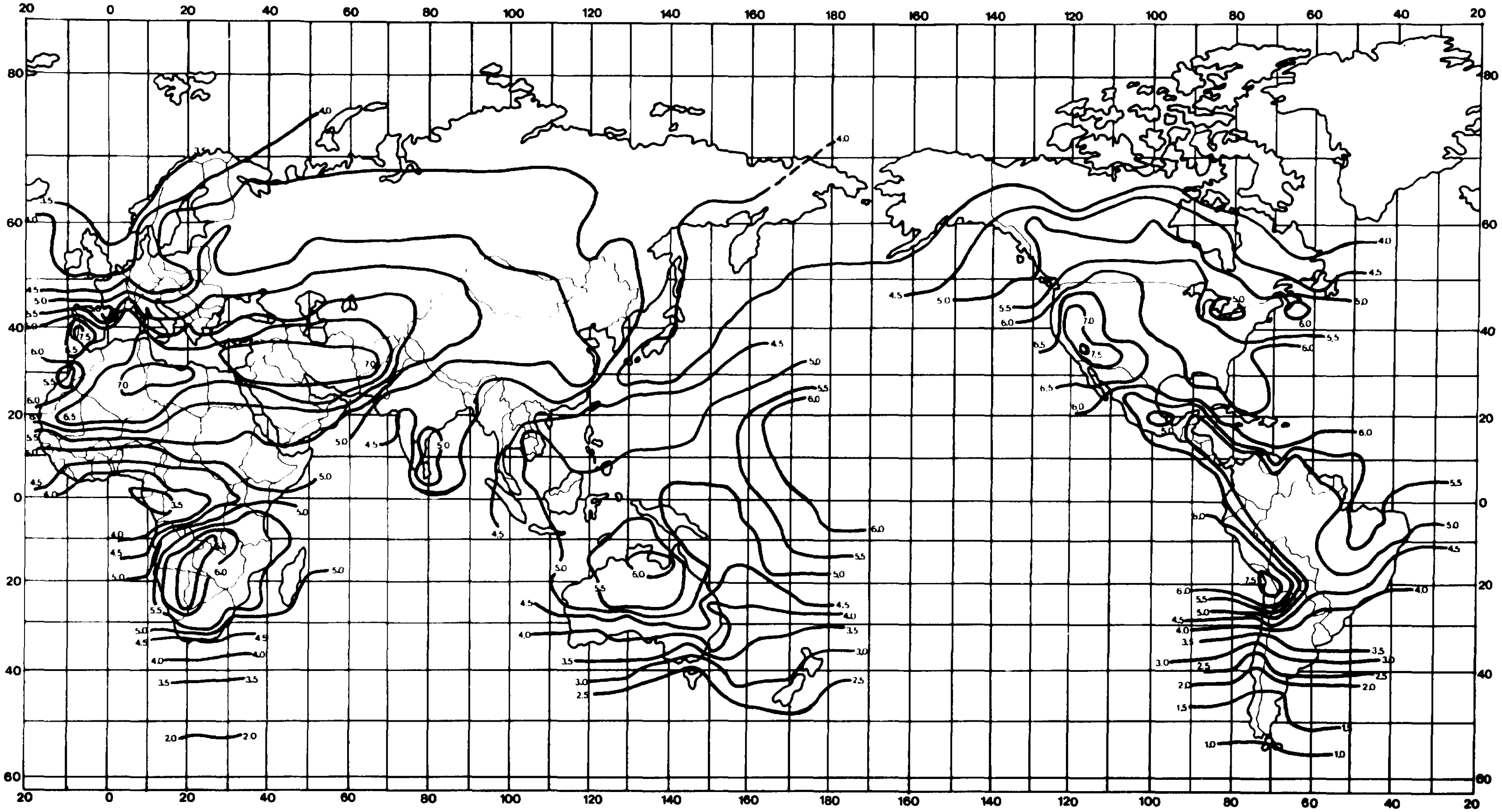
WINTER - Tilt angle equals the latitude angle

Daily total solar radiation incident on a tilted surface in kWh/m2/day



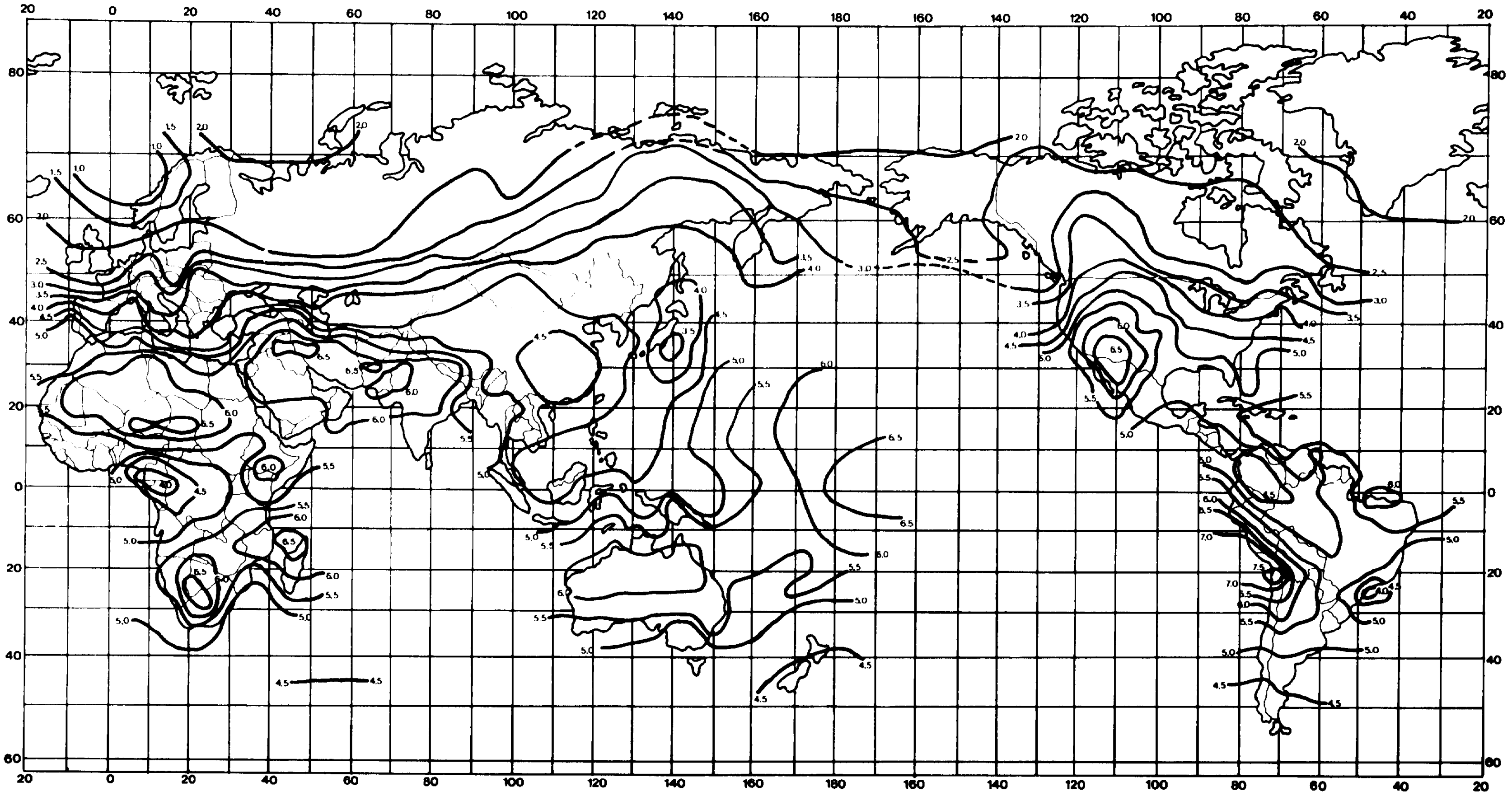
SPRING - Tilt angle equals the latitude angle

Daily total solar radiation incident on a tilted surface in kWh/m2/day



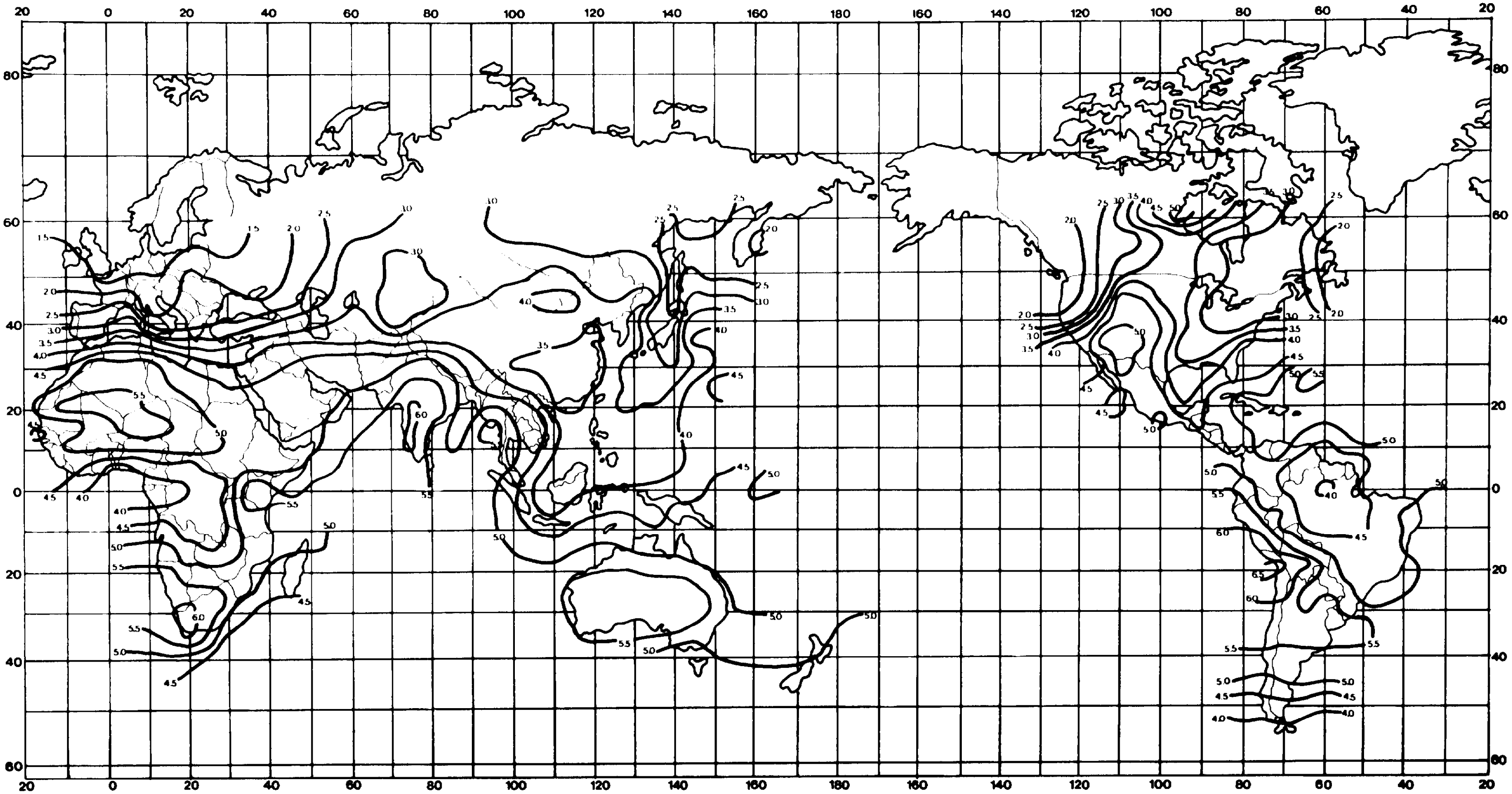
SUMMER - Tilt angle equals the latitude angle

Daily total solar radiation incident on a tilted surface in kWh/m2/day



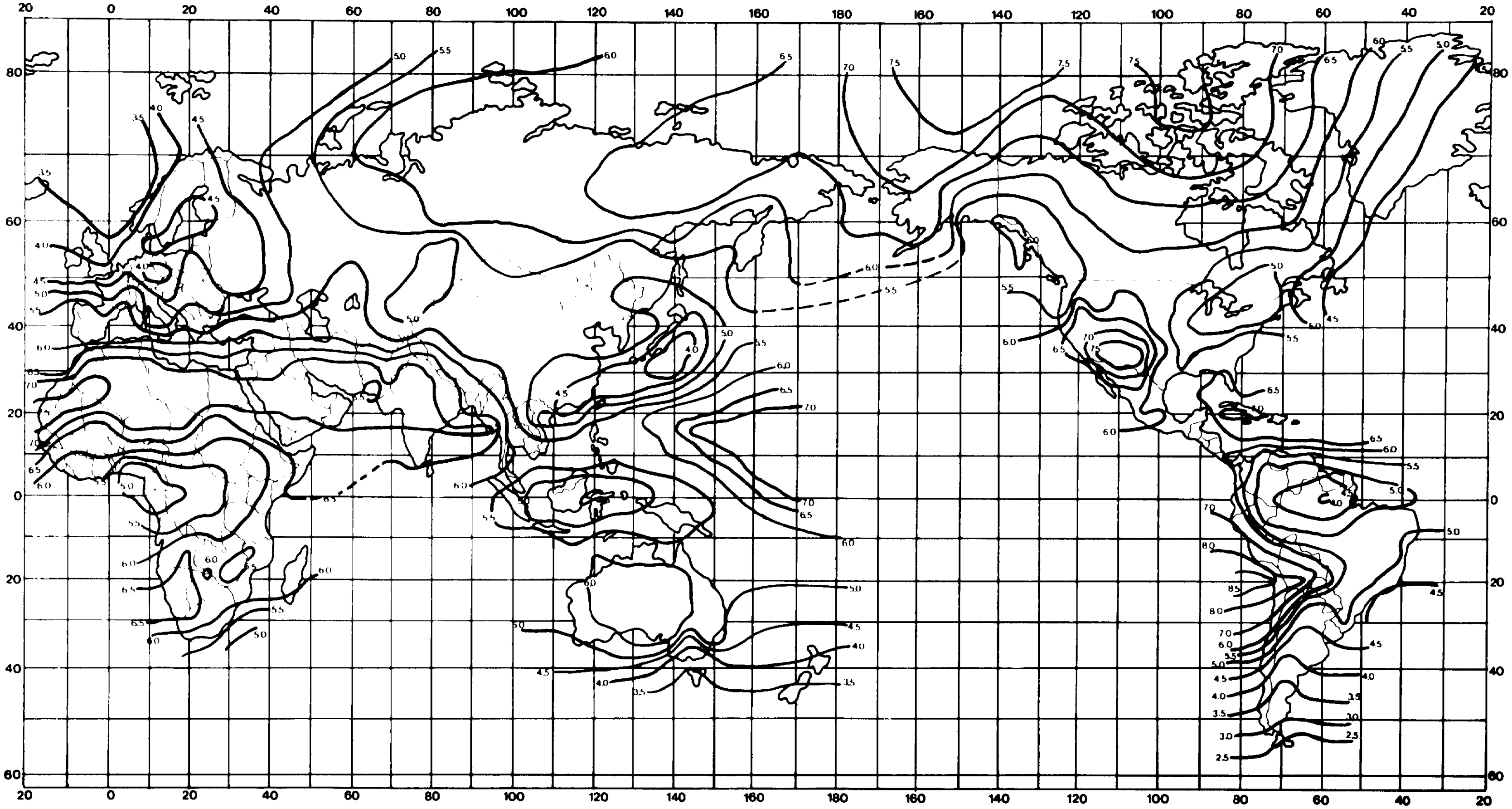
AUTUMN - Tilt angle equals the latitude angle -15°

Daily total solar radiation incident on a tilted surface in kWh/m²/day



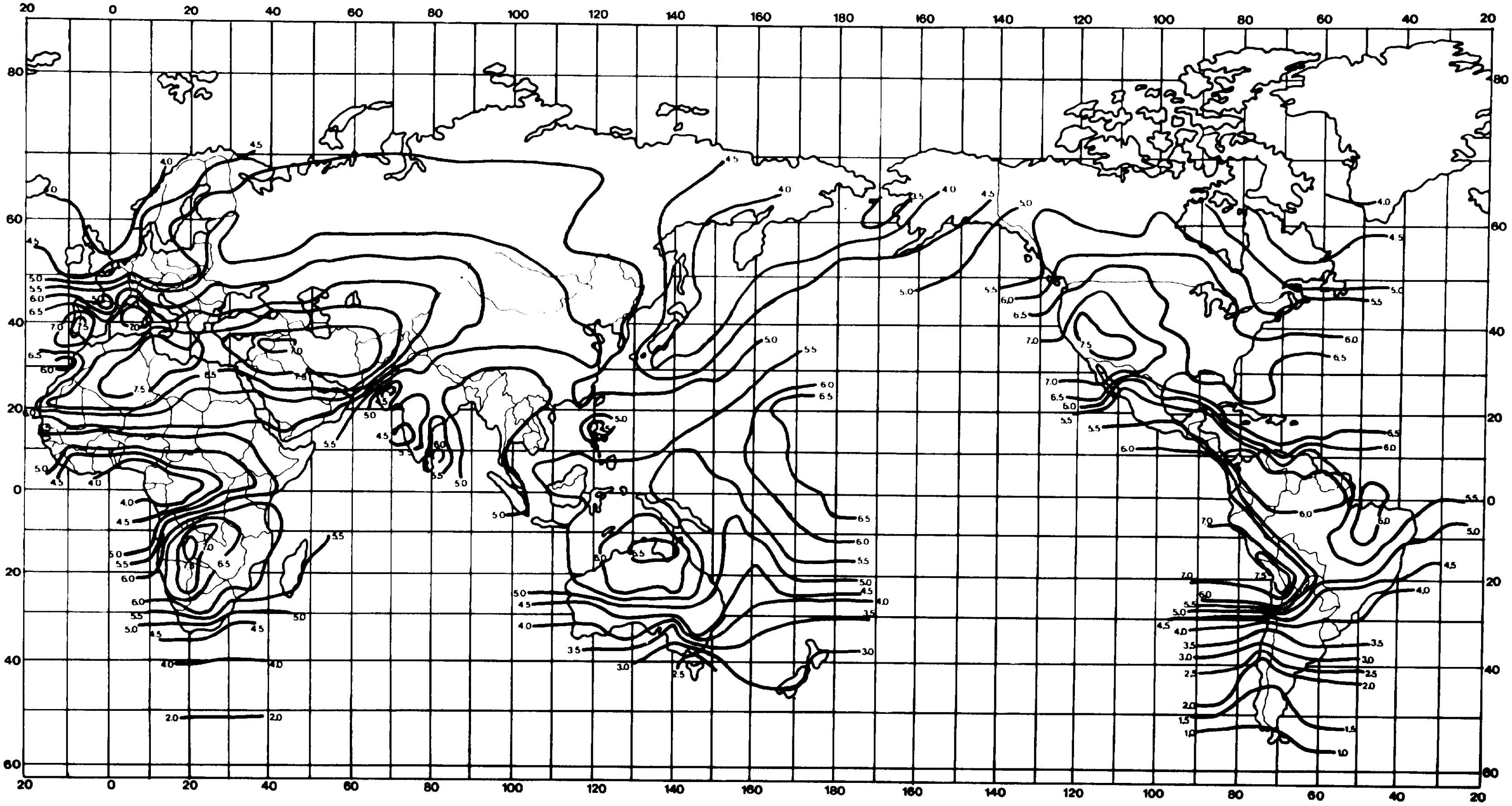
WINTER - Tilt angle equals the latitude angle -15°

Daily total solar radiation incident on a tilted surface in kWh/m²/day



SPRING - Tilt angle equals the latitude angle -15°

Daily total solar radiation incident on a tilted surface in kWh/m2/day



SUMMER - Tilt angle equals the latitude angle -15°

Daily total solar radiation incident on a tilted surface in kWh/m²/day

APPENDIX B

SAMPLE SIZING WORKSHEETS & INSTRUCTIONS

WORKSHEET #1 CALCULATE THE LOADS (FOR EACH MONTH OR SEASON AS REQUIRED)

DESIGN NOTES:

1 Load Description	2 QTY	3 Load Current (A)	4 Load Voltage (V)	5A DC Load Power (W)	5B AC Load Power (W)	6 Daily Duty Cycle (HRS/DAY)	7 Weekly Duty Cycle (DAYS/WK)	8 Power Conversion Efficiency (DECIMAL)	D 9 Nominal System Voltage (V)	10 Amp-Hour Load (AH/DAY)
DC		X	X	=	N/A	X	X ÷7	÷	÷	=
DC		X	X	=	N/A	X	X ÷7	÷	÷	=
DC		X	X	=	N/A	X	X ÷7	÷	÷	=
DC		X	X	=	N/A	X	X ÷7	÷	÷	=
AC		X	X	N/A	=	X	X ÷7	÷	÷	=
AC		X	X	N/A	=	X	X ÷7	÷	÷	=
AC		X	X	N/A	=	X	X ÷7	÷	÷	=
AC		X	X	N/A	=	X	X ÷7	÷	÷	=
11 Total Load Power (W)			DC 11A		AC 11B			12 Total Amp-Hour Load (AH/DAY)		

13 Total DC Load Power (W) 11A	14 Total AC Load Power (W) 11B	15 Nominal System Voltage (V) 9	16 Peak Current Draw (A)	17 Total Amp-Hour Load (AH/DAY) 12	18 Wire Efficiency Factor (DECIMAL) D	19 Battery Efficiency Factor (DECIMAL) D	20 Corrected Amp-Hour Load (AH/DAY)
	+	÷	=		÷	÷	=

WORKSHEET #2 DESIGN CURRENT AND ARRAY TILT

21					
System Location		Latitude		Longitude	
Insolation Location		Latitude		Longitude	

DESIGN NOTES:

	Tilt at Latitude -15°					Tilt at Latitude					Tilt at Latitude +15°				
MONTH	22A Corrected Load (AH/DAY) 20		23A Peak Sun (HRS/DAY)		24A Design Current (A)	22B Corrected Load (AH/DAY) 20		23B Peak Sun (HRS/DAY)		24B Design Current (A)	22C Corrected Load (AH/DAY) 20		23C Peak Sun (HRS/DAY)		24C Design Current (A)
J		÷		=			÷		=			÷		=	
F		÷		=			÷		=			÷		=	
M		÷		=			÷		=			÷		=	
A		÷		=			÷		=			÷		=	
M		÷		=			÷		=			÷		=	
J		÷		=			÷		=			÷		=	
J		÷		=			÷		=			÷		=	
A		÷		=			÷		=			÷		=	
S		÷		=			÷		=			÷		=	
O		÷		=			÷		=			÷		=	
N		÷		=			÷		=			÷		=	
D		÷		=			÷		=			÷		=	

Select the largest design current and corresponding peak sun from each latitude and enter below

Latitude -15°	
25A Peak Sun (HRS/DAY)	26A Design Current (A)

Latitude	
25B Peak Sun (HRS/DAY)	26B Design Current (A)

Latitude +15°	
25C Peak Sun (HRS/DAY)	26C Design Current (A)

Now select the smallest design current and corresponding peak sun

27 Peak Sun (HRS/DAY		28 Design Current (A)
Tilt Angle	=	

NOTE: DO NOT MIX TRACKING AND FIXED ARRAY DATA ON THE SAME SHEET.

WORKSHEET #3 CALCULATE SYSTEM BATTERY SIZE

29 Corrected Amp-Hour Load (AH/DAY) 20	30 Storage Days D	31 Maximum Depth of Discharge (DECIMAL) D	32 Derate for Temperature (DECIMAL) D	33 Required Battery Capacity (AH)	34 Capacity of Selected Battery (AH)	35 Batteries In Parallel
	X	÷	÷	=	÷	=

NOTE: BLOCK 35. ROUND UP FOR CONSERVATIVE DESIGN.

36 Nominal System Voltage (V) 9	37 Nominal Battery Voltage (V)	38 Batteries In Series	39 Batteries In Parallel 35	40 Total Batteries
	÷	=	X	=

BATTERY INFORMATION	
Make	
Model	
Type	
Nominal Voltage (V)	
Rated Capacity (AH)	

41 Batteries In Parallel 35	42 Capacity of Selected Battery (AH) 34	43 System Battery Capacity (AH)	44 Maximum Depth of Discharge (DECIMAL) 31	45 Usable Battery Capacity (AH)
	X	=	X	=

NOTE: USE MANUFACTURER'S DATA TO FILL IN BATTERY INFORMATION BLOCK

DESIGN NOTES:

WORKSHEET #4 CALCULATE SYSTEM ARRAY SIZE

DESIGN NOTES:

46 Design Current (A) 28		47 Module Derate Factor (DECIMAL) D		48 Derated Design Current (A)		49 Rated Module Current (A) D		50 Modules in Parallel
	÷		=		÷		=	

		51 Nominal Battery Voltage 37		52 Batteries in Series 38	53 Voltage Required for Load (V)		54 Highest Temperature Module Voltage (V)		55 Modules in Series		56 Modules in Parallel 50		57 Total Modules
1.20	x		x			÷		=		x		=	

NOTE: USE MANUFACTURER'S SPECIFICATIONS TO FILL IN PV MODULE INFORMATION BLOCK.

58 Modules in Parallel 50		59 Rated Module Current (A)		60 Rated Array Current (A)
	x		=	
		61 Module Short Circuit Current (A)		62 Array Short Circuit Current (A)
	x		=	

63 Modules in Series 55		64 Rated Module Voltage (V)		65 Array Rated Voltage (V)
	x		=	
		66 Open Circuit Module Voltage (V)		67 Array Open Circuit Voltage (V)
	x		=	

PV MODULE INFORMATION

Make/Model			**Nominal Volts**	
Length		**Width**	**Thickness**	
Weight			**Bypass Diode**	Y N
Voltage (V)	At STC	Open Circuit	At Highest Expected Temperature	
Current (A)	At STC	Short Circuit		

NOTES: BLOCK 50 - ROUND UP FOR CONSERVATIVE DESIGN.
BLOCK 55 - ROUND UP OR SELECT ANOTHER MODULE WITH SUFFICIENT VOLTAGE TO CHARGE THE BATTERIES WHEN OPERATING AT THE HIGHEST EXPECTED TEMPERATURE.

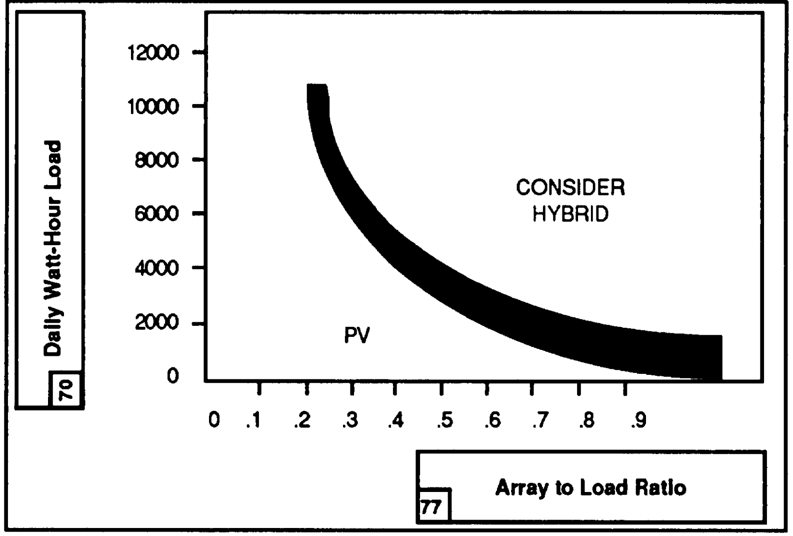
WORKSHEET #5 HYBRID DESIGN DETERMINATION

DESIGN NOTES:

68 Corrected Amp-Hour Load (AH/DAY) 20		69 Nominal System Voltage (V) 9		70 Watt-Hour Load (WH/DAY)		71 Conversion Factor		72 Annual Kilowatt-Hr Load (KWH/YEAR)
	X		=		X	.365	=	

73 Derated Design Current (A) 48		74 Nominal System Voltage (V) 9		75 Design Array Power (W)		76 Watt-Hour Load (WH/DAY) 70		77 Array to Load Ratio (DECIMAL)
	X		=		÷		=	

78 Hybrid Indicator



Hybrid Design Flag

Yes	No

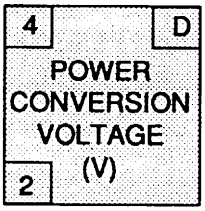
IF YES, USE HYBRID WORKSHEETS TO COMPLETE SIZING OF A HYBRID SYSTEM. IF NO, PROCEED TO FUNCTIONAL SPECIFICATION SHEETS.

INSTRUCTIONS FOR SYSTEM SIZING WORKSHEETS

These worksheets and instructions are for use in sizing stand-alone PV systems. Most of these systems will contain battery storage subsystems.

Each block of the worksheet has a number in the upper left comer. These instructions correspond to those block numbers.

A number in the lower left comer is a cross reference and indicates that a value calculated previously should be used.



A “D” in the upper right comer of a block indicates that a default value can be found in these instructions.

Shaded blocks contain numbers that will be used again later in the sizing process.

PV powered applications such as water pumping, cathodic protection, hybrid, or direct drive differ only in the load calculation method; the remaining sizing procedure is the same. Load sizing worksheets and instructions are included for these special applications.

WORKSHEET #1 - Calculate the Loads

If the load demand varies widely from month-to-month (or season-to-season), you must fill out Worksheet #1 for each month. Usually the system size will be dictated by the worst-case month – the month with the largest load and the lowest solar insolation. Consider this month first.

1 **LOAD DESCRIPTION:** List each load (i.e., fluorescent lamp, pump, radio). Enter the dc loads at the top and the ac loads, if any, at the bottom part of the worksheet.

2 **QTY:** Enter the number of identical loads in the system.

3 **LOAD CURRENT (A):** Enter an estimate of the current required by each load when operating. Use the manufacturer’s rated current, or measure the current.

4 **LOAD VOLTAGE (V):** Enter the voltage of the load, i.e., 120 volt ac, 24 volt dc, etc. The operating voltage is usually listed on the appliance.

5A **DC LOAD POWER (W):** Calculate and enter the power required by the dc load. Power equals the product of voltage and current.

5B **AC LOAD POWER (W):** Calculate and enter the power required by the ac load. Ignore the power factor for this calculation.

6 **Daily Duty Cycle (HRS/DAY):** Enter the average amount of time per day the load will be used. (Enter fractions of hours in decimal form, i.e., 1 hour, 15 minutes would be entered as 1.25.)

7 **Weekly Duty Cycle (DAYS/WK):** Enter the average number of days each week the load will be used.

8 **Power Conversion Efficiency (DECIMAL):** This factor accounts for power loss in systems using power conditioning components (converters or inverters). If the appliance requires ac power or dc power at a voltage other than your system voltage, you should enter the conversion efficiency of the device. If you do not have the actual efficiency of the converter being used, use the default values given below for initial sizing.

POWER CONVERSION EFFICIENCY DEFAULT	
DC TO AC	0.85
DC TO DC	0.90

9 **Nominal System Voltage (V):** Enter the desired system voltage. The system voltage is normally the voltage required by the largest loads. Common values are 12 or 24 volts dc and 120 volts ac.

10 **Amp-Hour Load (AH/DAY):** Calculate the average energy requirement per day in ampere-hours by performing the calculations as indicated by the mathematical symbols across the page.

11 **Total DC and AC Load Power (W):** Enter the individual ac and/or dc loads.

11A Total dc load in Watts.
11B Total ac load in Watts.

12 **Total Ampere-Hour Load (AH/DAY):** Calculate the daily average system load in ampere-hours.

13 **Total DC Load Power (W):** Enter value from Block 11A.

14 **Total AC Load Power (W):** Enter value from Block 11 B.

15 **Nominal System Voltage (V):** Enter value from Block 9.

16 **Peak Current Draw (A):** Calculate the maximum current required if all the loads are operating simultaneously. This value is used for sizing fuses, wiring, etc.

17 **Total Ampere-Hour Load (AH/DAY):** Enter value from Block 12.

18 **Wire Efficiency Factor (DECIMAL) (1 - WIRE LOSS):** Enter the decimal fraction accounting for loss due to wiring and switchgear. This factor can vary from 0.95 to 0.99. Wire size should be chosen to keep wire loss in any single circuit to less than 3 percent (>0.97).

WIRE EFFICIENCY FACTOR DEFAULT = 0.98

19 **Battery Efficiency Factor (DECIMAL):** Enter the battery efficiency which is equal to ampere-hours out divided by ampere-hours in. Use manufacturer's data for specific battery. Assume constant voltage operation.

BATTERY EFFICIENCY FACTOR DEFAULT = 0.9

20 **Corrected Amp-Hour Load (AH/DAY):** Calculate the energy required to meet the average daily load plus losses.

WORKSHEET #2 - Design Current and Array Tilt

An array set at the same angle as the latitude of the site will receive the maximum annualsolar radiation. If the load demand is high in the winter (northern hemisphere), set the array tilt at latitude plus 15°. For a predominant summer load, set the array tilt angle at latitude minus 15°. Calculate the design current for all three tilt angles if the load demand varies widely throughout the year.

21 **System Location/Insolation Location:** Enter the latitude and longitude of the system site and the location of the insolation data used. See Appendix A.

22A, B, & C **Corrected Load (AH/DAY):** See Block 20 Worksheet #1. Enter the corrected load for each month for each tilt angle.

23A, B, & C **Peak Sun (HRS/DAY):** Enter the average number of hours each day when insolation was 1,000 watts per square meter. Enter the value for each month for each tilt angle. Weather data for selected sites is given in Appendix A.

NOTE: Peak sun hours are equal to the average kilowatt-hours/m^2-day.
1 kwh/m^2 = Langley/85.93 = 316.96 Btu/ft^2 = 3.6 w/m^2.

24A, B, & C **Design Current (A):** Calculate the current required to meet the system load.

NOTE: The recommended tilt angle for the array is selected by first determining the largest design current for each of the three tilt angles; then selecting the smallest of those three values.

25A + 26A
25B + 26B
25C + 26C **Peak Sun (HRS/DAY) and Design Current (A):** Select and enter the largest monthly design current and corresponding peak sun hours from columns 24A, 24B, and 24C.

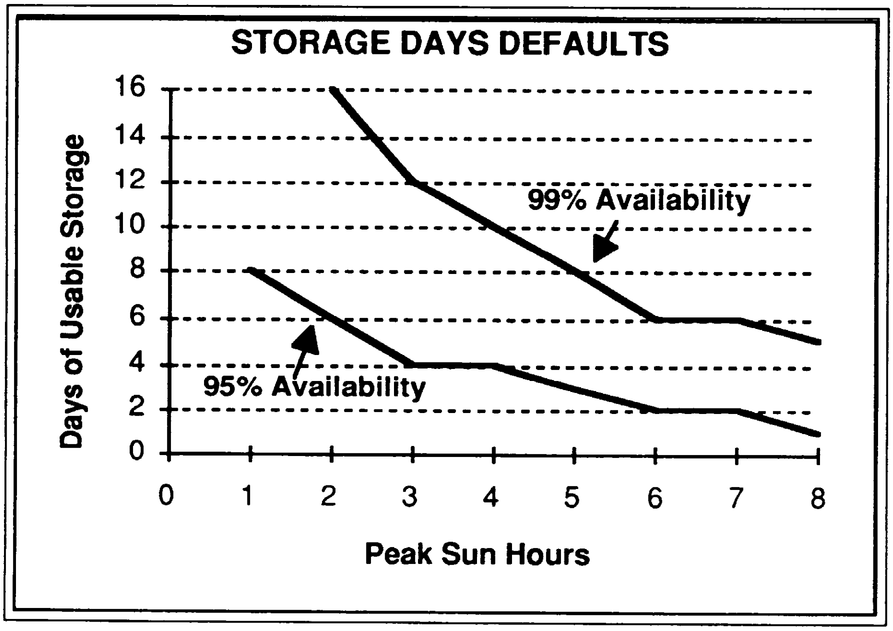
27 & 28 **Peak Sun (HRS/DAY) and Design Current (A):** Select and enter the smallest of the three design currents and the corresponding peak sun hours from 25A, B, or C and 26A, B, or C.

WORKSHEET #3 - Calculate System Battery Size

29 **Corrected Amp-Hour Load (AH/DAY):** Enter value from Block 20 Worksheet #1.

30 **Storage Days:** Choose and enter the consecutive number of days the battery subsystem is required to meet the load with no energy production by the array. System availability is defined as critical (99 percent available) or non critical (95 percent available) and directly affects thenumber of storage days. Use the chart below to find the recommended number of storage days if no better estimate can be made.

31 **Maximum Depth of Discharge (DECIMAL):** Enter the maximum discharge allowed for the battery. This depends on size and type of battery. Consult the battery manufacturer or use default values below.



MAXIMUM DEPTH OF DISCHARGE BATTERY TYPE	DEFAULT
Lead Acid Starting	0.25
Lead Acid Traction	0.75
Nickel Cadmium	0.90

32 **Derate for Temperature (DECIMAL):** Enter a factor that derates the battery capacity for cold operating temperatures. Ask the battery manufacturer for this information. If no better information is available derate a lead acid battery's capacity one percent for each degree Celsius below 20°C that the battery will operate at.

TEMPERATURE CORRECTION FACTOR DEFAULT = 0.9

33 **Required Battery Capacity (AH):** Calculate the battery capacity required to meet the daily load for the required number of days.

NOTE: Select a battery for your system and record the specifications in the battery information block.

34 **Capacity of Selected Battery (AH):** Enter the manufacturer's rating of battery storage capacity in ampere-hours. Batteries are normally rated at optimum test conditions; 20°C, and discharge rates of C/20 or lower.

35 **Batteries in Parallel:** Calculate the number of parallel connected batteries required to provide the storage capacity.

36 **Nominal System Voltage (V):** Enter the value from Block 9, Worksheet #1.

37 **Nominal Battery Voltage (V):** Enter the rated voltage of the selected battery, i.e., 2, 6, or 12 volts.

38 **Batteries in Series:** Calculate the number of series connected batteries required to provide the system voltage.

39 **Batteries in Parallel:** Enter the value from Block 35.

40 **Total Batteries:** Calculate the total number of batteries in the system.

41 **Batteries in Parallel:** Enter the value from Block 35.

42 **Capacity of Selected Battery (AH):** Enter the value from Block 34.

43 **System Battery Capacity (AH):** Calculate the battery system storage capacity.

44 **Maximum Depth of Discharge (DECIMAL):** Enter the value from Block 31.

45 **Usable Battery Capacity (AH):** This is the amount of ampere-hours that can safely be used from the installed batteries.

WORKSHEET #4 - Calculate System Array Size

46 **Design Current (A):** Enter the value from Block 28, Worksheet #2.

47 **Module Derate Factor (DECIMAL):** Enter a factor to adjust module current from standard operating conditions (SOC) of 1,000 w/m² and 45°C temperature to field conditions, i.e., dust accumulations, mismatch loss between modules, degradation over time, etc.) Ask the module distributor or use the default values below.

MODULE DERATE FACTOR DEFAULT	
MODULE TYPE	FACTOR
CRYSTALLINE	0.9
AMORPHOUS	0.7

48 **Derated Design Current (A):** Calculate the minimum array current necessary to supply the average daily load at the chosen site.

NOTE: Select a PV module and record the specifications in the module information block. Be sure to determine the module voltage when it is operating at the highest temperatures expected for your site.

49 **Rated Module Current (A):** Enter the rated module operating current at 1,000 w/m² and 45°C operating temperature as given by the manufacturer.

50 **Modules in Parallel:** Calculate the number of parallel connected modules required to provide the array current.

51 **Nominal Battery Voltage (V):** Enter the value from Block 37 Worksheet #3.

52 **Batteries in Series:** Enter the value from Block 38 Worksheet #3.

53 **Voltage Required to Charge Batteries (V):** Calculate the minimum voltage required to charge the batteries.

54 **Voltage at Highest Module Temperature (V):** Enter this value from the manufacturer's specifications.

55 **Modules in Series:** Calculate the number of series connected modules required to produce the system voltage. You must not round down. Round up or select another module with a higher operating voltage.

56 **Modules in Parallel:** Enter the value from Block 50.

57 **Total Modules:** Calculate the total number of modules in the array.

58 **Modules in Parallel:** Enter value from Block 50.

59 **Rated Module Current (A):** Enter the module current when operating at 1,000 w/m² and 45°C temperature.

60 **Rated Array Current (A):** Calculate the rated array current when operating at 1,000 w/m² and 45°C temperature.

61 **Module Short Circuit Current (A):** Enter module short circuit current when operating at 1,000 w/m² and 45°C temperature.

62 **Array Short Circuit Current (A):** Calculate the array short circuit current when operating at 1,000 w/m² and 45°C temperature.

63 **Modules in Series:** Use the value from Block 55.

64 **Rated Module Voltage (V):** Enter modulevoltage when operating at 1,000 w/m² and 45°C temperature.

65 **Array Rate Voltage (V):** Calculate array voltage when operating at 1,000 w/m² and 45°C temperature.

66 **Open Circuit Module Voltage (V):** Enter module open circuit voltage when operating at 1,000 w/m² and 45°C temperature.

67 **Array Open Circuit Voltage (V):** Calculate array open circuit voltage when operating at 1,000 w/m² and 45°C temperature.

NOTE: In some applications you may wish to know the highest voltages that might be produced by the array. This will occur when the array is operating at its lowest temperature. Use manufacturer’s data to determine module voltage for the coldest temperatures expected.

WORKSHEET #5 - Hybrid Design Determination

Completing this worksheet will give an indication of whether a hybrid power system should be considered for this application.

68 **Total Amp-Hour Load (AH):** Enter the value from Block 20 Worksheet #1.

69 **Nominal System Voltage (V):** Enter the value from Block 9 Worksheet #1.

70 **Watt-Hour Load (WH/DAY):** Calculate the average daily load power of the system.

71 **Conversion Factor:** Multiplying by this factor converts watt-hours per day to kilowatt hours per year.

72 **Annual Kilowatt-Hour Load (KWH/YEAR):** Calculate the average annual load power. This value is helpful if a hybrid system is required.

73 **Derated Design Current (A):** Enter the value from Block 48 Worksheet #4.

74 **Nominal System Voltage (V):** Enter the value from Block 9 Worksheet #1.

75 **Design Array Power (W):** Calculate the average daily power required by the load.

76 **Watt-Hour Load (WH/DAY):** Enter the value from Block 70.

77 **Array to Load Ratio (DECIMAL):** Calculate the factor used to determine if a hybrid design should be considered.

78 **Hybrid Indicator:** Plot a point on the graph using values from Blocks 76 and 77.

NOTE: If the hybrid indicator suggests a hybrid system, complete the hybrid worksheets, HY#1 and HY#2. Compare life cycle cost analyses of both designs and make a decision as to which would be the optimum system.

	A1 Array Short Circuit Current (A) 62		A2 Minimum Controller Current (A)		A3 Rated Controller Current) (A)		A4 Controllers in Parallel	
1.25	X		=		÷		=	

DESIGN NOTES:

A5

(CONTROLLER)

Make/Model ______

Rated Voltage ______

Rated Current ______

Features

Temperature Compensation ______

Reverse Current Protection ______

Adjustable Set Points)

High Voltage Disconnect ______

High Voltage Re-connect ______

Low Voltage Disconnect ______

Low Voltage Re-connect ______

Meters

Battery Voltage ______

Array Current ______

Load Current ______

POWER CONDITIONING UNITS SPECIFICATION

Inverter

System Requirements

B1 Wave Form ______
B2 DC System Voltage ______ (V)
B3 AC System Voltage ______ (V)
B4 Surge Capacity ______ (W)
B5 Total AC Watts ______ (W)
B6 Maximum Single AC Load ______ (W)
B7 Maximum Simultaneous AC Load ______ (W)
B8 Inverter Run Time at Maximum Simultaneous Load ______ (MIN)
B9 Inverter Continuous Duty Rating ______ (W)
B10 Required Inverter Efficiency at Load ______ (%)

B11 Inverter Specifications

Make ______
Model ______
Wave Form ______
Input Voltage (DC) ______ (V)
Output Voltage (AC) ______ (V)
Surge Capacity ______ (W)

FEATURES:
- Battery Charging ( )
- Voltmeter ( )
- Remote Control ( )
- Generator Start ( )
- Transfer Switch ( )
- Maximum Power Tracking ( )

DESIGN NOTES:

Converter

System Requirements

C1 Input DC Voltage ____ to ____ (V)
C2 Output DC Voltage ____ to ____ (V)
C3 Output Power ____ (W)
C4 Operating Temperature ____ to ____ (C°)

C5 Converter

Make ______
Model ______
Input Voltage ______ (V)
Output Voltage ______ (V)
Output Current ______ (A)
Operating Temperature ______ (C°)

FEATURES:
- Adjustable Output Voltage ______ (V)

PROTECTION COMPONENTS SPECIFICATION

Protected Circuit	Protection Device				Rated Current	Rated Voltage	Description
	Switch	Diode	Fuse	Movistor			
D1							
D2							
D3							
D4							
D5							
D6							
D7							
D8							
D9							
D10							
D11							
D12							
D13							
D14							

DC WIRE SIZING SPECIFICATION

E1 Wire Runs	E2 System Voltage (V)	E3 Maximum Current (A)	E4 One Way Length (FT)	E5 Allowed Voltage Drop (%)	E6 Allowance for Temperature Derate	E7 AWG Number	E8 Wire Type
Array Circuit							
Module to Module							
Array to Controller or Battery							
DC Circuits							
Battery to Battery							
Battery or Controller to DC Loads							
Branch Circuits							
A							
B							
C							
D							
E							
Battery Charger to Batteries							
Battery to Inverter Or Converter							

System Grounding	**Wire Type**	**AWG Number**	**Type of Earth Ground**
E9 **Equipment Ground**			
E10 **System Ground**			

DESIGN NOTES:

AC WIRE SIZING SPECIFICATION

DESIGN NOTES:

Wire Sizing And Specification (DC Side)							
F1 Wire Runs	F2 System Voltage (V)	F3 Maximum Current (A)	F4 One Way Length (FT)	F5 Allowed Voltage Drop (%)	F6 Allowance for Temperature Derate	F7 AWG Number	F8 Wire Type
AC Circuits							
Inverter to AC Loads							
Branch Circuits							
A ______							
B ______							
C ______							
D ______							
E ______							
F ______							
G ______							
Generator							
Generator to Battery Charger							
Generator to AC Load Center							

System Grounding	Wire Type	AWG Number	Type of Earth Ground
F9 Equipment Ground			
F10 System Ground			

INSTRUCTIONS FOR SPECIFICATION WORKSHEETS

The next five sheets show some of the parameters used to specify hardware for stand-alone PV systems. It is recommended that data from several manufacturers be obtained and studied while completing these sheets. These manufacturers' data are required to make intelligent design tradeoffs. Also, appropriate articles in the NEC should be studied. These electrical code requirements have been developed to ensure safe, durable system installations.

Controller Specification

Select a controller that operates at the nominal dc system voltage.

A1 **Array Short Circuit Current (A):** Enter the value from Block 62 Worksheet #4.

A2 **Minimum Controller Current (A):** Calculate the minimum controller current. The multiplier of 1.25 oversizes the controller by 25 percent to allow for current production at highest solar irradiance conditions.

A3 **Rated Controller Current (A):** If a single controller cannot be found that will handle the current calculated in A2, parallel controllers may be used. Enter the manufacturer's rated value of the selected controller.

A4 **Controllers in Parallel:** Calculate the number of controllers in parallel.

A5 **Controller:** Use the form to describe the controller characteristics and features desired or available from the manufacturer. If any of the controller settings are adjustable, indicate the desired setting.

Power Conditioning Units Specification

Inverter

List the desired characteristics of an inverter in the space provided and read manufacturers' literature for candidate inverters.

B1 **Waveform:** Specify the wave form desired. See inverter section starting on page 39.

B2 **DC System Voltage (V):** Enter the dc system voltage from Block 9, Worksheet #1. This value might have to be changed depending on the availability, performance, and cost of inverters.

B3 **AC System Voltage (V):** Enter the ac voltage desired.

B4 **Surge Capacity (W):** Enter the highest power that might be required for a short period. Starting motors may require up to six times the rated operating current.

B5 **Total AC Watts (W):** Enter the total ac load from Block 11B Worksheet #1.

B6 **Maximum Single AC Load (W):** Enter the maximum single ac load from those listed on Worksheet #1.

B7 **Maximum Simultaneous AC Load (W):** Enter the maximum expected simultaneous ac load. This is determined by summing the loads that could possibly operate at the same time. See Worksheet #1.

B8 **Inverter Run Time at Maximum Simultaneous Load (MIN):** Estimate and enter the length of time in minutes that the inverter will have to support the maximum simultaneous ac loads.

B9 **Inverter Continuous Duty Rating (W):** Estimate the average power required from the inverter. Study the loads listed on Worksheet #1.

B10 **Required Inverter Efficiency at Load (%):** Enter the desired inverter efficiency at the average load. (Note: Manufacturers usually quote inverter efficiencies under ideal test conditions.)

B11 **Inverter Specifications:** Enter data from the manufacturer's data sheet for the selected unit.

Converter

The parameters listed should be considered when specifying a dc to dc converter. List the desired system specifications in the spaces provided and review manufacturer's literature to identify converters that meet the requirements.

C1 **Input DC Voltage (V):** Enter the input dc voltage from Block 9, Worksheet #1.

C2 **Output DC Voltage (V):** Enter the required output dc voltage of the converter.

C3 **Output Power (W):** Enter the power requirements of the specific loads that the converter must supply.

C4 **Operating Temperature (C°):** Enter the operating temperature range that the converter will be subjected to.

C5 **Converter:** Select an available converter and list its specifications.

Protection Components Specification

Switches, circuit breakers, fuses, and diodes are used for safe operation and maintenance of a stand-alone PV system and are necessary to protect people and equipment. Review applicable electrical codes for guidance. Any switch must be capable of interrupting the current, ac or dc, flowing in the circuit. AC rated switches and fuses will fail in dc circuits and should not be used. A fuse must be rated for dc current if used in a dc circuit. Fuses and switches are often included in a single package. A blocking diode may be used to prevent current flowing from the battery toward the array. Some controllers provide this protection internally. All protection components should be installed in weather resistant enclosures.

D1-D14 **Protected Circuit:** List the circuit where the protection device is to be installed. For example, the PV array output, the inverter to ac load, etc. Then check the device to be installed and its current and voltage ratings.

Wire Sizing (DC or AC) Specification Sheet

Review applicable codes and regulations before selecting the wire to be used in a stand-alone PV system. Determine whether single or multiple conductor wire should be used. Select a wire with a sheath (covering) that will withstand existing conditions. Be sure to specify sunlight resistant wire for locations where the wire will be exposed. Consider using metal conduit to protect the wires. Allow for temperature derate on ampacity if the wire will be exposed to temperatures exceeding 30°C. Grounding should be done according to local regulations. The following instructions apply to both ac or dc wire sizing.

E1 or F1 **System Voltage (V):** Enter the system voltage for each circuit.

E2 or F2 **Maximum Current (A):** Enter the maximum current for each circuit.

E3 or F3 **One Way Length (M):** Measure or estimate the length of wire runs in the system. This is the distance between components in the system--such as array to controller or controller to battery.

E4 or F4 **Allowed Voltage Drop (%):** Specify the maximum voltage drop for each of the circuits. If local regulations do not specify a maximum, use a default value of 3 percent voltage drop in any branch circuit and a maximum of 5 percent voltage drop from voltage source to load.

E5 or F5 **Allowance for Temperature Derate:** If current carrying conductors are exposed to temperatures greater than 30°C (84°F) their ampacity will be reduced. Consult Table 310-16 in the NEC or ask wire manufacturers for amount of derate.

E6 or F6 **Wire Size:** Determine the size of wire for each of the wire runs. Using the following tables for quick reference, the maximum one-way wire distance for copper conductors of certain size can be determined for 12-, 24-, 48-, and 120-volt circuits.

E7 or F7 **Wire Type:** Note the wire type including insulation material or coatings.

E8 or F8 **Equipment Ground:** Wires are typically No. 8 bare copper or larger. Refer to applicable codes.

E9 or F9 **System Ground:** Ground wires should be equal to or larger than the largest current carrying conductor. Locate the ground as close to the battery as possible. Refer to local regulations for grounding requirements.

Note: All grounding for your system should be made at a single point.

					Maximum One-Way Wire Distance (Feet)									
				3% Voltage Drop; 12-Volt Circuit; Annealed Copper Wire at 20° C										
AWG Wire Size		14	12	10	8	6	4	3	2	1	0	00	000	0000
Resistance (Ω/1000 ft.)		2.52500	1.58800	0.99890	0.62820	0.39510	0.24850	0.19700	0.15630	0.12390	0.09827	0.07793	0.06180	0.04901
Amperes	Watts	Distance	Distance	Distance	Distance	Distance	Distance	Distance	Distance	Distance	Distance	Distance	Distance	Distance
1	6	286	453	721										
1	12	143	227	360	573									
2	24	71	113	180	287	456	724							
3	36	48	76	120	191	304	483	609	768					
4	48	36	57	90	143	228	362	457	576	726				
6	72	24	38	60	96	152	241	305	384	484	611	770		
8	96	18	28	45	72	114	181	228	288	363	458	577	728	
10	120	14	23	36	57	91	145	183	230	291	366	462	583	735
12	144	12	19	30	48	76	121	152	192	242	305	385	485	612
14	168	10	16	26	41	65	103	131	165	208	262	330	416	525
16	192	9	14	23	36	57	91	114	144	182	229	289	364	459
18	216	8	13	20	32	51	80	102	128	161	204	257	324	408
20	240	7	11	18	29	46	72	91	115	145	183	231	291	367
25	300	6	9	14	23	36	58	73	92	116	147	185	233	294
30	360	5	8	12	19	30	48	61	77	97	122	154	194	245
35	420	4	6	10	16	26	41	52	66	83	105	132	166	210
40	480	4	6	9	14	23	36	46	58	73	92	115	146	184
45	540	3	5	8	13	20	32	41	51	65	81	103	129	163
50	600	3	5	7	11	18	29	37	46	58	73	92	117	147
60	720	2	4	6	10	15	24	30	38	48	61	77	97	122
70	840		3	5	8	13	21	26	33	42	52	66	83	105
80	960		3	5	7	11	18	23	29	36	46	58	73	92
90	1080		3	4	6	10	16	20	26	32	41	51	65	82
100	1200		2	4	6	9	14	18	23	29	37	46	58	73
110	1320			3	5	8	13	17	21	26	33	42	53	67
120	1440			3	5	8	12	15	19	24	31	38	49	61
130	1560			3	4	7	11	14	18	22	28	36	45	57
140	1680			3	4	7	10	13	16	21	26	33	42	52
150	1800			2	4	6	10	12	15	19	24	31	39	49
160	1920				4	6	9	11	14	18	23	29	36	46
170	2040				3	5	9	11	14	17	22	27	34	43
180	2160				3	5	8	10	13	16	20	26	32	41
190	2280				3	5	8	10	12	15	19	24	31	39

				Maximum One-Way Wire Distance (Feet)										
				3% Voltage Drop; 24-Volt Circuit; Annealed Copper Wire at 20° C										
AWG Wire Size		14	12	10	8	6	4	3	2	1	0	00	000	0000
Resistance (Ω/1000 ft.)		2.52500	1.58800	0.99890	0.62820	0.39510	0.24850	0.19700	0.15630	0.12390	0.09827	0.07793	0.06180	0.04901
Amperes	Watts	Distance	Distance	Distance	Distance	Distance	Distance	Distance	Distance	Distance	Distance	Distance	Distance	Distance
0.5	12	570	907											
1	24	285	453	721										
2	48	143	227	360	573	911								
3	72	95	151	240	382	607	966							
4	96	71	113	180	287	456	724	914						
6	144	48	76	120	191	304	483	609	768	969				
8	192	36	57	90	143	228	362	457	576	726	916			
10	240	29	45	72	115	182	290	365	461	581	733	924		
12	288	24	38	60	96	152	241	305	384	484	611	770	971	
14	336	20	32	51	82	130	207	261	329	415	523	660	832	
16	384	18	28	45	72	114	181	228	288	363	458	577	728	918
18	432	16	25	40	64	101	161	203	256	323	407	513	647	816
20	480	14	23	36	57	91	145	183	230	291	366	462	583	735
25	600	11	18	29	46	73	116	146	184	232	293	370	466	588
30	720	10	15	24	38	61	97	122	154	194	244	308	388	490
35	840	8	13	21	33	52	83	104	132	166	209	264	333	420
40	960	7	11	18	29	46	72	91	115	145	183	231	291	367
45	1080	6	10	16	25	40	64	81	102	129	163	205	259	326
50	1200	6	9	14	23	36	58	73	92	116	147	185	233	294
60	1440	5	8	12	19	30	48	61	77	97	122	154	194	245
70	1680	4	6	10	16	26	41	52	66	83	105	132	166	210
80	1920	4	6	9	14	23	36	46	58	73	92	115	146	184
90	2160	3	5	8	13	20	32	41	51	65	81	103	129	163
100	2400	3	5	7	11	18	29	37	46	58	73	92	117	147
110	2640	3	4	7	10	17	26	33	42	53	67	84	106	134
120	2880		4	6	10	15	24	30	38	48	61	77	97	122
130	3120		3	6	9	14	22	28	35	45	56	71	90	113
140	3360			5	8	13	21	26	33	42	52	66	83	105
150	3600			5	8	12	19	24	31	39	49	62	78	98
160	3840				7	11	18	23	29	36	46	58	73	92
170	4080				7	11	17	21	27	34	43	54	69	86
180	4320				6	10	16	20	26	32	41	51	65	82
190	4560				6	10	15	19	24	31	39	49	61	77

					Maximum One-Way Wire Distance (Feet)									
				3% Voltage Drop; 48-Volt Circuit; Annealed Copper Wire at 20° C										
AWG Wire Size		14	12	10	8	6	4	3	2	1	0	00	000	0000
Resistance (Ω/1000 ft.)		2.52500	1.58800	0.99890	0.62820	0.39510	0.24850	0.19700	0.15630	0.12390	0.09827	0.07793	0.06180	0.04901
Amperes	Watts	Distance	Distance	Distance	Distance	Distance	Distance	Distance	Distance	Distance	Distance	Distance	Distance	Distance
0.5	24													
1	48	571.4	906.8											
2	96	285.7	453.4	720.8										
3	144	190.5	302.3	480.5	764.1									
4	192	142.9	226.7	360.4	573.1	911.2								
6	288	95.2	151.1	240.3	382.0	607.4	9657.9							
8	384	71.4	113.4	180.2	286.5	455.6	7243.5	913.7						
10	480	57.1	90.7	144.2	229.2	364.5	5794.8	731.0	921.3					
12	576	47.6	75.6	120.1	191.0	303.7	4829.0	609.1	767.8	968.5				
14	672	40.8	64.8	103.0	163.7	260.3	4139.1	522.1	658.1	830.2				
16	768	35.7	56.7	90.1	143.3	227.8	3621.7	456.9	575.8	726.4	915.8			
18	864	31.7	50.4	80.1	127.3	202.5	3219.3	406.1	511.8	645.7	814.1			
20	960	28.6	45.3	72.1	114.6	182.2	2897.4	365.5	460.7	581.1	732.7	923.9		
25	1200	22.9	36.3	57.7	91.7	145.8	2317.9	292.4	368.5	464.9	586.1	739.1	932.0	
30	1440	19.0	30.2	48.1	76.4	121.5	1931.6	243.7	307.1	387.4	488.5	615.9	776.7	979.4
35	1680	16.3	25.9	41.2	65.5	104.1	1655.6	208.8	263.2	332.1	418.7	527.9	665.7	839.5
40	1920	14.3	22.7	36.0	57.3	91.1	1448.7	182.7	230.3	290.6	366.3	462.0	582.5	734.5
45	2160	12.7	20.2	32.0	50.9	81.0	1287.7	162.4	204.7	258.3	325.6	410.6	517.8	652.9
50	2400	11.4	18.1	28.8	45.8	72.9	1159.0	146.2	184.3	232.4	293.1	369.6	466.0	587.6
60	2880	9.5	15.1	24.0	38.2	60.7	965.8	121.8	153.6	193.7	244.2	308.0	388.3	489.7
70	3360	8.2	13.0	20.6	32.7	52.1	827.8	104.4	131.6	166.0	209.3	264.0	332.9	419.7
80	3840	7.1	11.3	18.0	28.7	45.6	724.3	91.4	115.2	145.3	183.2	231.0	291.3	367.3
90	4320	6.3	10.1	16.0	25.5	40.5	643.9	81.2	102.4	129.1	162.8	205.3	258.9	326.5
100	4800	5.7	9.1	14.4	22.9	36.4	579.5	73.1	92.1	116.2	146.5	184.8	233.0	293.8
110	5280		8.2	13.1	20.8	33.1	526.8	66.5	83.8	105.7	133.2	168.0	211.8	267.1
120	5760		7.6	12.0	19.1	30.4	482.9	60.9	76.8	96.9	122.1	154.0	194.2	244.8
130	6240		7.0	11.1	17.6	28.0	445.8	56.2	70.9	89.4	112.7	142.1	179.2	226.0
140	6720			10.3	16.4	26.0	413.9	52.2	65.8	83.0	104.7	132.0	166.4	209.9
150	7200			9.6	15.3	24.3	386.3	48.7	61.4	77.5	97.7	123.2	155.3	195.9
160	7680			9.0	14.3	22.8	362.2	45.7	57.6	72.6	91.6	115.5	145.6	183.6
170	8160				13.5	21.4	340.9	43.0	54.2	68.4	86.2	108.7	137.1	172.8
180	8640				12.7	20.2	321.9	40.6	51.2	64.6	81.4	102.7	129.4	163.2

					Maximum One-Way Wire Distance (Feet)									
				3% Voltage Drop; 120-Volt Circuit; Annealed Copper Wire at 20° C										
AWG Wire Size		14	12	10	8	6	4	3	2	1	0	00	000	0000
Resistance (Ω/1000 ft.)		2.52500	1.58800	0.99890	0.62820	0.39510	0.24850	0.19700	0.15630	0.12390	0.09827	0.07793	0.06180	0.04901
Amperes	Watts	Distance	Distance	Distance	Distance	Distance	Distance	Distance	Distance	Distance	Distance	Distance	Distance	Distance
0.5	60													
1	120													
2	240	714.3												
3	360	476.2	755.7											
4	480	357.1	566.8	901.0										
6	720	238.1	377.8	600.7	955.1									
8	960	178.6	283.4	450.5	716.3									
10	1200	142.9	226.7	360.4	573.1	911.2								
12	1440	119.0	188.9	300.3	477.6	759.3								
14	1680	102.0	161.9	257.4	409.3	650.8								
16	1920	89.3	141.7	225.2	358.2	569.5	905.4							
18	2160	79.4	125.9	200.2	318.4	506.2	804.8							
20	2400	71.4	113.4	180.2	286.5	455.6	724.3	913.7						
25	3000	57.1	90.7	144.2	229.2	364.5	579.5	731.0	921.3					
30	3600	47.6	75.6	120.1	191.0	303.7	482.9	609.1	767.8	968.5				
35	4200	40.8	64.8	103.0	163.7	260.3	413.9	522.1	658.1	830.2				
40	4800	35.7	56.7	90.1	143.3	227.8	362.2	456.9	575.8	726.4	915.8			
45	5400	31.7	50.4	80.1	127.3	202.5	321.9	406.1	511.8	645.7	814.1			
50	6000	28.6	45.3	72.1	114.6	182.2	289.7	365.5	460.7	581.1	732.7	923.9		
60	7200	23.8	37.8	60.1	95.5	151.9	241.4	304.6	383.9	484.3	610.6	769.9	970.9	
70	8400	20.4	32.4	51.5	81.9	130.2	207.0	261.1	329.0	415.1	523.3	659.9	832.2	
80	9600	17.9	28.3	45.0	71.6	113.9	181.1	228.4	287.9	363.2	457.9	577.4	728.2	918.2
90	10800	15.9	25.2	40.0	63.7	101.2	161.0	203.0	255.9	322.8	407.0	513.3	647.2	816.2
100	12000	14.3	22.7	36.0	57.3	91.1	144.9	182.7	230.3	290.6	366.3	462.0	582.5	734.5
110	13200	13.0	20.6	32.8	52.1	82.8	131.7	166.1	209.4	264.1	333.0	420.0	529.6	667.8
120	14400	11.9	18.9	30.0	47.8	75.9	120.7	152.3	191.9	242.1	305.3	385.0	485.4	612.1
130	15600	11.0	17.4	27.7	44.1	70.1	111.4	140.6	177.2	223.5	281.8	355.3	448.1	565.0
140	16800	10.2	16.2	25.7	40.9	65.1	103.5	130.5	164.5	207.5	261.7	330.0	416.1	524.7
150	18000	9.5	15.1	24.0	38.2	60.7	96.6	121.8	153.6	193.7	244.2	308.0	388.3	489.7
160	19200	8.9	14.2	22.5	35.8	56.9	90.5	114.2	144.0	181.6	229.0	288.7	364.1	459.1
170	20400	8.4	13.3	21.2	33.7	53.6	85.2	107.5	135.5	170.9	215.5	271.7	342.7	432.1
180	21600	7.9	12.6	20.0	31.8	50.6	80.5	101.5	128.0	161.4	203.5	256.6	323.6	408.1

WATER PUMPING WORKSHEET #1 WP

CALCULATE THE WATER PUMPING LOAD

NOTE: THE UNITS FOR WATER VOLUME AND HEAD ARE LITERS AND METERS RESPECTIVELY.

1P Source Capacity (L/HR)	2P Water Required per Day (L/DAY)	3P D Pumping Time Factor	4P Peak Sun (HRS/DAY)	5P Pumping Rate (L/HR)
		÷	÷	=

6P Static Level (M)	7P Drawdown Level (M)	8P Static Lift (M)	9P Discharge Head (M)	10P Static Head (M)	11P D Allowance For Friction (DECIMAL)	12P Static Head (M) 10P	13P Total Dynamic Head (M)
	+	+	+	=	x	+	=

14P Water Required per Day (L/DAY) 2P	15P Total Dynamic Head (M) 13P	16P Conversion Factor	17P Hydraulic Energy (WH/DAY)	18P Pump System Efficiency (DECIMAL)	19P Array Energy (WH/DAY)	20P D Nominal System Voltage (V)	21P Amp-Hour Load (AH/DAY)
	x	÷ 367	=	÷	=	÷	=

WATER PUMP AND MOTOR INFORMATION	
Make/Model	
Pump Type	
Motor Type	
Input Voltage (AC/DC)	
Optimum Current (A)	
Pumping Subsystem Efficiency	

22P Amp-Hour Load (AH/DAY) 21P	23P D Wire Loss Factor (DECIMAL)	24P D Battery Efficiency Factor (DECIMAL)	25P Corrected Amp-Hour Load (AH/DAY)
	÷	÷	=

NOTE: IF THE WATER PUMPING SYSTEM HAS NO BATTERY ENTER 1.0 IN BLOCK 24.

DESIGN NOTES:

WATER PUMPING WORKSHEET #2 WP

PUMPED WATER AND PUMPING RATE

DESIGN NOTES:

26P	27P	28P	29P	30P	31P	32P	33P	34P
Modules in Parallel	Rated Module Current (A)	Nominal System Voltage (V)	Pump System Efficiency (DECIMAL)	Conversion Factor	Peak Sun (HRS/DAY)	Module Derate Factor (DECIMAL)	Total Dynamic Head (M)	Pumped Water (L/DAY)
50	49	20P	18P		4P	47	13P	
	X	X	X	X 367	X	X	÷	=

NOTE: MAKE SURE THE PUMPING RATE IN BLOCK 38P IS LESS THAN THE SOURCE CAPACITY IN BLOCK 1P.

35P	36P	37P	38P
Pumped Water (L/DAY)	Pumping Time Factor	Peak Sun (HRS/DAY)	Pumping Rate (L/HR)
34P	3P	4P	
	÷	÷	=

INSTRUCTIONS FOR WATER PUMPING WORKSHEETS

WORKSHEET #1WP - Calculate Water Pumping Load

NOTES: (1) Steps 1P - 5P should be completed before starting to size a water pumping system. (2) Use Worksheet #1WP, then Worksheets #2-5, and, to complete the design, use Worksheet #2WP. (3) Liters are used as the measure of volume. (One U.S. gallon = 3.785 liters) Meters are use as the measure of head. (One foot = 0.3048 meters)

1P **Source Capacity (L/HR):** Enter the long-term water yield that the source is capable of supplying in liters/hour. This value may be estimated or measured with a pail of known volume and a watch.

2P **Water Required Per Day (L/DAY):** Enter the average daily water needed to meet user demand. If this value varies on a monthly basis, choose the month with the highest water demand and the lowest peak sun hours as the design month. Enter that months water demand in the worksheet.

3P **Pumping Time:** Enter the number of hours the pump will operate in a 24 hour period. This number will equal the peak sun hours unless batteries are used.

PUMPING TIME FACTOR DEFAULTS	
DIRECT CONNECTED PUMPS	1.0
WITH MATCHING DEVICES	1.2
WITH BATTERY STORAGE	HOURS OF OPERATION / PEAK SUN HOURS

4P **Peak Sun (HRS/DAY):** Enter the peak sun hours per day for the design month and the system configuration used (fixed tilt or tracking). Solar data for some locations are provided in Appendix A.

5P **Pumping Rate (L/HR):** Calculate the pumping rate. If the rate is not high enough to meet the daily demand, there are threeoptions available: 1) reduce the daily water usage, 2) increase the pumping time factor by using a battery, or 3) enhance the water source to increase the yield.

6P **Water Level (M):** Enter the vertical distance measured from the ground level to the water level in the source when no water is being pumped.

7P **Drawdown Level (M):** Enter the vertical distance measured from the static water level to the water level when the source is being pumped. This value is often determined by test pumping when the source is developed. If no drawdown level is available, use an estimate of 10 percent of static level.

8P **Discharge Level (M):** Enter the total vertical distance that the water will be lifted above ground level to the point of discharge, i.e., the water tank, faucet, etc.

9P **Discharge Head (M):** Enter the pressure, expressed in meters, at which the water will exit the distribution system. For water delivery to nonpressurized tanks or troughs, this value is zero.

10P **Static Head (M):** Calculate the total vertical distance that the water is to be lifted while pumping-without considering friction.

11P **Allowance for Friction (DECIMAL):** Enter the pressure caused by friction in the pipe delivery system expressed as a percent of the static head. It can be calculated if the characteristics of the pipes and the pumping rate are known. Friction should be kept below 10 percent of the static sum.

FRICTION DEFAULT = 5 PERCENT OF STATIC HEAD; ENTER 0.05

12P **Static Head (M):** Enter the value from Block 10P.

13P **Total Dynamic Head (M):** Calculate the total of all lifts and pressures corrected for friction, expressed in meters.

14P **Water Required Per Day (L/DAY):** Enter the value from Block 2P.

15P **Total Dynamic Head (M):** Enter the value from Block 13P.

16P **Conversion Factor:** Dividing by 367 converts the product of daily water requirement in liters per day and total dynamic head in meters, to the hydraulic energy required in Watt-hours per day.

17P **Hydraulic Energy (WH/DAY):** Calculate the energy required to lift the water.

18P Pumping System Efficiency (DECIMAL): This is the average daily efficiency that the pumping system will achieve. Pumping efficiency varies with total dynamic head, solar insolation, and type of pump. Request values of typical average efficiency from the pump manufacturer. If manufacturers' information is not available, use the default values presented.

PUMPING SUBSYSTEM DEFAULTS		
HEAD (METERS)	PUMPING SYSTEM TYPE	SYSTEM EFFICIENCY
5	SURFACE ROTARY	25%
20	SURFACE ROTARY	15%
20	JET or SUBMERSIBLE	25%
100	SUBMERSIBLE or DISPLACEMENT	35%
>100	DISPLACEMENT	45%

19P Array Energy (WH/DAY): Calculate the energy that the array must provide to the pumping system to meet average daily water requirements.

20P Nominal System Voltage (V): Enter the average voltage at which the system will operate during the pumping day. 1) For battery systems, this will be the same as the nominal battery voltage. 2) For ac pumping systems or dc systems with maximum power tracking, this will be the average peak power voltage for the array, adjusted for operating temperature. 3) For dc direct coupled systems, voltage will vary throughout the day.

21P Amp-Hour Load (Ah/day): Calculate the daily array output expressed in ampere-hours.

22P Amp-Hour Load (AH/DAY): Enter the value from Block 21P.

23P Wire Loss Factor (DECIMAL): The decimal fraction accounting for energy loss in the system wiring. Increasing the size of wire used will decrease the losses. Wire loss should never exceed 5 percent.

WIRE EFFICIENCY FACTOR DEFAULT = .98

24P **Battery Efficiency Factor (DECIMAL):** This factor accounts for losses in the battery storage subsystem. If no batteries are used enter 1.0.

BATTERY EFFICIENCY FACTOR DEFAULT = 0.9

25P **Corrected Amp-Hour Load (AH/DAY):** Calculate the daily energy required to meet the load. Enter this value in Worksheet #2 Block 22A, 22B, and 22C.

NOTE: To complete the water pumping system, use Worksheets #2-5. Then complete Worksheet #2WP.

WORKSHEET #2WP - Pumped Water and Pumping Rate

26P **Modules in Parallel:** Enter the value from Block 50 Worksheet #4.

27P **Rated Module Current (A):** Enter the value from Block 49 Worksheet #4.

28P **Nominal System Voltage (V):** Enter the value from Block 20P Worksheet #1WP.

29P **Pumping Subsystem Efficiency (DECIMAL):** Enter the value from Block 18P Worksheet #1 WP.

30P **Conversion Factor:** Dividing by 367 converts the product of daily water requirement in liters per day and total dynamic head in meters to the hydraulic energy in Watt-hours per day.

31P **Peak Sun (HRS/DAY):** Enter the value from Block 4P Worksheet #1WP.

32P **Module Derate Factor (Decimal):** Enter the value from Block 47 Worksheet #4.

33P **Total Dynamic Head (M):** Enter value from Block 13P Worksheet #1WP.

34P **Pumped Water (L/DAY):** Calculate the amount of water to be pumped per day.

35P **Pumped Water (L/DAY):** Enter the value from Block 34P.

36P **Pumping Time:** Enter the value from Block 3P Worksheet #1WP.

37P **Peak Sun (HRS/DAY):** Enter the value from Block 4P Worksheet #1WP.

38P **Pumping Rate (L/HR):** Calculate the rate of pumped water and compare with the source capacity in Block 1P Worksheet #1WP.

HYBRID WORKSHEET #1 HY

CALCULATE THE BATTERY CAPACITY, GENERATOR SIZE, AND PERCENT CONTRIBUTION OF THE ARRAY AND GENERATOR

DESIGN NOTES:

1Y Corrected Amp-Hour Load (AH/DAY) 20	2Y D Storage Days for Hybrid System	3Y D Maximum Depth of Discharge (DECIMAL)	4Y D Derate for Temperature (DECIMAL)	5Y Hybrid Battery Capacity (AH)	6Y Peak Current Draw (A) 16	7Y Battery Discharge Time (HOURS)
	X	÷	÷	=	÷	=

8Y Hybrid Battery Capacity (AH) 5Y	9Y D Battery Charge Time (HOURS)	10Y Maximum Battery Charge Rate (A)	11Y Nominal System Voltage (V) 9	12Y Nominal Charging Power (W)	13Y D Efficiency of Battery Charger (DECIMAL)	14Y D Generator Derate Factor (DECIMAL)	15Y Generator Size (W)
	÷	=	X	=	÷	÷	=

16Y D Hybrid Array to Load Ratio	17Y D Load Provided by Array (DECIMAL)

	18Y Load Provided by Array (DECIMAL) 17Y	19Y Load Provided by Generator (DECIMAL)	20Y Annual Kilowatt-Hour Load (KWH/YR) 72	21Y Annual Generator Output (KWH)
1.0	−	=	X	=

22Y Annual Generator Output (KWH) 21Y	23Y Conversion Factor	24Y Nominal Charging Power (W) 12Y	25Y Annual Generator Run Time (HRS)	26Y D Oil Change Interval (HRS)	27Y Services per Year (NUMBER)
	X 1000	÷	=	÷	=

HYBRID
WORKSHEET #2 HY

CALCULATE THE NUMBER OF MODULES AND BATTERIES IN SERIES AND PARALLEL

DESIGN NOTES:

28Y D	29Y	30Y	31Y	32Y	33Y
Hybrid Array to Load Ratio	Watt-Hour Load (WH/DAY)	Hybrid Array Power (W)	Nominal System Voltage (V)	Rated Module Current (A)	Modules in Parallel
16Y	70		9	59	
	X	=	÷	÷	=

34Y	35Y	36Y	37Y	38Y
Nominal System Voltage (V)	Nominal Module Voltage (V)	Modules in Series	Modules in Parallel	Total Modules
9			33Y	
	÷	=	X	=

39Y	40Y	41Y
Hybrid Battery Capacity (AH)	Capacity of Selected Battery (AH)	Hybrid Batteries in Parallel
5Y		
	÷	=

42Y	43Y	44Y	45Y	46Y
Nominal System Voltage (V)	Nominal Battery Voltage (V)	Hybrid Batteries in Series	Hybrid Batteries in Parallel	Total Hybrid Batteries
9	36		41Y	
	÷	=	X	=

47Y	48Y	49Y	50Y	51Y
Hybrid Batteries in Parallel	Capacity of Selected Battery (AH)	Hybrid System Battery Capacity (AH)	Maximum Depth of Discharge (DECIMAL)	Usable Battery Capacity (AH)
41Y	40Y		3Y	
	X	=	X	=

INSTRUCTIONS FOR HYBRID SYSTEM WORKSHEETS

Before using these worksheets, you should have completed Worksheets M-5 and determined that a hybrid system is an option for your application.

Hybrid Worksheet #1 HY - Calculate Battery Capacity, Generator Size, and Percent Contribution of PV Array and Generator

1Y **Corrected Amp-Hour Load (AH/DAY):** Enter value from Block 20 Worksheet #1.

2Y **Storage Days for Hybrid System:** Enter the number of days of storage for the hybrid system. This value is usually smaller than for a stand-alone system because the generator is available for backup.

DAYS OF STORAGE DEFAULT = 3 DAYS

3Y **Maximum Depth of Discharge (DECIMAL):** Enter the value from Block 31 Worksheet #3 if the same battery will be used. If another battery is selected, use the manufacturer's specifications to select a safe depth of discharge.

4Y **Derate for Temperature (DECIMAL):** Enter the value from Block 32 Worksheet #3 if the same battery will be used.

ALLOWANCE FOR TEMPERATURE DERATE OF BATTERY = 0.9

5Y **Hybrid Battery Capacity (AH):** Calculate the required hybrid battery capacity.

6Y **Peak Current Demand (A):** Enter the value from Block 16 Worksheet #1.

7Y **Battery Discharge Time (HOURS):** Calculate the battery discharge factor-this is the number of hours the battery can supply the peak current to the load. This factor should be greater than 5 to prevent damage to the batteries. If less than 5, increase the number of storage days and recalculate 1Y through 7Y.

8Y **Hybrid Battery Capacity (AH):** Enter the value from Block 5Y.

9Y **Battery Charge Time (HOURS):** Enter the minimum time that will be used to charge the battery. Determine the maximum charging current that should be used for the chosen battery from the manufacturer's specifications.

CHARGE TIME DEFAULT = 5

10Y Maximum Battery Charge Rate (A): Calculate the maximum battery charge rate.

11Y Nominal System Voltage (V): Enter the value from Block 9 Worksheet #1.

12Y Nominal Charging Power (W): Calculate the charging power required.

13Y Efficiency of Battery Charger (DECIMAL): Determine and enter the battery charger efficiency. See manufacturers' specifications

BATTERY CHARGER EFFICIENCY DEFAULT = 0.8

14Y Generator Derate (DECIMAL): Generator power output should be derated for high altitude operation because the thinner air reduces combustion efficiency. Ask your generator supplier what derate factor should be used. If no other information is available, use a default of 3 percent per 1000 feet of elevation above sea level for gasoline, diesel, and propane fueled generators. Use 5 percent for natural gas generators. For example, a 5000 Watt diesel generator operating at 9000 feet elevation should be considered as a 3650 Watt generator.

$$[5000 *(1 - 9 * 0.03)] = 3650$$

15Y Generator Size (W): Calculate the generator size to the nearest whole number.

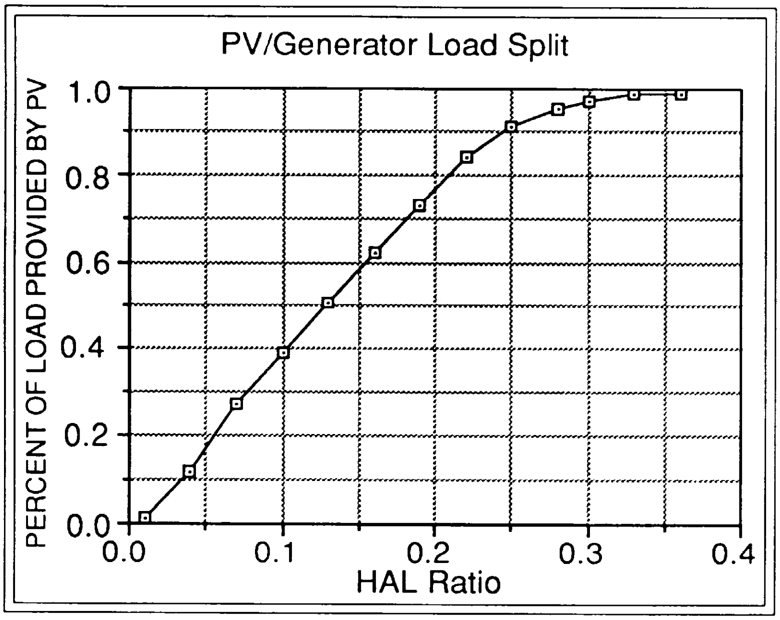
16Y Hybrid Array to Load Ratio (HAL): Determine the split between generator and PV power using the graph provided on the next page. Start with the HAL factor calculated in Block 77, Worksheet #5 and determine the amount of load provided by the PV array. In most cases this will indicate a high percentage of PV power and therefore a high initial cost for the system. System designers adjust the HAL to change the PV array size depending on the application and the budget available. The percentage of the load provided by PV power, and thus the initial cost, increase as you move up the curve. The shape of this curve will change slightly with weather patterns. For areas with long periods of inclement weather, the slope of the curve will decrease, indicating a smaller PV array for a given HAL value.

17Y Load Provided by Array (DECIMAL): Enter the number selected from the left axis of the graph that corresponds to the HAL ratio chosen.

18Y Load Provided by PV Array (DECIMAL): Enter the value from Block 17Y.

19Y Load Provided by Generator (DECIMAL): Calculate the percentage of load provided by the generator.

20Y Annual Kilowatt-Hour Load (KWH/YR): Enter value from Block 72 Worksheet #5.



21Y **Annual Generator Output (KWH):** Calculate the annual generator output.

22Y **Annual Generator Output (KWH):** Enter the value from Block 21Y.

23Y **Conversion Factor:** This factor converts kilowatt-hours to watt-hours.

24Y **Nominal Charging Power (W):** Enter the value from Block 12Y.

25Y **Annual Generator Run Time (hr):** Calculate the time the generator will run in a typical year.

26Y **Oil Change Interval (HRS):** Select and enter number of operating hours between oil changes for your generator. Some typical intervals are given in the following table along with suggested intervals for more thorough cleaning and maintenance and engine rebuild.

GENERATOR MAINTENANCE INTERVAL DEFAULT			
	Oil Change	Engine Cleaning and Tune-up	Engine Rebuild
Gas (3600 RPM)	50 hours	300 hours	5,000 hours
Gas (1800 RPM)	100 hours	300 hours	5,000 hours
Diesel	400 hours	1,200 hours	7,200 hours

27Y **Services Per Year (NUMBER):** Calculate the recommended number of service calls per year.

Hybrid Worksheet #2 HY - Calculate Number of Modules and Batteries

28Y **Hybrid Array to Load Ratio:** Enter the value from Block 16Y Worksheet #1HY.

29Y **Watt-Hour Load (WH/DAY):** Enter the value from Block 70 Worksheet #5.

30Y **Hybrid Array Power (W):** Calculate the hybrid array power.

31Y **Nominal System Voltage (V):** Enter the value from Block 9 Worksheet #1.

32Y **Rated Module Current (A):** Enter the value from Block 59 Worksheet #4.

33Y **Modules in Parallel:** Calculate the number of modules connected in parallel required to provide the array current. Rounding down will mean more generator operating time.

34Y **Nominal System Voltage (V):** Enter the value from Block 31Y Worksheet #1HY.

35Y **Nominal Module Voltage (V):** Enter the nominal module voltage from Block 64 Worksheet #4.

36Y **Modules in Series:** Calculate the number of series connected modules required to produce the system voltage.

37Y **Modules in Parallel:** Enter the value from Block 33Y.

38Y **Total Modules:** Calculate the total number of modules required.

39Y **Hybrid Battery Capacity (AH):** Enter the value from Block 5Y Worksheet #1HY.

40Y **Capacity of Selected Battery (AH):** Enter the rated capacity for the selected battery from manufacturers' specifications.

41Y **Hybrid Batteries in Parallel:** Calculate the number of parallel connected batteries required to provide the storage capacity.

42Y **Nominal System Voltage (V):** Enter the value from Block 31Y Worksheet #1HY.

43Y **Nominal Battery Voltage (V):** Enter the nominal battery voltage from Block 37 Worksheet #3.

44Y **Batteries in Series:** Calculate the number of series connected batteries required to provide the system voltage.

45Y **Batteries in Parallel:** Enter the value from Block 41Y.

46Y **Total Hybrid Batteries:** Calculate the total number of batteries in the system.

47Y **Hybrid Batteries in Parallel:** Enter the value from Block 41Y.

48Y **Capacity of Selected Battery (AH):** Enter the value from Block 40Y.

49Y **Hybrid System Battery Capacity (AH):** Calculate the battery subsystem storage capacity.

50Y **Maximum Depth of Discharge (DECIMAL):** Enter the value from Block 3Y Worksheet #1HY.

51Y **Usable Battery Capacity (AH):** Calculate the usable battery capacity of the hybrid system.

Note: Use the Component Specification Worksheets to complete the design.

DIRECT DRIVE WORKSHEET #1DD

MATCH THE ARRAY CURRENT AND LOAD CURRENT

DESIGN NOTES:

1D DEVICE LOAD INFORMATION

Device		▨	**Nominal**	**Maximum**
Model		**Voltage (V)**		
Make		**Current (A)**		

2D Nominal Device Current (A)	3D D Wire Efficiency Factor (DECIMAL)	4D Maximum Design Current (A)	5D D Module Derate Factor (DECIMAL)	6D Design Current (A)	7D Rated Module Current (A)	8D Modules in Parallel
	÷	=	÷	=	÷	=

9D Nominal Device Voltage (V) 1D	10D Nominal Module Voltage (V) 1D	11D Modules in Series	12D Modules in Parallel 8D	13D Total Modules
	÷	=	X	=

	14D Rated Module Current (A) 7D	15D Modules in Parallel 8D	16D Maximum Current (A)
1.25	X	X	=

PV MODULE INFORMATION

Make/Model			**Nominal Volts**		
Length		**Width**	**Thickness**		
Weight			**Bypass Diode**	**Y**	**N**
Voltage (V)	**At STC**	**Open Circuit**	**At Highest Expected Temperature**		
Current (A)	**At STC**	**Short Circuit**	▨		
			▨		

DIRECT DRIVE WIRING AND PROTECTION HARDWARE SPECIFICATION

DESIGN NOTES:

WIRE SIZING AND SPECIFICATION (DC SIDE)

17D Wire Runs	18D System Voltage (V)	19D Maximum Current (A)	20D One Way Length (FT)	21D Allowed Voltage Drop (%)	22D Allowance for Temperature Derate	23D AWG Number	24D Wire Type
Array to Load							

25D

ARRAY TO LOAD DISCONNECT

Type ____________________

Current Rating ____________________ (A)

Voltage Rating ____________________ (V)

26D

OVERCURRENT PROTECTION

Type ____________________

Current Rating ____________________ (A)

Enclosure Type ____________________

INSTRUCTIONS FOR SMALL DIRECT-DRIVE WORKSHEETS

These two worksheets may be used to design small direct-drive PV systems.

Direct-Drive Worksheet #1 DD - Match the Array and Load Current

1D **Device Load Information:** Determine the specifications for the device to be powered and enter the information indicated.

2D **Nominal Device Current (A):** Enter the nominal (rated) current required by the load.

3D **Wire Efficiency Factor (DECIMAL):** Enter the wire loss factor. This factor should be ≥0.98 since the array and load are direct coupled.

WIRE EFFICIENCY FACTOR DEFAULT = .98

4D **Maximum Design Current (A):** Calculate the maximum current required.

5D **Module Derate Factor (DECIMAL):** Enter a factor that adjusts module current for dirt accumulation on modules, degradation, mismatch loss between module and load, etc. If manufacturers' recommended values are not available use the defaults suggested below.

MODULE DERATED FACTOR DEFAULT	
TYPE	FACTOR
CRYSTALLINE AMORPHOUS	0.9 0.7

6D **Design Current (A):** Calculate the design current.

7D **Rated Module Current (A):** Select a candidate module and enter the rated module current. Fill in the information indicated in the module data block on the worksheet.

8D **Modules in Parallel:** Calculate the number of parallel connected modules needed to provide the load current.

9D **Nominal Device Voltage (V):** Enter the nominal operating voltage of the device.

10D **Nominal Module Voltage (V):** Enter the expected operating voltage of the module at the highest expected temperature.

11D **Modules in Series:** Calculate the number of series connected modules necessary to produce the required load voltage.

12D **Modules in Parallel:** Enter the value from Block 8D.

13D **Total Modules:** Calculate the total number of modules required.

14D **Rated Module Current (A):** Enter the value from Block 7D.

15D **Modules in Parallel:** Enter the value from Block 8D.

16D **Maximum Current (A):** Calculate the maximum current including the 25 percent safety factor.

Direct Drive Wiring and Protection Hardware Specification

This worksheet provides a convenient form for specifying the wire and disconnects to be used in the direct-drive system.

17D **Wire Runs:** List the wire runs.

18D **System Voltage (V):** Enter the nominal system voltage.

19D **Maximum Current (A):** Enter the maximum rated current for each wire run. Select a wire that will withstand the highest expected temperature.

20D **One Way Length (FT):** Determine the one-way wire distance in feet from the array to the load.

21D **Allowed Voltage Drop:** Specify the maximum allowable percentage voltage drop for each wire run. The NEC stipulates a maximum of 5 percent voltage drop from voltage source to load.

22D **Allowance for Temperature Derate:** See Table 310-16 of the NEC for suggested derate factors.

23D **AWG Number:** Determine the American Wire Gauge (AWG) size for the wire. Using the four tables provided on pages B-26 to B-29 for quick reference, the maximum one-way wire distance for copper conductors of certain size can be determined for 12-, 24-, 48-, and 120-volt circuits.

24D **Wire Type:** Select the wire type and describe the type of insulation and wire covering. See Table 310-13 for information on conductor applications and wire coverings.

25D **Array to Load Disconnect:** Select a dc rated switch that will safely interrupt the highest expected current.

26D **Overcurrent Protection (if necessary):** Select a fuse that will protect the device and the array-to-load conductors. Use a factor of 1.25 times the maximum short circuit current of the array. Most direct drive systems do not require overcurrent protection.

CATHODIC PROTECTION WORKSHEET #1 CP

LOAD CURRENT DETERMINATION

DESIGN NOTES:

	1C D Metal Coating Efficiency (DECIMAL)	2C Total Metal Surface Area (FT^2)	3C Bare Metal Surface Area (FT^2)	4C D Metal Protection Current Density (A/FT^2)	5C Estimated Protection Current (A)	6C Measured Protection Current (A)
1.0	–	x	=	x	=	

NOTES:
1) USE 5C TO ESTIMATE LOAD CURRENT IF ACTUAL FIELD MEASUREMENTS ARE NOT AVAILABLE.
2) CC IS THE ABBREVIATION FOR CUBIC CENTIMETER.
3) ENTER 1.0 IN BLOCK 13C IF ONLY ONE ANODE IS USED.

7C Required Protection Current 5C or 6C	8C D Rated Anode Current (A)	9C Number of Anodes
	÷	=

10C D Soil Resistivity (OHM/CC)	11C Conversion Factor	12C D Single Anode Resistance to Earth (OHMS)	13C D Multiple Anode Factor	14C Anode(s) Resistance to Earth (OHMS)	15C Required Protection Current 7C	16C Required System Voltage
	÷ 1000	x	x	=	x	=

17C Required Protection Current 7C	18C D Daily Duty Cycle (HRS/DAY)	19C Amp Hour Load (AH/DAY)	20C D Wire Efficiency Factor (DECIMAL)	21C D Battery Efficiency Factor (DECIMAL)	22C Corrected Amp-Hour Load (AH/DAY)
	x	=	÷	÷	=

INSTRUCTIONS FOR CATHODIC PROTECTION WORKSHEETS

These instructions are for the cathodic protection worksheet. Once the corrected ampere-hour load is determined, the sizing and specification of components is completed using the same worksheets used for other systems. The sizing procedure given here is for small cathodic protection systems such as buried water tanks. **It is suggested that an experienced cathodic protection engineer be consulted regarding load sizing, particularly on larger systems.**

Cathodic Protection Worksheet #1 CP

NOTE: Steps 1C through 5C can be used to estimate the load current if field measurements are not available. If the current is known, enter the value in 6C.

1C **Metal Coating Efficiency (DECIMAL):** An efficiency associated with the degree of protection provided by various metal coatings (i.e., paint, coal tar, pipe wrap, etc.). Typically metal coating efficiencies are 90 to 95 percent effective.

METAL COATING EFFICIENCY DEFAULT = .9

2C **Total Metal Surface Area (W):** Enter the total surface area of the metal structure to be protected.

3C **Bare Metal Surface Area (FT^2):** Calculate the metal surface area remaining unprotected by coating.

4C **Metal Protection Current Density (A/FT^2):** Enter the current density necessary to reverse the metal loss (corrosion) for a particular metal.

CURRENT DENSITY DEFAULTS	
UNCOATED STEEL PIPE IN DAMP SOIL	3 mA/ft^2
COATED STEEL IN DAMP SOIL	0.02 mA/ft^2
UNCOATED STEEL TANK IN SAND	1 mA/ft^2
UNCOATED STEEL WHARF IN SEA WATER	5 mA/ft^2

5C **Estimated Protection Current (A):** Calculate the value of load current and enter this value in 6C.

6C **Measured Protection Current (A):** Enter the value determined using a temporary test installation. Using such field measurements also allows the identification of the least resistive soil for anode placement.

7C **Required Protection Current (A):** Enter the value from Block 5C or Block 6C.

8C **Anode Current (A):** Enter the maximum current specified for the type of anode that will be used. Ask the anode supplier for this information. If no information is available use the default for a graphite anode.

MAXIMUM ANODE CURRENT DEFAULT = 2 A

9C **Number of Anodes:** Calculate the number of anodes required to provide the protection current.

10C **Soil Resistivity (OHM-CC):** Enter the resistivity of the soil. This is usually given in units of ohms per cubic centimeter. If no measurement data are available use the default values given.

SOIL RESISTIVITY DEFAULT	
SOIL TYPE	RESISTIVITY
Dry, Sandy	25,000
Loam	10,000
Wet, Swampy	5,000
Wet, Salt Water	1,000

11C **Conversion Factor:** A constant used to obtain a multiplier factor consistent with the anode-to-earth resistance for a single anode.

12C **Anode to Earth Resistance (OHMS):** Enter the value obtained from the anode supplier. If no information is available, enter the value from the table below. This table gives the estimated resistance for a single vertical anode buried in soil with resistivity of 1,000 ohm/cc. For other soil resistivities, multiply the values in the table by the ratio of “actual soil resistivity divided by 1,000.”

Resistance to Earth of a Single Vertical Anode, (Ohms)							
	Length, ft.						
Diameter, (in)	2	3	4	5	6	7	8
3	8.3	6.2	5.0	4.3	3.7	3.3	3.0
4	7.5	5.7	4.7	4.0	3.5	3.1	2.8
6	6.4	5.0	4.1	3.5	3.1	2.8	2.5
8	5.7	4.5	3.7	3.2	2.9	2.6	2.3
10	5.1	4.1	3.5	3.0	2.7	2.4	2.2
12	4.6	3.8	3.2	2.8	2.5	2.3	2.1
14	4.2	3.5	3.0	2.6	2.3	2.1	2.0
16	3.9	3.3	2.8	2.5	2.2	2.0	1.9

Source: Catalogue Data, Cathodic Protection Service, Houston, Texas, 1958

13C **Multiple Anode Factor (DECIMAL):** Enter the value of a nonlinear adjustment factor that accounts for interaction between the number of anodes and the distance between them in a cathodic protection system. In general, the resistance of two anodes in parallel will have more resistance than one half the resistance of a single anode. See the following table.

ADJUSTING FACTORS FOR MULTIPLE ANODES					
No. of Anodes	Anode Spacing in Feet				
	5'	10'	15'	20'	25'
1	1.000	1.000	1.000	1.000	1.000
2	0.652	0.576	0.551	0.538	0.530
3	0.586	0.460	0.418	0.397	0.384
4	0.520	0.385	0.340	0.318	0.304
5	0.466	0.333	0.289	0.267	0.253
6	0.423	0.295	0.252	0.231	0.218
7	0.387	0.265	0.224	0.204	0.192
8	0.361	0.243	0.204	0.184	0.172
9	0.332	0.222	0.185	0.166	0.155
10	0.311	0.205	0.170	0.153	0.142
11	0.292	0.192	0.158	0.141	0.131
12	0.276	0.180	0.143	0.132	0.122
13	0.262	0.169	0.139	0.123	0.114
14	0.249	0.160	0.131	0.116	0.107
15	0.238	0.152	0.124	0.109	0.101
16	0.226	0.144	0.117	0.103	0.095
17	0.218	0.138	0.112	0.099	0.091
18	0.209	0.132	0.107	0.094	0.086
19	0.202	0.127	0.102	0.090	0.082
20	0.194	0.122	0.098	0.086	0.079

14C **Anodes Resistance to Earth (ohms):** Calculate the total resistance of the system.

15C **Required Protection Current (A):** Enter the value from Block 7C.

16C **Required System Voltage (V):** Calculate the voltage required to impress the necessary protection current.

17C **Required Protection Current (A):** Enter the value from Block 7C.

18C **Daily Duty Cycle (HRS/DAY):** Enter 24 hours if the system is to be powered all the time. Most cathodic protection systems are.

19C **Amp-Hour Load (AH/DAY):** Calculate the total ampere-hour load (ampere-hour/ day).

20C **Wire Efficiency Factor (DECIMAL) (1 - WIRE LOSS):** The decimal fraction accounting for loss due to wiring. This factor can vary from 0.95 to 0.99. Wire size should be chosen to keep wire loss in any single circuit to less than 3 percent (>0.97).

WIRE EFFICIENCY FACTOR DEFAULT = .98

21C **Battery Efficiency Factor (DECIMAL):** This factor accounts for the losses of the battery storage subsystem. Use data from the manufacturer for specific batteries.

BATTERY EFFICIENCY FACTOR DEFAULT = .9

22C **Corrected Amp-Hour Load (AH/DAY):** Calculate the energy required to meet the average daily load. This value can be used with Worksheets 2, 3, and 4 to complete the system design.

LIFE-CYCLE COST ANALYSIS WORKSHEET

1LC PROJECT DESCRIPTION:

2LC ECONOMIC PARAMETERS:

1. Years in Life-Cycle:
2. Investment Rate:
3. General Inflation Rate:
4. Fuel Inflation Rate:

Net Discount Rate (2-3) =

Differential Fuel Inflation (4-3) =

Item	Single Present Worth Year	Uniform Present Worth Years	Dollar Amount		Present Worth Factor (Table 4 or 5)		Present Worth Amount
3LC Capital Equipment and Installation			____	X	1	=	____
4LC Operation & Maintenance							
• Labor		____	____	X	____	=	____
• Materials		____	____	X	____	=	____
• Insurance		____	____	X	____	=	____
• Other		____	____	X	____	=	____
5LC Energy Costs							
•		____	____	X	____	=	____
•		____	____	X	____	=	____
6LC Repair and Replacement							
•	____		____	X	____	=	____
•	____		____	X	____	=	____
•	____		____	X	____	=	____
•	____		____	X	____	=	____
•	____		____	X	____	=	____
•	____		____	X	____	=	____
7LC Salvage							
•	____		____	X	____	=	____
•	____		____	X	____	=	____

8LC TOTAL LIFE-CYCLE COST **(ITEMS 3+4+5+6-7)**

NOTES:

INSTRUCTIONS FOR LIFE-CYCLE COST WORKSHEETS

1LC **Project Description:** Enter project identity.

2LC **Economic Parameters:** Select and enter period and rates. Net discount rate is equal to the obtainable investment rate (2) minus general inflation (3). Differential fuel inflation is equal to the expected rate of fuel inflation (4) minus general inflation (3).

3LC **Capital Equipment and Installation:** Enter the full cost of equipment and installation as an initial capital cost. Initial cost of equipment is not discounted.

4LC **Operation and Maintenance:** These are annually recurring costs and should be discounted using the appropriate factor from Table 4, "Uniform Present Worth Factors" on page 63. Use the Net Discount Rate calculated above. The uniform present worth years should correspond to the years in the life-cycle.

5LC **Energy Costs:** Enter the annually recurring costs for a generator or utility hookup. These are discounted using Table 5. Use a rate equal to the net discount rate minus differential fuel inflation rate. The uniform present worth years should correspond to the years in the life-cycle.

6LC **Repair and Replacement:** Enter the estimated repair costs that are planned for a specific year, such as replacement of a battery bank. The estimated cost of each repair/replacement should be discounted using Table 3, Single Present Worth Factors on page 62. Use the net discount rate and the year in which the repair or replacement is planned.

7LC **Salvage:** Enter the salvage credit, usually figured at 20 percent of the original equipment cost. This value should be discounted using Table 3, selecting the last year of the life cycle period and the net discount rate.

8LC **Total Life-Cycle Cost:** Calculate the present worth column for items 3 to 6 and subtract item 7, to obtain the total life-cycle cost for the project.

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