Electricity from sunlight

Solar Energy supply for Homes and Buildings

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& GTZ-GATE, May 2002

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1 Introduction

At the start of the third millennium, 70% of the rural population in developing countries is still without electricity. While every German citizen consumes more than 5,000 kWh per year, billions of people still have to rely on candles and kerosene to get some light during the night.

Modern households, companies as well as public services depend on electricity. Electricity is a precondition for development. Far from the public mains, few options exist to operate even basic electrical appliances.

Photovoltaics is one of the most prominent options. It can help to raise standards of living and facilitates the operation of services and businesses.

Furthermore, in a world of ecological damage and manmade climatic changes, photovoltaics is one of the very few environmentally friendly energy systems.

There are already millions of photovoltaic systems of various sizes in operation worldwide, many of them in developing countries. The solar industry produces 5 million modules every year, and production is increasing at about 20% per year.

2 About this Guide

This guide has been designed for those who intend to install a stand-alone or **autonomous PV system** of medium size (power range of 200 - 2,000 W_p) for

- **households** that are in need of lighting, refrigeration and entertainment,
- shops and bars that want to provide some basic services such as music, videos or cold drinks to customers,
- **offices** that like to operate computers and communications equipment,
- **workshops** that struggle to improve their work with small electric tools,
- **health centers** that want to store vaccines and drugs.

The guide helps you to decide whether photovoltaics is the right choice to suit your specific requirements. It gives an introduction to some essential technical aspects and recommendations for the planning process. This includes an explanation of a brief design procedure. It is not suitable for designing a system on your own since you will need a qualified supplier in any case. This is followed by some basic rules and hints for running a system. Finally, you will find some sources to get further information.

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3 A First Checklist

The most essential question is, **whether a photovoltaic system is technically and economically feasible for your purpose.** Sometimes it is quite obvious that solar power would not be the best solution. You can save time and money if you realize this early on. Please check the following questions.

- Is electricity really a high priority compared with other unsatisfied demands?
- Are you without a reasonably reliable mains connection that is within reach or expected to be in the near future?
- Can you afford and finance an investment of at least 2,000 € (1 € ~ 1 US $)?
- Is your daily energy demand smaller than 20 kWh?
- Do you want to operate appliances with a power demand of less than one kilowatt only?
- Can you provide the technical and financial means for regular operation, maintenance and replacement?
- Are gensets, fuel supply and technical service difficult to obtain or expensive?
- Are significant changes in ownership, use, consumption or the financial and economic situation unlikely in future?

If your answers include a "No", it is unlikely that photovoltaics will be the most economic choice for you. This doesn't necessarily mean that generator sets are a suitable option either.

Generator sets are the main competitor of photovoltaic systems in rural areas. They are widely distributed and well-known, but so are their drawbacks, such as high costs, difficult and unreliable fuel supply as well as intensive operating and maintenance requirements.

4 Photovoltaics

Sunshine is a form of energy. Solar cells – the technology is called photovoltaics - transform light into electricity.

Solar cells don't need sunshine, just light, but the sunlight intensity is several times higher when the sky is not overcast.

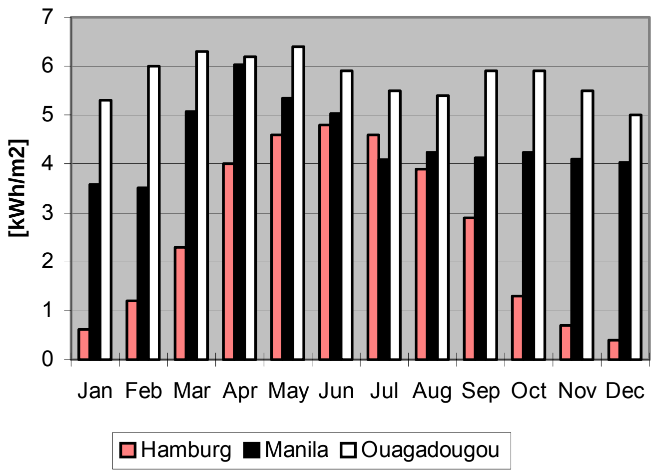

Figure 1: Global insolation for selected sites

The cell output is highest when the sunbeams fall perpendicular on the solar cell. The light energy that falls on a surface over a period of time is called insolation. Typical mean daily insolations in developing countries are 4–5.5 kWh/m^2. Such energy would drive a car for ~ 5 km.

Insolation data are available for many sites, usually as mean daily figures per month. Sometimes other units of measurement are applied:

1 kWh/m^2. = 1 MJ/m^2 / 3.6 = 1 Langley / 86 = 1 cal/cm^2 / 86 = 1 BTU/ft^2 / 317

5 Systems and Components

A typical solar system for power supply to buildings consists of a solar generator for power generation, a battery to store this energy, a charge controller to operate the battery in a suitable way, the appliances and sometimes a power conditioning unit such as an inverter.

Besides these technical components, the **users** always represent an important interactive part of the system which should not be forgotten.

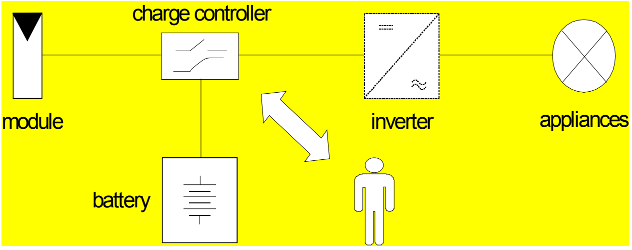

Figure 2: Block diagram of a PV system

5.1 The generator

The heart of a photovoltaic system is the generator itself. The generator is the connection of any number of **solar modules** (also called panels). A standard module consists of 36 **solar cells**. Modules have a lifetime of more than 20 years.

Retail prices for modules are currently (2001) € 5 to 8 per W_p. In other words, a 50 W_p module will cost about € 250 to 400.

In the field, modules with mono-crystalline and poly-crystalline cells are applied almost exclusively.

Solar modules are rated in **peak watts** [W_p] according to their output under optimal outdoor conditions. Thus, a 50 W_p module can be expected to supply 50 W of power in full sunshine. The performance is reduced by high temperatures.

The modules are connected in series and/or in parallel depending on the system requirements. A serial connection increases the voltage, a parallel connection increases the current.

> ***Example***
> *A 24 V system with a nominal power rating of 300 W_p can be combined from two 50 W_p modules connected in series (2 ∗ 12 V = 24 V) and three parallel strings with two modules (3 ∗ 2 ∗ 50 W = 300 W).*

5.2 The battery

Batteries are applied to store energy for times of little or no sunlight.

They are the most sensitive component of any photovoltaic system and require a certain amount of care. They are not easy-going like batteries in cars.

Only lead-acid batteries are used in the field. They come in different types:

- **Automotive batteries** (regular type, used in cars, also called SLI batteries)
  ↘ very short service life, high maintenance, only shallow charging
  ↗ very low price, good availability
- Automotive batteries (**heavy- duty type**, used in trucks and buses)
  ↘ short service life, medium maintenance, shallow discharging
  ↗ low price, good availability
- **Solar batteries** (different designs)
  ↘ medium discharging, limited availability, medium price
  ↗ better service life, limited maintenance
- **High-quality batteries** (diff. designs)
  ↘ expensive (4-6∗autom. battery price)
  ↗ high service life, low maintenance, rather deep discharging

Regular batteries have to be filled up with distilled water in certain intervals. A few are **maintenance-free**. Only those of the gel-type are suitable in solar systems.

Automotive batteries are unsuitable if any alternative exists. Heavy-duty ones may be used in smaller systems with severe budget constraints or if others are not available. High-quality, deep-cycle batteries are optimal for solar applications. Solar batteries are a compromise between quality and costs.

The service life of batteries, which is expressed in **cycles** of charging and discharging periods, increases with

- the quality of the battery,
- the quality of the charge controller,
- low temperature,
- a low depth of discharge and
- careful operation and maintenance.

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The **depth of discharge** (DoD) is that portion of the **battery capacity** which is removed during discharging. The capacity is indicated in ampere hours (Ah) or sometimes in days of autonomy. This is the number of days a fully charged battery can satisfy the energy demand.

Example
A 12 V, 60 Ah battery can store 12 V ∗ 60 Ah = 720 Wh. At a 75% depth of discharge, 540 Wh have been removed and the remaining capacity is 180 Wh / 12 V = 15 Ah. If the daily energy demand is 270 Wh, the battery has 2 days of autonomy.

As a rule of thumb, reducing the DoD by half will double the number of cycles.

The common 12 V battery includes six cells of 2 V in one housing.

Characteristics of battery types Figures depend on type and operating conditions			
	automot.	solar	quality
Energy efficiency	70%	75%	80%
Self-discharge/mo.	20%	4%	2.5%
Costs per kWh	70 €	120 €	300 €
Maintenance	4x/a	2x/a	1x/a

Table 1: Battery characteristics

As with modules, batteries are connected in series for higher voltage levels or in parallel to increase the capacity. Batteries that are connected should be **identical** in type, capacity, age and electrolyte density. Parallel connection should be avoided if possible.

5.3 The controller

Batteries have to be protected against overcharging and deep discharging by a **charge controller.** Charge controllers are also referred to as charge regulators and battery control units (BCU).

During charging, the battery voltage increases. At a certain voltage, the battery starts "gassing". **Gassing**, the production of hydrogen and oxygen, reduces the life expectancy as well as the required maintenance periods and should be avoided.

A controller avoids excessive gassing by maintaining the voltage at the **end-of-charge** level of about 14.0 V, depending on the battery type and temperature.

The end-of-charge level may be adapted to the battery temperature by means of a **temperature sensor**.

In contrast to charging, the voltage of a battery being discharged declines. In a **deep-discharged** state, chemical processes occur which will reduce the battery lifetime quickly. To protect the battery, the loads have to be cut off at a certain voltage. High-quality batteries are less sensitive to deep discharging.

For automotive batteries, manufacturers recommend discharging of only 30%, while 80% is common practice.

Individual batteries will develop differently after some time of operation. Worn-out cells have to be identified and removed in order to protect those that are still in good condition.

Battery type	Max. discharge	Cut-off voltage
Automotive battery	30 - 50%	11.8-11.5 V
Heavy-duty battery	50 - 70%	11.5-11.2 V
Solar battery	60 - 80%	11.4-11.0 V
High-quality battery	80%	11.0-10.8 V

Table 2: Discharge conditions for batteries

A new generation of controllers adapt the charging process and the load management to the state of charge and the ageing process of the batteries. System efficiency and battery lifetime benefit from this, but such controllers are sophisticated and currently hardly available in developing countries.

Charge controllers may provide a lot of additional helpful functions and features, but this makes them more expensive and reliability may suffer as a result.

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Controllers are designed for maximum input and output currents. **Safety measures** may include protection against short circuit, overvoltage, overloads, reverse polarity, wrong connection and environmental hazards. Controllers should indicate the state of charge and a load cut-off.

5.4 The inverter

Solar modules and batteries operate with DC. The technical electricity sector, however, is based on AC. Many electrical appliances, devices and accessories are only available for AC. An **inverter** transforms low-voltage DC supplied by a solar system into high-voltage AC. The input of an inverter is designed for 12 V (24 V, 48 V, etc.), depending on the type. At the output it produces 110 or 240 V AC. Inverters are designed for stand-alone as well as for grid-connected systems.

Inverters are available with a wide variety of different qualities and features. Not surprisingly, low-price inverters are generally of poor quality and not very suitable for solar operation.

Inverters are designed for a maximum load. They provide a certain **overload capacity** for a short-term demand arising e.g. from the starting current of a motor.

High-quality inverters have an efficiency of more than 90% between 10% and 100% rated power.

Inverters produce a **sinusoidal current** like the mains, a modified square or a square wave current. Square wave inverters are not suitable. Sinusoidal inverters are optimal. Modified square inverters are approx. 40% cheaper, but electronic and motor-equipped appliances (TVs, computers, pumps, fans, refrigerators, etc.) may run poorly or may even be damaged.

Safety measures include protection against short circuit, overload, high input and output voltage, high temperature and reverse polarity.

5.5 Wiring

Many system failures are caused by unsuitable or improperly installed cables, connectors, switches or sockets. Their current, voltage and power ratings should be in line with the system characteristics.

Unlike AC, in DC systems switching the poles (+) and (-) will cause problems. The application of special DC fittings is recommended. Otherwise, high-quality AC items should be applied. The current ratings of AC-switches can be applied only for 12 V/ 24 V DC systems. In high-voltage DC systems, they have to be higher.

The current drawn by an appliance or circuit can be calculated by dividing the power rating by the system voltage.

> ***Example***
> *A 1 kW inverter in a 24 V system will draw a current of 42 A (1,000 W / 24 V). Add safety margins and take overload capacity into account.*

Like other electric components, accessories (particularly cables) cause losses. Since energy is expensive, these should be minimized. The power loss within a copper wired cable depends on the current I, the cable length L (back and forth) and the cross-section A of the wire as follows:

$$\Delta P\ [W] = 0.018 * I^2\ [A^2] * L\ [m] / A\ [mm^2]$$

> ***Example***
> *For a generator current of 5 A and a cable of 1.5 mm^2 with a length of 10 m (one-way) the power loss will be*
> $0.018 * (5\ A)^2 * (2 * 10\ m) / 1.5\ mm^2 = 6\ W$
>
> *In a 12 V system, this would be 10% of the whole generator power.*

Losses can be reduced by increasing the **cross-section** of wires or by **higher voltage** levels. Keep the losses in the generator circuit as well as in the load circuits below 5% (better: 3%) and in the controller-battery circuit below 0.5%. The necessary cross-section of the cable is

$$A\ [mm] = 0.018 * I * L / U / 0.05\ (=5\%)$$

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Use appropriate outdoor cables to connect the modules, protect them against sunlight and damage (e.g. by rodents) and lay cables in conduits where appropriate.

5.6 Appliances

5.6.1 Lighting

Bulbs have an efficiency of only 5%. **Halogen lamps** are only slightly more efficient. They are, therefore, not suitable for solar systems.

Cross-section [mm^2]	1.5	2.5	4	6	10
American wiregauge	16	14	12	10	8
P_{MAX} = 50 W	12	20	32	48	80
P_{MAX} = 100 W	6	10	16	24	40
P_{MAX} = 200 W	3	5	8	12	20
P_{MAX} = 400 W	1.5	2.5	4	6	10
P_{MAX} = 800 W	0.75	1.25	2	3	5
P_{MAX} = 1,600 W	0.37	0.65	1	1.5	2.5

Maximum cable length back and forth in m in a 12 V system; with 24 V, multiply length by 4, divide by 2 to halve losses

Table 4: Max. cable length for 5% power loss

Fluorescent lamps of the tube or compact type are 5 times more efficient and can last 5,000 hours and more. They need a good and efficient electronic ballast for operation. Fluorescent lamps with electronic ballasts cost about 10 € for AC and 20 € for DC.

5.6.2 Audio and video devices

Most appliances such as TVs, receivers or video recorders operate on AC. There are a few exceptions including some DC TVs. Color TVs consume more than black & white ones. There are considerable differences between individual brands.

Size	Power
17 cm	20 W
25 cm	40 W
37 cm	60 W

Table 3: Power demand of color TVs

TVs should not be operated in stand-by. Controllers and inverters may disturb operation of TVs and radios.

Transistor radios and cassette players are operated by batteries at a voltage below 12 V. Since batteries are expensive, such appliances should also be connected to the solar system through a **voltage converter**. For mobile operation, rechargeable NiCad batteries can be applied that are charged with a 12 V **NiCad charger**.

5.6.3 Water pumps

Some tens of thousands of pumps powered by solar generators are currently in use worldwide. A variety of pumps for low water demand are available on the market. These include **single-stage centrifugal pumps** for lifting heads << 10m and **diaphragm pumps** for larger heads, both DC- and AC-operated. They are surface-mounted, floating or submerged pumps. DC pumps with brushes need regular replacements.

The **energy requirement** (E) for a daily water demand (Q), a pumping head (h, water level to tank inlet or pipe outlet) and a pump efficiency (η = 0.2-0.4, depending on type and pumping head) is

$$E\,[kWh] = h\,[m] * Q\,[m^3/d] / 367 / \eta$$

The reliability varies widely. Some pumps only work for a few hundred hours of operation. Poor water quality will cause problems. Simple pumps for typical demands such as 1 m^3/h over small heads will cost about 100 – 200 €.

5.6.4 Refrigerators

Refrigerators are available for AC and DC. DC refrigerators are more expensive. They cost more than 600 €. The size has only a small effect on the price.

Only low-consumption refrigerators of the compressor type are suitable for solar systems. A 100 l high-quality refrigerator without an icebox may consume approximately 300 Wh at 24°C and 450 Wh at 32°C. Ice production, a high demand for cold drinks and a low-efficiency type can easily double or triple this figure. Box

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types are more efficient. Special types are available for vaccine storage.

Starting at low voltage levels (<11.5 V) is a problem for many refrigerators.

6 Planning a New System

6.1 Planning process

※ Reach an overall agreement with other people who are responsible!

※ If you are a staff member, obtain the authorization of the management!

※ Clarify objectives, priorities and budget!

※ Establish user requirements and site conditions!

※ Collect information on energy alternatives!

※ Make a general system appraisal!

※ Compile specific data for planning of the selected technology!

※ Ensure availability of necessary inputs (personnel, money, information, permits)!

※ Prepare a tender, evaluate quotations and order the system!

※ Implement operation, maintenance, energy management and monitoring!

6.2 Tips, warnings & recommendations

※ A cheap system may prove expensive if it is unreliable and of poor quality!

※ A system is more than just technical components. The users and the operator are just as important. Keep their interests and capabilities in mind!

※ Limiting consumption is an absolute priority to reduce system size and costs. Neglect appliances of minor importance! Use cheaper alternatives (e.g. kerosene instead of electric cooker)! Apply efficient appliances only! Reduce operation times!

※ It may be a good idea to start with a smaller system. A small system can be expanded later.

※ Think carefully! Solar systems have many advantages but mains electricity or diesel generators also have their merits.

※ Learn from the experience of others!

※ Make the system simple! The more complex it is, the more problems you can expect to have.

6.3 System concept

Decide whether you want to use one system or several. It may be useful to split them up

♦ if some **loads** are installed **far from the center** (cable losses and costs),

♦ if **different users** are involved (no responsibility→excessive consumption)

A system can be DC or AC on the load side. A DC system is simpler and safer. An inverter, which is required for AC systems, produces losses, extra costs and increases the system complexity.

On the other hand, DC appliances are more expensive and often not available, cable losses are high and electricians are not familiar with DC.

Decide in favor of AC the bigger and more complex a system is to be.

Select DC the poorer the quality of the inverters available and the more difficult the access to technical service is to be.

A mixed system is often a good compromise. Use AC for powerful appliances with short running times (e.g. copy machine) and DC for loads with low but continuous demand (e.g. lights).

6.4 Sizing the system

System sizing means adapting the supply to the demand. A system that is too small will not satisfy the demand, and a system that is too big will be a waste of money.

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Supply (=insolation) and demand are both variable throughout the year. Matching both variables is only possible to a certain extent. With every solar system you will have times when there is energy in excess and times when it is scarce.

This is no different from generator sets. Due to periods of maintenance, scarce fuel supply, breakdowns, etc., there are also shut-down times.

With proper sizing and a **battery autonomy** of 3 days, you can limit energy shortages to about 1%; that corresponds to 4 days in a year.

The final sizing should be done by your supplier, who will use a computer simulation program in most cases. With your own sizing, you can check the reliability of the results and get an idea of the size and costs of the system.

(Use the design table on the next page. All shaded cells that show numbers include formulas. Do not overwrite them! Mark those cells and press F9 for calculation. If you have a German-based PC operating system, please use the notation 0,85 instead of 0.85.)

6.4.1 Calculating the demand

List all appliances you need with their respective power requirements. Decide how many hours they will be operated. Calculate the demand E_{LOAD}.

6.4.2 Sizing the generator

Collect insolation records from the nearest meteorological station(s). Insolation levels are generally not subject to much local variation.

Next, choose a **design insolation** which is the worst insolation during those times of the year that the building is in full-time operation.

Tilting the generator can enhance this figure. In tropical regions the effect is mostly negligible. At higher latitudes, increase the design insolation by the degree of latitude in %.

> ***Example***
> *At Dubai (25° N), the minimum insolation of 3.7 kWh/(m² a) in December can be increased by 25% to 4.6 kWh/(m² a).*

The generator has to cover the energy consumption (E_{LOAD}) plus the system losses. The system losses are calculated by the **efficiencies** (η) of the components.

$$E_{GEN} \sim E_{LOAD} / (0.85 * \eta_{BAT} * \eta_{INV})$$

The battery efficiency η_{BAT} depends on the battery type [➲ Table 1]. η_{INV} is the mean operating efficiency of the inverter (not the maximum or rated efficiency) and is applicable in AC systems only. It may be as good as 0.9 (high-quality, small power variations) or as poor as 0.5 (low-quality, continuous low partial load).

> ***Example***
> *An AC system with a solar battery, a good inverter and a demand of 4.0 kWh/d will require an energy supply of about 6.9 kWh/d [6.9=4.0/(0.85*0.80*0.85)].*

Now the required generator power can easily be determined:

$$P_{GEN} = E_{GEN} / G_{DESIGN}$$

> ***Example***
> *The appropriate generator power for a site in Dubai with the design insolation of 4.6 kWh/(m²*d), and for the DC system above with 6.9 kWh/d is 1.5 kW_p (=6.9/4.6)*

6.4.3 Sizing the battery

Battery sizing has to take into consideration that only part of the rated capacity is available. This is the allowable **depth of discharge** (DoD).

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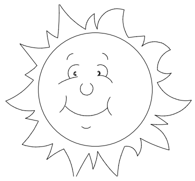


CALCULATION OF DAILY ENERGY DEMAND

Appliance	Power		Daily use		Energy demand
	W	*	h	=	0 Wh
	W	*	h	=	0 Wh
	W	*	h	=	0 Wh
	W	*	h	=	0 Wh
	W	*	h	=	0 Wh
	W	*	h	=	0 Wh
	W	*	h	=	0 Wh
	W	*	h	=	0 Wh

Σ

E_{LOAD} = **0 Wh**

/

0.85 * [η_{BAT}] * [η_{INV}] = **0,0**

=

E_{GEN} = **0 Wh**

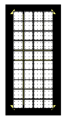
/

MIN **0 kWh/m²** + **kWh/m²** = **0 kWh/m²**

Tilt Correction

=

Generator size - P_{GEN} = 0 W



Insolation	
Month	**kWh/m²**
Jan	
Feb	
Mar	
Apr	
May	
Jun	
Jul	
Aug	
Sep	
Oct	
Nov	
Dec	

E_{LOAD} = **0 Wh**

/

η_{INV} = **0**

*

Autonomy = d

/

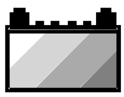
U_{BAT} = V

/

Depth of discharge =

=

Battery size - C_{BAT} = 0 Ah



Priority Loads

No.		Power		Total Power
	*	W	=	0 W
	*	W	=	0 W
	*	W	=	0 W
	*	W	=	0 W
	*	W	=	0 W
	*	W	=	0 W

Inverter size

Σ **W** = P_{INV}

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The battery capacity is calculated as

C_{BAT}[Ah] = E_{LOAD} [kWh/d] / η_{INV} / DoD / U_{BAT} [V] $*$ Aut [d] / 1000

> **Example**
> *The capacity for a 60 V (U_{BAT}) solar battery with a DoD of 60%=0.6, an energy demand of 4.6 kWh/d, a good inverter (η_{INV}= 0.85)* and an Autonomy Aut of 3 days *is 338Ah=4.6kWh/d/0.85/0.8/60V$*$3d /1000*

6.4.4 Sizing the inverter

The inverter can be sized to operate all loads at the same time. It is very unlikely, however, that all loads are in operation at the same time. Generally it is adequate if the inverter output matches the sum of the power ratings of all high-priority loads.

$P_{INV} = \Sigma P_{LOAD,\ prior.}$

Furthermore, the **overload capacity** of the inverter should be sufficient to start every single appliance (motors, etc.).

6.4.5 Check the costs

With the design figures, you can make an initial cost estimate. The system cost [I] including transport and installation can be roughly estimated as I[€]=

($6*P_{GEN}$[W]+$0.15*C_{BAT}$[Wh]+P_{INV}[W])$*$1.4

Is this in line with your budget? If not, try to reduce the energy demand and go back to Chapter 6.4.1.

6.5 Select a supplier

You will find suppliers of solar systems in nearly every country of the world. The job of a supplier should not end with the delivery of the system. Check for installation, training and **after-sales services**.

The experience of suppliers varies widely. Try to get an impression of the quality of their workmanship and services. Ask for references and check them. Visit the companies' headquarters.

Contact several suppliers. Evaluate the **quotations**. Do not compare just the price, also consider the technical quality, services and the suppliers' experience.

7 Running a System

Solar systems are not difficult to operate and maintain, nor are they dangerous. Nevertheless, certain aspects should be borne in mind.

7.1 Installation

7.1.1 Mounting the generator

Maximize the output of the generator by choosing an optimal orientation. As a rule of thumb, you should incline the module at the degree of latitude towards the equator.

> **Example**
> *In Karachi, Pakistan, 24° north of the equator, the right tilt angle is 24° south.*

To allow rain water to run off, the tilt angle should be at least 15°. Close to the equator, turn the module in that direction to face the sun at noon during the month with the lowest insolation.

> **Example**
> *In Nairobi, Kenya, 1° south of the equator, with the lowest insolation in July, turn the module at 15° to the north.*

An area of approximately 10 m^2 is required per kW_p.

Output will obviously be lower if the generator is in the **shade** of buildings or trees. Even if just a small part is shaded, the whole generator will be affected. Therefore, avoid any shading especially around noon.

An **installation on the ground** is simpler and allows for regular cleaning and control. If theft and vandalism are a problem, the generator should be installed on the roof or on long poles. Space should be left for air circulation on the underside to reduce the temperatures.

The modules have to be fixed securely. The **mounting structure** should be made of weather-proofed materials such as galvanized steel. Stainless steel or aluminum are also suitable, but expensive.

7.1.2 Electric installation

A qualified electrician with experience in solar systems should do the wiring and installation of the electric components.

Significant aspects to be considered in installation are:

- ※ Keep all cable lengths to a minimum.
- ※ Protect cables and components against weather, rodents and damage.
- ※ Put the battery in a cool and well ventilated place not far from the generator.
- ※ Place a fuse or circuit breaker in the battery circuit.
- ※ Put inverters and controllers in a cool place.
- ※ Make sure that cables and accessories are suitable for your systems.
- ※ All connections should be securely fixed and protected.
- ※ Terminals and cables should be clearly marked (AC / DC, + / -).
- ※ Do not mix up the polarities.
- ※ Earth the array and all major appliances.

7.2 Operation

Clearly define **responsibilities** for operation and maintenance. Operators and users should be adequately informed and trained.

Take care to provide for good **load management** to balance supply and consumption. Reduce the consumption if the battery is in a low state of charge. Make sure that users feel responsible and don't consume energy carelessly. The consumption can easily be controlled by a conventional kWh-meter.

Indicators for the state of charge found on most controllers are not very precise. Check the **state of charge** (SOC) quarterly by measuring the battery voltage and/or the electrolyte density (ED). Measuring the electrolyte density is more reliable. The measurement has to be made in a state of inactivity (no charging and discharging for at least 1 hour).

SOC [%]	U [V]	ED [kg/l]
100	12.6	1.23
80	12.4	1.20
50	12.2	1.16
20	11.8	1.13

Mean figures that depend on battery type, age and temperature

Table 5: Battery indicators for state of charge

Batteries degrade in the long run. Seriously degraded batteries have to be removed to protect the other ones. Their different voltage and electrolyte density can identify worn-out cells. Deviations of more than 0.2 V or 0.02 kg/l are critical.

7.3 Maintenance

Monthly

- ※ Check the electrolyte level of all battery cells; add pure distilled water if necessary.
- ※ Clean modules with water or soft cloth (in times of no rainfall).
- ※ Check fluorescent tubes and remove worn-out tubes.

Quarterly

- ※ Measure the electrolyte density and/or the battery voltage and remove worn-out batteries.
- ※ Clean and grease battery poles.
- ※ Check all electrical connections for tightness and corrosion.
- ※ Check fuses and protective devices.
- ※ Check the mounting structure of the generator; tighten bolts if necessary.
- ※ Check appliances for proper operation.
- ※ Check stock of spare parts.

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8 Further Information

This guide is a summary of a brochure by the same title available from GATE/GTZ.

For more technical details, refer to Solar Electricity (S. Roberts; 1991; Prentice Hall Int., UK; ISBN 0-13-826314-0)

8.1 Useful links

http://www.crest.org/cgi-bin/gem/gem.pl
Gateway to sustainable energy information on the web, extended link list

http://www.solarenergy.org
Non-profit organization providing assistance for use of renewable energies

http://www.self.org
Non-profit organization promoting solar rural electrification in developing countries

Supplier addresses

http://energy.sourceguide.com/index.shtml
Renew. energy suppliers & organizations

http://www.jxj.com/suppands/renenerg/
Database of renewable energy suppliers

Solar database

http://eosweb.larc.nasa.gov/sse/
Surface meteorology & solar energy data

http://www.eng.uml.edu/Dept/Energy/solbase.html
Solar radiation data for cities worldwide

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