Circle 521

Maximum-Power-Point-Tracking Solar Battery Charger

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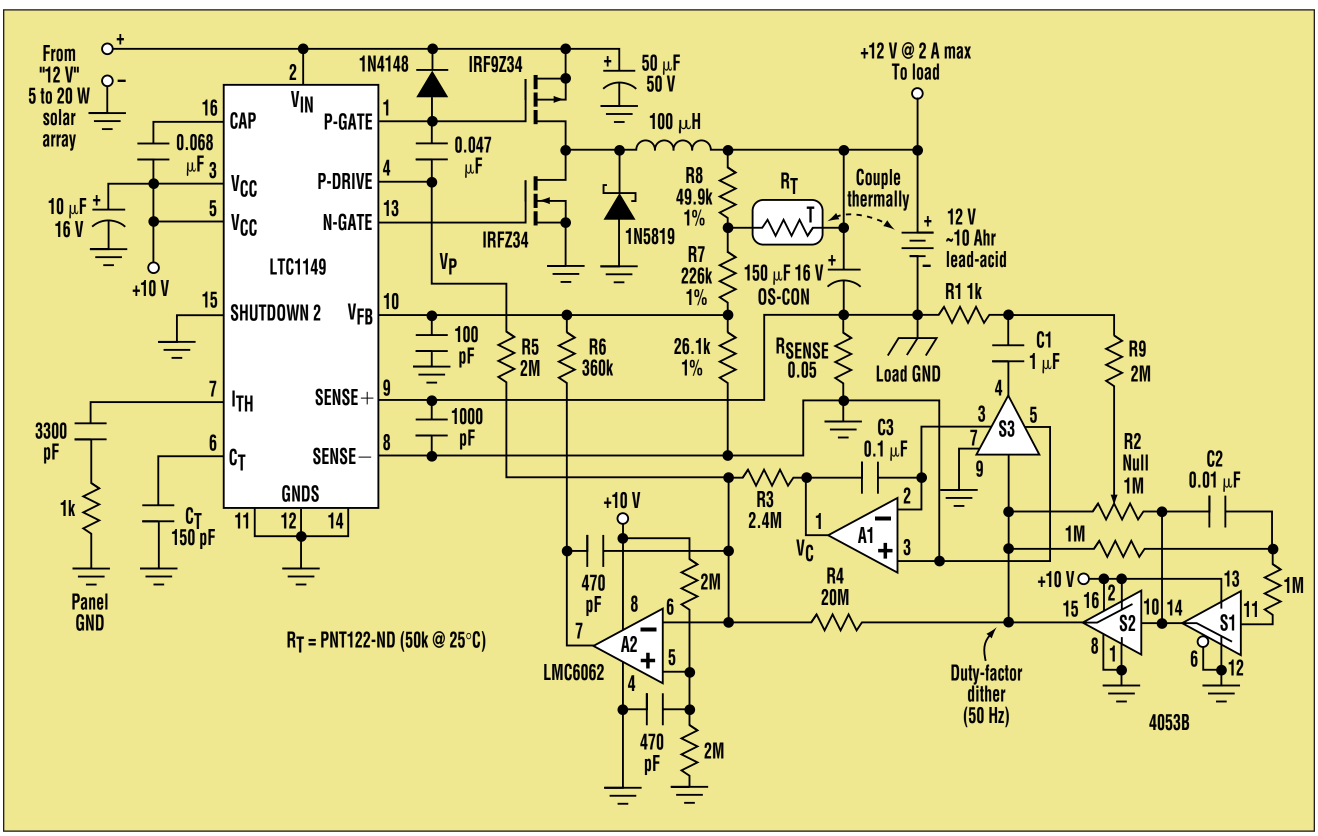
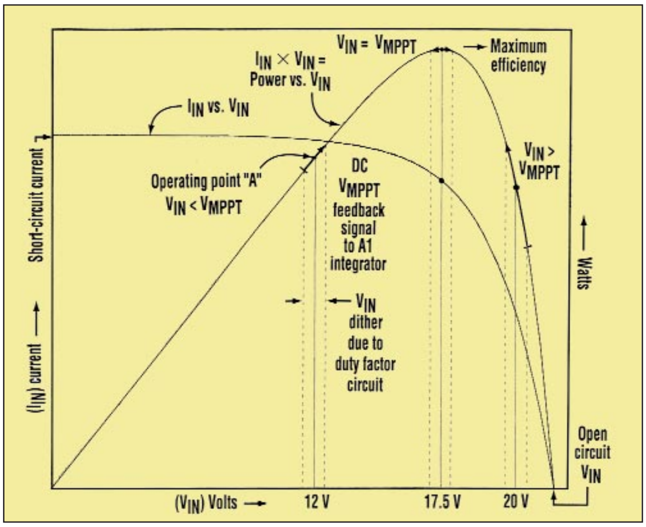
Sustainable electrical sources like solar photovoltaic arrays are becoming increasingly important as environmentally friendly alternatives to fossil fuels. But, while they're nice for the environment, sustainable sources aren't always easy to apply. These sources are characterized by both stringent peak-power limitations and "use it or lose it" availability. Successful application of sustainable energy sources therefore depends on strict attention to efficiency in both power conversion and energy storage.

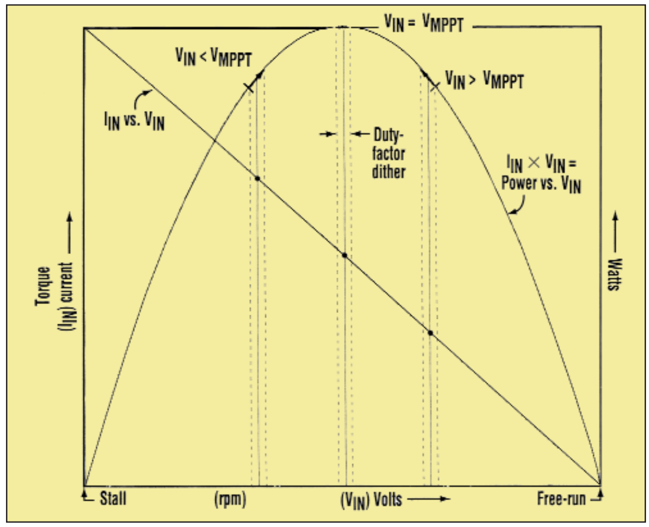
For small systems, workable energy-management schemes usually include a rechargeable battery and battery charger. A shortcoming of this solution is that ordinary battery chargers, even efficient ones, do an imperfect job of squeezing the last milli-



1. This Maximum-Power-Point-Tracking charger, used in small solar power systems, overcomes the shortcomings of ordinary battery chargers.



2. The I/V and P/V curves are given for a typical photovoltaic array when exposed to "standard" sunlight intensity of 1 kW/m^2. Standard design approaches dictate an increased number of cells to provide usable charging currents for "normal" ranges of solar insolation.



3. The Maximum-Power-Point-Tracking (MPPT) technique also can be applied to other sustainable energy sources like small water turbines, such as the "Pelton-wheel" impulse turbine (above), due to its similar power output versus loading characteristics.

watt from sustainable sources over realistic combinations of ambient and battery conditions.

The circuit shown addresses this problem in small solar power systems *(Fig. 1)*. It works by continuously optimizing the interface between the solar array and battery. The principle in play, sometimes called Maximum Power Point Tracking, is illustrated in the I/V and P/V curves for a typical photovoltaic array *(Fig. 2)* exposed to "standard" sunlight intensity (insolation) of 1 kW/m^2.

To accommodate a useful range of insolation and battery voltage variation, designers of solar panels make the number of cells large enough so that a useful level of charging current is provided even when the light level is low and the battery voltage is high. Consequently, when lighting conditions happen to be more favorable, these panels can produce up to 50% more voltage and 30% more power than the battery wants. Simple direct connection of panel to battery will therefore cause inefficient operation at point "A," with the excess power lost as heat in the solar panel.

Figure 1 does better than that by combining a high-efficiency (≈95%) SMPS circuit (LTC1149) with an analog power-conversion optimization loop. To understand how it works, assume battery B1 is in a state of discharge. In this condition, E1 will accept all of the current the SMPS can supply (subject to the ≈2.5-A current limit set by R_{SENSE}) at a voltage around 12 V. If U1 drives Q1 to a 100% duty factor, inefficient operation at the direct-connect point "A" will result.

However, the optimization circuit doesn't let that happen. Instead, 50-Hz multivibrator S1/S2 causes A2 to continuously dither Q1's duty factor by about ±10%. The result is a dither of approximately ±1 V in V_{IN}. There's also a corresponding 50-Hz modulation of the average power extracted from the solar panel as reflected in the return current through R_{SENSE}.

The 50-Hz ac waveform across R_{SENSE} is filtered by R1C1 and synchronously demodulated by S3. This dc error signal, whose polarity indicates the slope of the solar panel I/V curve wherever V_{IN} happens to be sitting, is integrated by A1 to close a feedback loop around A2. For example, if the SMPS happens to be operating at a V_{IN} below the maximum power point ($V_{IN} < V_{MPPT}$), then there will be a positive correlation between V_{IN} and I_{SENSE}, and A1 will ramp toward lower average duty factors and higher V_{IN}. By contrast, operation at $V_{IN} > V_{MPPT}$ reverses the dither phase relationship and A1 ramps toward higher duty factors and lower V_{IN}. Either way we get convergence toward V_{MPPT} and maximum charging current for B1.

This mode of operation continues as B1 charges and its voltage rises to the ≈14.1-V terminal-voltage setpoint determined by the R6-R7-R8-R_T network. Once reached, A2 saturates with zero output and normal LTC1149 constant-voltage regulation takes over. R_T provides temperature compensation appropriate for typical lead-acid battery chemistry. R2 allows for A1 offset nulling, which is particularly important at low panel output levels. The circuit makes no provision for preventing reverse current from being drawn from the battery under no-light conditions, but since the drain—even in total darkness—is less than 3 mA (comparable to typical battery self-discharge rates), adding a blocking diode would actually reduce overall efficiency.

The MPPT technique has much wider application than just photovoltaics alone. That's because conceptually similar functionality of power output versus loading can be seen in the I/V curves of other sustainable energy sources. Such sources are small water turbines (e.g. the "Pelton-wheel" impulse turbine of Figure 3) and fixed-pitch-rotor wind-power turbines, when either is combined with constant field alternators.

The voltage, current, and power produced by any of these sources is highly variable in response to ambient conditions (insolation, hydrostatic head, or windspeed) and dramatically dependent on the electrical impedance of the imposed load (V vs. I). Under any combination of ambient conditions, each of these sources is characterized by exactly one ideal load impedance, which will result in operation at V_{MPPT} and maximum power transfer. Also of benefit is the simplifying absence of confusing local maxima in the power versus voltage curves.

Of course, the actual physics behind the I/V curves for the various sources are very different. In the case of photovoltaics, the primary energy-producing process is recombination of photoelectric charge carriers and how the rate of such recombination varies with output voltage, temperature, and insolation. For wind-power generators, the dominant parameter is the interaction of "Tip Speed Ratio" (defined as turbine peripheral velocity divided by wind speed) with the aerodynamic design of the turbine. For small hydroelectric generators, it's the fluid dynamics of the turbine or "runner" as they relate to the pressure and volume of the available water source. But the MPPT charger really doesn't care about these details. It just blindly climbs the I/V curve to the V_{MPPT} summit.

Figure 1's circuit can therefore be easily adapted to any of these systems. The only modification necessary is a bigger C2 (0.1 µF to 1 µF) to slow the dither rate to 5-Hz to 0.5-Hz frequencies compatible with the inertial time constant of mechanical power sources. In addition, wind-power applications will benefit from an overspeed preventer. This V_{IN}-limiting circuit is basically just a big Zener diode connected across the input terminals that dumps excess power in conditions of high wind speeds and low battery demand. Consequently, it prevents overrevving of the turbine and alternator. For higher power applications (25 W and up) or other output voltage ranges, consult Linear Technology LTC1149 application literature.