Solar-array controller needs no multiplier to maximize power

Stephen Woodward - December 05, 2008

Solar-photovoltaic arrays are among the most efficient, cost-effective, and scalable “green” alternatives to fossil fuels, and researchers are almost daily announcing new advances in photovoltaic technology. But successful application of photovoltaics still depends on strict attention to power-conversion efficiency. Figure 1 shows one reason for this attention.

Figure 1 It is important to operate solar-photovoltaic arrays at their maximum power point.

A photovoltaic array’s delivery of useful power to the load is a sensitive function of load-line voltage, which in turn depends on insolation—that is, sunlight intensity—and array temperature. Operation anywhere on the current/voltage curve except at the optimal maximum-power-point voltage results in lowered efficiency and a waste of valuable energy. Consequently, methods for maximum-power-point tracking are common features in advanced solar-power-management systems because they can boost practical power-usage efficiency—often by 30% or more.
Because of its generality, a popular maximum-power-point-tracking-control algorithm is perturb and observe, which periodically modulates, or perturbs, the load voltage; calculates, or observes, the instantaneous transferred power response; and uses the phase relationship between load modulation and calculated power as feedback to “climb the hill” of the current/voltage curve to the maximum-power-point optimum. The perturb-and-observe algorithm is the basis of the maximum-power-point-tracking-control circuit (Figure 2, in yellow) but with a twist (in blue), which achieves a feedback function equivalent to a current-times-voltage power calculation but without the complexity of a conventional multiplier. The idea relies on the well-known logarithmic behavior of transistor junctions, $V_{BE} = (kT/q)\log(Ic/I_s) = (kT/q)\left[\log(I_c) - \log(I_s)\right]$, where $V_{BE}$ is the base-to-emitter voltage. It also relies on the fact that adding logarithms is mathematically equivalent to multiplication. Here’s how.

![Diagram](image)

**Figure 2** This maximum-power-point-tracking controller relies on well-known logarithmic behavior of transistor junctions. (Click to enlarge)

Capacitor $C_2$ couples a 100-Hz, approximately 1V-p-p-modulation or 1V-p-p-perturbation square wave from the $S_1/S_2$ CMOS oscillator onto the photovoltaic-input voltage, $V$. The current/voltage curve of the array causes the input current, $I$, to reflect the $V$ modulation with a corresponding voltage-time-current input-power modulation. $IC_{1A}$ forces $I_{Q1}$ to equal $I \times x_1$, where $I$ is the solar-array current and $x_1$ is a gain constant. $IC_{1B}$ forces $I_{Q2}$ to equal $V/(499 \ \Omega)$, where $V$ is the solar-array voltage. Thus, $V_{Q1} = (kT/q)\left[\log(I) - \log(I_{S1}) + \log(x_1)\right]$ and $V_{Q2} = (kT/q)\left[\log(V) - \log(I_{S2}) - \log(499 \ \Omega)\right]$. $V_{Q1}$ is the base-emitter voltage of $Q_1$; $k$ is the Boltzman constant; $T_1$ is the temperature of $Q_1$; $q$ is the elementary charge of the electron; $I$ is the current input from the solar panel’s negative terminal; $I_{S1}$ is the saturation current of $Q_1$; $x_1$ is the arbitrary gain constant, which $IC_3$ determines; $V$ is the voltage...
input from the solar panel’s positive terminal; $I_{S2}$ is the saturation current of $Q_2$; $K$ is degrees Kelvin; $V_{PF}$ is the power-feedback signal; and $V_{IP}$ is the calculated power-input signal. Because $k$, $q$, $I_{S1}$, $I_{S2}$, $x_1$, and 499 kΩ are all constants and $T_1=T_2=T$, however, for the purposes of the perturb-and-observe algorithm, which is interested only in observing the variation of current and voltage with perturbation, effectively, $V_{Q1}=(kT/q)\log(I)$, and $V_{Q2}=(kT/q)\log(V)$.

The series connection of $Q_1$ and $Q_2$ yields $V_{PF}=V_{Q1}+V_{Q2}=(kT/q)[\log(I)+\log(V)]=(kT/q)\log(I)$, and, because of IC$_{1B}$’s noninverting gain of three, $V_{IP}=3(kT/q)\log(V)I=765 \mu V/%$ of change in watts. The $V_{IP}$ log (power) signal couples through $C_1$ to synchronous demodulator $S_1$, and error integrator and control op amp IC$_{1c}$ integrates the rectified $S_1$ output on $C_3$. The IC$_{1c}$ integrated error signal closes the feedback loop around the IC$_3$ regulator and results in the desired maximum-power-point-tracking behavior.

Using micropower parts and design techniques holds the total power consumption of the maximum-power-point-tracking circuit to approximately 1 mW, which avoids significantly eroding the efficiency advantage—the point of the circuit in the first place. Meanwhile, simplifying the interface between the maximum-power-point-tracking circuit and the regulator to only three connection nodes—I, V, and F—means that you can easily adapt the universal maximum-power-point-tracking circuit to most switching regulators and controllers. Therefore, this Design Idea offers the efficiency advantages of a maximum-power-point-tracking circuit to small solar-powered systems in which more complex, costly, and power-hungry implementations would be difficult to justify.