Making Sense of Photovoltaic System Losses

When designing and installing a solar-based renewable energy system, it's important to make decisions that will result in the most power being extracted from your PV array. This means accounting for, and minimizing, losses associated with a variety of system components. NOTE: Values in the following figures have been approximated for the purposes of illustration.

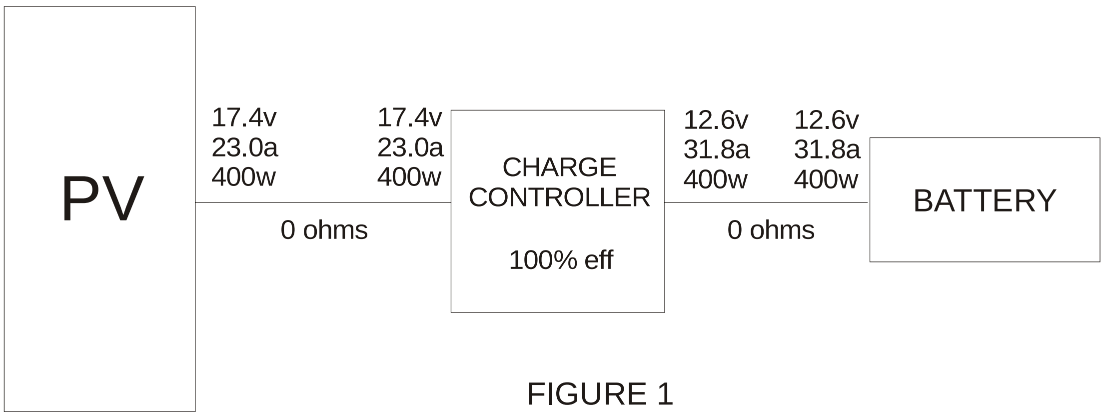

FIGURE 1

A theoretically ideal system, as illustrated in Figure 1, would contribute nothing in the way of loss. The PV array would always produce its rated power, and this power would always be fully available to charge batteries or drive loads. The 100% efficiency of such a system is, of course, impossible to achieve. The PV array is rated for 400 watts, and produces a current of 23.0 amps at 17.4 volts. The wiring has no resistance, and the charge controller introduces no loss; it is a perfect power converter, matching the PV's 17.4 volts to the battery's 12.6 volts. The end result is 400 watts being generated by the PV and 400 watts being absorbed by the battery.

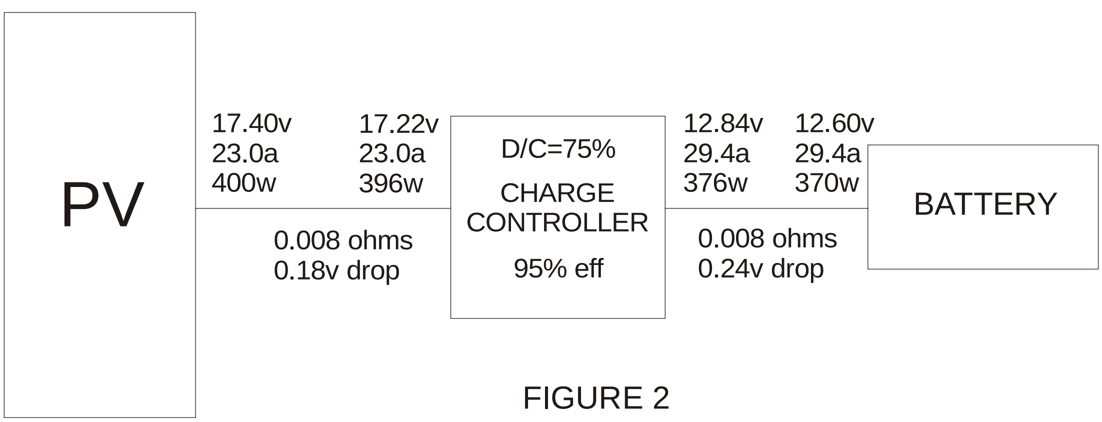

FIGURE 2

Figure 2 shows a typical system under ideal real-life conditions. The PV still produces its rated output of 400W because it is operating at its rated temperature of 25^{o}C and an insolation of 1kW/m^2. However, we now have wire resistance to contend with, which in this installation equals about 8 milliohms between the PV and the charge controller, and also 8 milliohms between charge controller and battery. This resistance introduces voltage drops in these two wiring runs. At 23.0A, from PV to charge controller, this means a drop of about 180mV, for a loss of about 4W. Between charge controller and battery, the drop is slightly greater because the current is larger (owing to the decrease in voltage, yet constant power conversion of the

MPPT charge controller). So we have about 240mV drop here – a loss of about 6W. The charge controller also introduces some loss. At 95% efficiency under these operating conditions, the loss is about 20W. After taking the above losses into consideration, this system produces 370W from a 400W PV array. This is typical of the performance of a solar system operating under best-case real-life conditions.

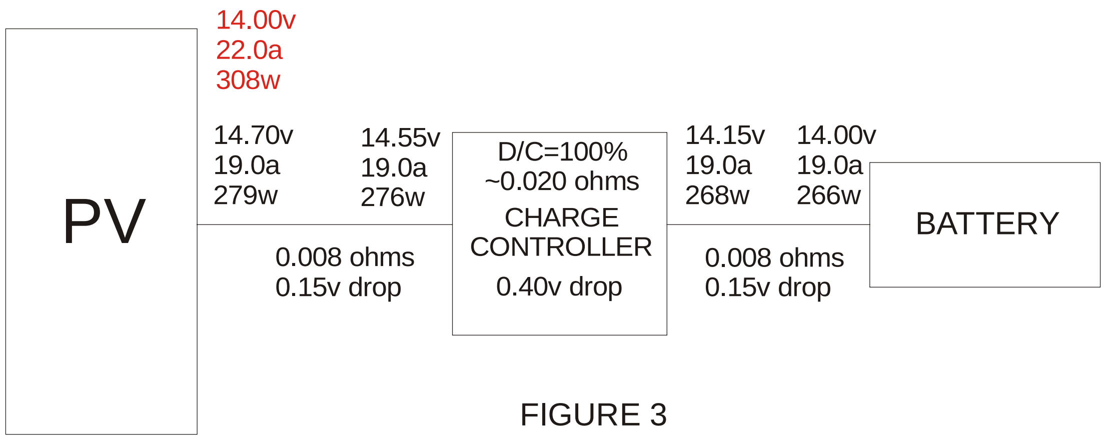

FIGURE 3

In reality, there will also be other factors that will limit optimal system performance. Take the example in Figure 3. Here we have a PV array that has been exposed to full sunlight on a warm afternoon. The PV's temperature is perhaps now 40°C or more above its optimal 25°C rating. As a result, its Vmp is no longer 17.4V, but rather much lower – around 14.0V in our example. Imp also drops slightly with a hot monocrystalline PV, so we can expect about 22.0A at 14.0V at this temperature, or about 308W. This alone is a 92W reduction from the full power rating of this PV. Notice, however, that the battery has also been charging for a while now, and its voltage has risen to 14.0V. With a 14.0V input from the PV charging a 14.0V battery, the duty cycle of the charge controller will equal 100% (percent duty cycle equals voltage out divided by voltage in). But also notice that the charge controller is only 95% efficient. This means there will be a loss within the controller. At 100% duty cycle, this loss will take the form of a resistance, which will equal about 20 milliohms. Note also that at 100% duty cycle, current will be constant throughout the entire system. What we must pay attention to now are the voltage drops associated with each loss in the system. The voltage at the battery at a given point in time is fixed for all practical purposes. The voltage drops within the circuit will add to the voltage at the battery, causing the system voltage to increase as you move from right to left in Figure 3. The wiring from battery to controller will drop about 150mV, the loss within the controller causes a drop of about 400mV through it, and the wiring from controller to PV causes another 150mV drop – for a total of 700mV. This means that the PV must operate at 700mV above the battery voltage, or 14.7V. At this voltage the PV is no longer operating at its maximum power point, so it is producing only 19.0A. The data in red shows what the output of the PV would be at its MPP. Because of these factors, we can expect only 266W from this system under these conditions, a 134W reduction from its full rated power.

Many of the non-idealities mentioned above can be mitigated by wiring the PV array for voltage that is higher than the nominal voltage of the battery. For example, with the MPT-3024, a 24-volt nominal array can be used to charge a 12-volt nominal battery bank. This ensures that the MPP of the array is always above the voltage of the battery, and is always capable of being tracked by the controller. A 24-volt array will also reduce system losses substantially because of its lower operating current for the same amount of power. Figure 4 shows an example of such an arrangement. It is identical to the system in Figure 3 (same components and operating conditions), except that the PV array has been wired for 24-volt nominal. The PV is now allowed to operate at its MPP (which is 28.0v), and losses in the wiring from PV to controller are now somewhat less than they were in the 12-volt system because the current is less. After all losses are accounted for, we're left with 288W for battery charging. This is 22W more than the 12-volt system in Figure 3, using the same components.

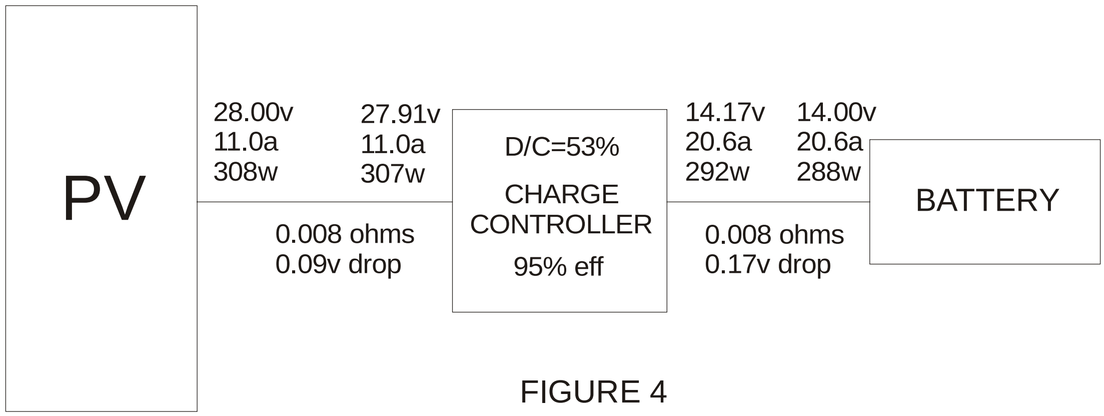

FIGURE 4

For optimal system performance, also pay close attention to the following:

1)PV ARRAY LOCATION AND ADJUSTMENT. Locate the array in full sunlight, facing south, and adjusted for seasonal changes of the sun's elevation.

2)PV ARRAY TYPE AND VOLTAGE. Use identical modules and wire them for 24-volt nominal voltage, if possible.

3)WIRING. Within practical limits, use heavy-gauge wiring and short wire runs. Make sure all connections are clean and tight.

4)CHARGE CONTROLLER. Keep the controller cool and out of direct sunlight. A cool controller will operate more efficiently and have a longer life.