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Maximum Power Point Tracking Using a DC-DC Converter Coupled to Photovoltaic Cells and a Battery

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ABSTRACT

Solar arrays provide power to loads and should ideally be operated at their maximum power point (MPP) to optimize the power output from the solar arrays under various environmental and operating conditions. Maximum power point tracking (MPPT) techniques control operating conditions so that the solar arrays are at or near the MPP. However, MPPT configurations use a DC-DC converter that contributes to power loss. The DC-DC converter in the disclosed configuration is relocated to a position in front of a battery, so that the power loss contributed by the DC-DC converter is reduced. A switch is also coupled across the DC-DC converter and can be switched closed so as to eliminate the power loss contribution of the DC-DC converter. The switch is closed in situations when the battery rather than the solar array is providing power to the load.

KEYWORDS

solar cell; photovoltaic cell; solar array; solar panel; photovoltaic array; photovoltaic panel; maximum power point (MPP); maximum power point tracking (MPPT); DC-DC converter

BACKGROUND

Solar cells convert light energy into electrical energy, for example converting solar energy from the sun into electrical energy supplied to a load. Solar cells are typically arranged in panels or arrays, so that the solar energy absorbed by individual solar cells can be accumulated together into electrical energy to power the load. The amount of power that can be extracted from a solar array (e.g., a grouping of some number of solar cells electrically coupled in series, in parallel, or a combination of both) is based on several factors, including environmental conditions and voltage loading conditions.

For a given environmental condition such as temperature (one plot shown in Figure 1 below), the amount of available power provided by a solar array varies based on the voltage loading of the solar array. For a given voltage condition, the amount of available power is influenced by environmental conditions, including the temperature of the solar array and the amount of solar radiation hitting the array (due to sunny or cloudy conditions). The chemical and material compositions of the solar cells also influence the amount of available power that can be provided by the solar cells under different operating conditions and/or environmental conditions.

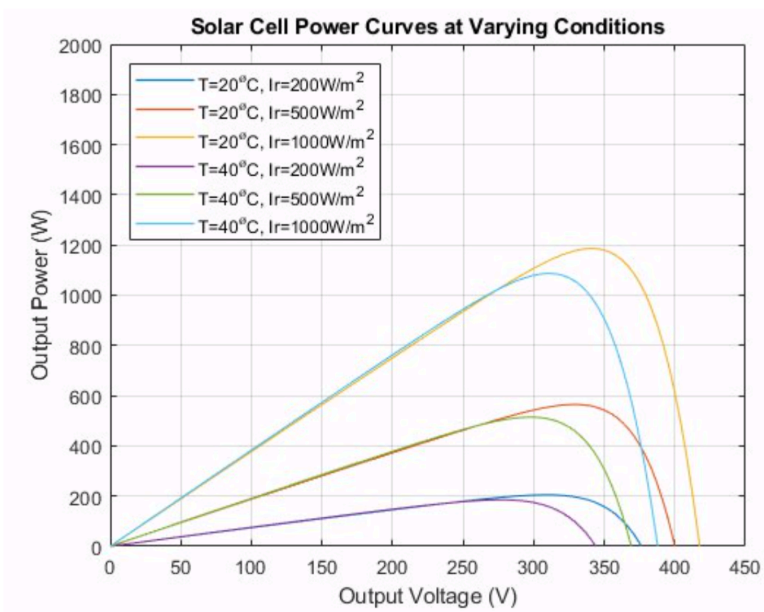

Figure 1

The plots of Figure 1 show that the power-voltage (P-V) characteristics of solar cells exhibit a non-linear behavior. The near optimal point at which to operate solar arrays is at or near the point of the P-V plots where the output power is greatest. This point is called the maximum power point (MPP). Maximum power point tracking (MPPT) techniques attempt to track the dynamically changing MPP, to ensure extraction of maximum power from the solar array as environmental conditions and operating conditions change.

In many applications, a solar array is coupled to a battery system that includes one of more batteries. The voltage of a battery is a function of its chemistry, state of charge (SOC), and electrical load. An example is shown in the graph of Figure 2 below.

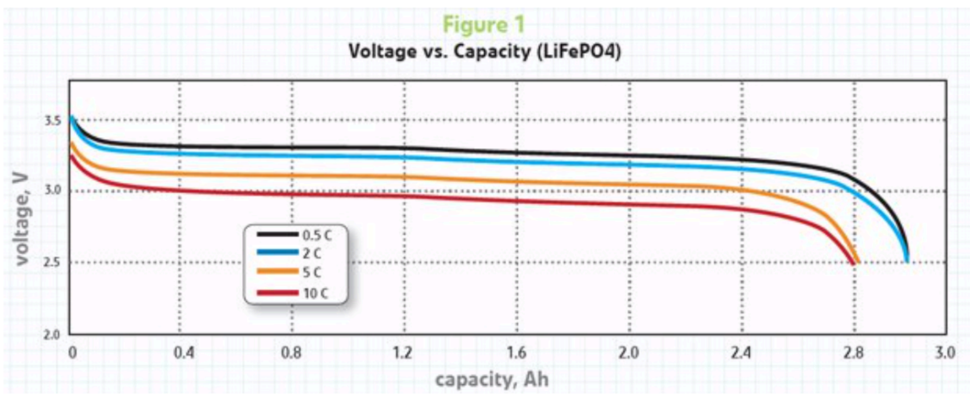

Figure 2

Over time, as the environmental conditions, battery SOC, and load conditions change, it is not feasible to choose a single operating voltage that will always realize the maximum solar power. A device (that uses an MPPT algorithm) is needed to actively monitor conditions and extract the maximum available solar power.

MPPT techniques serve at least two purposes. First, MPPT techniques use an algorithm to actively track the location of the MPP so as to guarantee that the solar array is operated at a voltage that produces the maximum power at any given time. As the operating/environmental conditions can be very dynamic (for instance affected by a breeze that changes the temperature of the solar array, by a cloud that partially blocks sun light, or by a change in the position and orientation of the solar array), the MPP is constantly changing. The MPPT algorithm constantly searches for the MPP, and then sets the loading downstream of the solar array to a value that corresponds to the MPP.

Second, MPPT architectures provide a DC-DC converter so that the output voltage of the solar array can be different than the voltage at the battery. For example, the DC-DC converter has circuitry to down convert a value of the output voltage of the solar array to a value of the voltage of the battery. By electrically decoupling the two voltages, the solar array may be operated at the MPP for the current environmental conditions (e.g., the solar array is operated at a particular MPP of one of the plots shown in Figure 1, for a particular environmental condition). However, the DC-DC converter also introduces some electrical loss in the conversion process, resulting in some power inefficiency.

DESCRIPTION

This disclosure presents an architecture that uses MPPT by electrically coupling and locating a DC-DC converter in a manner that reduces the amount of power loss due to the DC-DC converter.

In many typical applications (such as shown in Figure 3 below), a solar array (denoted as a photovoltaic array PV) serves as a power source. A battery is coupled to the photovoltaic array PV to receive energy for storage. A power load is coupled to the photovoltaic array PV and across the battery and is powered by the photovoltaic array PV or the battery. The power load in the example of Figure 3 is a motor controller MC.

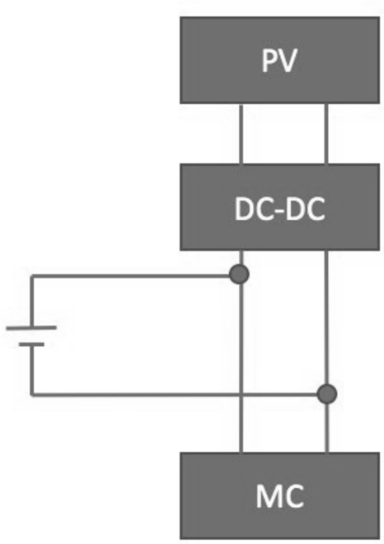

Figure 3

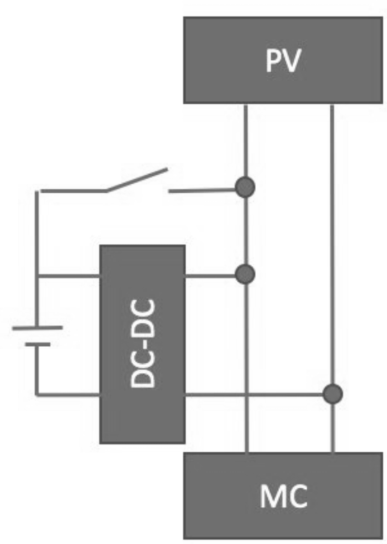

Figure 4

The typical configuration of Figure 3 uses an MPPT architecture/system that contains a DC-DC converter to convert the output voltage from the photovoltaic array PV from a first voltage value to second voltage value. This second voltage value (power) is then provided to the battery and to the load (motor controller MC).

The DC-DC converter is not a totally lossless electrical device. Some of the electrical power from the photovoltaic array PV that goes through the DC-DC converter is lost, generally as a function of the amount of total power. For example, 3% of the power that goes through the DC-DC converter may be turned into heat and dissipated. Because all of the output power from the photovoltaic array PV goes through the DC-DC converter in the configuration of Figure 3, 3% of the total output power from the photovoltaic array PV is lost.

Figure 4 shows a configuration that reduces the amount of loss in the total power. In the configuration of Figure 4, the DC-DC converter is moved to a location in front of the battery in the same circuit branch. In this configuration, with an electrical load running at the motor controller MC, the amount of power passing through the DC-DC converter is the solar power minus the load power. The loss using the configuration of Figure 4 is now 3% of a smaller amount of power, in this example. That is, the power loss in Figure 4 is 3% x (PVpower – MCpower), whereas the loss in Figure 3 is a larger loss at 3% x PVpower.

The DC-DC converter in Figure 4 can still be used to regulate the operating conditions of the photovoltaic array PV, and this enables the photovoltaic array PV to operate at the MPP. The relocation of the DC-DC converter to the position in Figure 4 reduces the power loss and enables using a smaller sized DC-DC converter because it will be handling a smaller amount of power.

In the configurations of Figures 3 and 4, the battery powers the electrical load (motor controller MC) when there is no solar power, such as when photovoltaic array PV is not receiving sufficient sunlight, is disabled, is decoupled from the system, etc. In the configuration of Figure 4 and under these circumstances when the photovoltaic array PV provides no power, this would mean that the power supplied by the battery (to the motor controller MC) would pass through the DC-DC converter. This battery supplied power is potentially subject to the power loss caused by the DC-DC converter.

To avoid this power loss, a bypass mechanism can be coupled across the DC-DC converter. Figure 4 shows a switch (which can be implemented in the form of a diode or other electrical device with switching capability) coupled in parallel to the DC-DC converter. Under normal operating conditions when the photovoltaic array PV is operating to provide power, the switch is open, enabling power from the photovoltaic array PV to flow through the DC-DC converter and into the battery. In operating conditions when the photovoltaic array PV does not provide power and it is the battery that needs to provide power to the load (motor controller MC), the switch is closed to form a short circuit (shunt) across the DC-DC converter. All of the power of the battery therefore flows through the shunt and bypasses the DC-DC converter, thereby avoiding power loss through the DC-DC converter. Using this configuration, the battery can power the load (motor controller MC), without the loss through the DC-DC converter, when solar power is not available.

CONCLUSION

Solar arrays provide power to loads and should ideally be operated at their maximum power point (MPP) to optimize the power output from the solar arrays under various environmental and operating conditions. Maximum power point tracking (MPPT) techniques and architectures control operating conditions so that the solar arrays are at or near the MPP. However, MPPT configurations use a DC-DC converter that contributes to power loss. The DC-DC converter in the disclosed configuration is relocated to a position in front of a battery, so that the power loss contributed by the DC-DC converter is reduced. A switch is also coupled across the DC-DC converter and can be switched closed so as to eliminate the power loss contribution of the DC-DC converter, in situations when the battery rather than the solar array is providing power to the load.