ABSTRACT

Solar arrays provide power to loads and are 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 techniques search for the MPP by repeatedly changing the voltage/current load of the solar array, until an operating point is determined that produces the maximum power at a given time. However, the process of repeatedly changing the voltage/current load for the entire array results in the entire array operating inefficiently during the search for the MPP. This disclosure describes a configuration to apply the MPPT technique to a single test cell in a solar array, rather than to all of the cells in the solar array. The MPP is determined from the single test cell, and the operating point for the entire array is adjusted based on the MPP determined from the single test cell.

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 influence the amount of available power that can be provided by the solar cells under different operating conditions and/or environmental conditions.

![Solar Cell Power Curves at Varying Conditions](image)

**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 include 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](image)

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 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 are 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 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). The DC-DC converter does introduce some electrical loss in the conversion process, resulting in some power inefficiency.

**DESCRIPTION**

This disclosure presents an architecture that uses a MPPT algorithm to search for the MPP, using one particular cell or group of cells in a solar array (rather than all of the cells in the solar array) as a test cell for searching. The MPP determined for the test cell represents the MPP for all of the other cells in the solar array.

Most MPPT algorithms work in generally the same way--they change the operating point of the entire solar array and monitor whether the total power goes up or down. An example configuration is shown below in Figure 3.
In many typical applications (such as shown in Figure 3 above), 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 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.

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 inverter is controlled (denoted by arrow A) by a controller, which also forms part of the MPPT system. The controller controls the power/current/voltage demand of the DC-DC converter. The controller is also able to monitor (denoted by arrow B) the power output of the entire photovoltaic array PV, such as by using voltage or current sensors.

As part of the MPPT algorithm to locate the MPP, the controller can control the voltage loading at the array side of the DC-DC inverter, thereby changing the operating point of the photovoltaic array PV. For instance, to increase the operating point of the photovoltaic array PV,
the controller increases the voltage loading at the array side of the DC-DC converter (arrow A) and then correspondingly monitors the power output (arrow B) of the photovoltaic array PV. If the power output goes up, then the controller continues to change the operating point in the same direction (increase the voltage loading), until the power output goes down. The MPP is determined as the operating point just before the power output goes down.

On the other hand, if the power initially went down when the voltage load was increased, then the controller changes the operating point in the other direction (reduces the voltage load at the array side of the DC-DC converter) so as to increase the total power output from the photovoltaic array PV, until the power output starts going down. Again, the MPP is determined as the operating point just before the power output goes down.

Sometime later, in order to know whether the algorithm is still setting the system at the best operating point corresponding to the MPP and because environmental conditions may have changed, the controller changes the operating point again as described above (increases or reduces the voltage load at the array side of the DC-DC converter) and monitors the change in power output of the photovoltaic array PV.

The algorithm described above shows that the controller is constantly searching for the best operating point that corresponds to the dynamically changing MPP, and whenever this searching process is being performed, the system is having to operate at a sub-optimal operating point (since the voltage load is constantly being reset at levels that do not draw the maximum power from the photovoltaic array PV). Because of the way that the algorithm searches for the optimal operating point, the results can also be affected by local maximums on the power curves of Figure 1. These local maximums can be caused by damage to the solar array, wherein damaged cells provide an inaccurate reading of the true MPP.
Figure 4 shows another configuration that addresses the drawbacks described above. The configuration of Figure 4 has some similarities to the configuration of Figure 3, except that the controller may monitor (denoted by arrow C) the MPP of one or more individual cells, alternatively or additionally to monitoring the MPP for all of the cells in the entire solar array (denoted by arrow B). Furthermore, Figure 4 explicitly depicts multiple photovoltaic arrays PV, whereas Figure 3 uses a single block labeled as the photovoltaic array PV to represent multiple arrays.

![Diagram of Figure 4](image)

**Figure 4**

In the configuration of Figure 4, at least one solar cell (in a single solar array or panel) is dedicated as a test cell for determining the optimal operating point. The single solar array can have one or more dedicated test cells (only one test cell shown in Figure 4 for purposes of clarity), and each of the other solar arrays may similarly have one or more test cells as well. Some panels may not have any test solar cells at all, if there is a sufficient number of test cell(s) in the other panel(s).

A rationale for the configuration of Figure 4 is that all or most solar cells in an individual solar array are oriented in the same direction and are subject to the same environmental conditions. Therefore, all cells in the same array will have the same MPP. It is not necessary to subject all of the solar cells in the same solar array to the changing voltage loadings while...
searching for the MPP. The controller may apply the MPPT algorithm (described above with respect to Figure 3) to a single solar cell (as a test cell), and the optimal operating point determined by testing that single solar cell will be representative of the entire solar array.

After the optimal operating point is determined from the test cell, the non-test cells in the same array can have their voltage loading reset or adjusted directly to the optimal operating point. This is achieved without having to operate these non-test cells at the interim voltage loadings in order to find the optimal operating point. Where there are large numbers of solar cells in a single array and where there is also a large number of arrays, multiple solar cells can be selected amongst the arrays if more test results are desired for comparison purposes.

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 control operating conditions so that the solar arrays are at or near the MPP. However, MPPT techniques search for the MPP by repeatedly changing the voltage/current load of the entire solar array, until an operating point is determined that produces the maximum power at a given time. The process of repeatedly changing the voltage/current load for the entire array, however, results in the entire array operating inefficiently during the search for the MPP. This disclosure describes a configuration to apply the MPPT technique to a single test cell in a solar array, rather than to all of the cells in the solar array. The MPP can be determined from the single test cell, and the operating point for the entire array can be adjusted based on the MPP determined from the single test cell.