A NEW MAXIMUM POWER POINT TRACKING APPROACH FOR PARTIAL SHADING CONDITIONS

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ABSTRACT: Partial shading conditions may reduce the energy yield in PV systems due to poor MPPT algorithm or system configuration. The MPPT techniques using scanning approach are capable of tracking the global peak power but it results in loss of energy each time the scan is performed. In this paper we propose a new scanning MPP approach that changes the time-interval between scans adaptively based on the probability of a shift of operating point having occurred.

Keywords: shading, inverter, photovoltaic

1 INTRODUCTION

Partial shading conditions may reduce the energy yield in PV systems [1-3]. For instance, partial shading on a PV array may result in different irradiance on the array’s individual modules. This again may result in different optimal operating voltages for the individual modules. There are in principle two approaches to handle this issue:

1. One solution is to pair each module with a separate power converter [4]. This allows the modules to operate at separate operating points. We will henceforth refer to this as the “module-converter approach”.

2. If the PV array is to be connected to one single power converter, multiple maximum power points (MPPs) on the power-voltage curve will occur. Conventional maximum power point trackers (MPPTs) tend to lock to a local MPP, which may not be the global optimum. One solution to ensure the operating point corresponds to the global optimum is to periodically scan the entire operating range and search for the global MPP [5, 6]. We will henceforth refer to this as the “scanning MPP approach”.

If we assume lossless power converters, the module-converter approach is able to harness more power. This is because the scanning MPP approach can only set one operating point for the entire PV array; therefore, all modules connected in parallel must have the same voltage, whereas all modules connected in series must carry the same current. Individual modules may therefore not operate at their own optimum, although the PV array as such is at its optimum operating point.

However, in reality lossless power converters do not exist and from the point of view of converter efficiency, a larger power rating is beneficial. Due to the relatively large power loss of the smaller, individual module converters, the module converter approach typically results in larger total power loss under normal, non-shaded operating conditions, than the approach that uses a central or string inverter. This shortcoming is particularly pronounced when partial shading conditions are rare. However, in situations where partial shading would be the norm, such as the building integrated systems, the module converter approach could be beneficial overall.

When the module converter approach is used, a scanning MPP algorithm is needed at the module level, since an individual module may also have multiple maxima in case of partial shading. To avoid such scanning, each bypass diode in the module would have to be paired with one power converter. Such an approach is feasible in principle, but would suffer even more from the relatively large power loss resulting from small power rating. Therefore, in practice, a scanning MPP algorithm is necessary whether string or module converters are used, and in the present paper we propose an improvement to the scanning MPP approach.

A scanning MPP mechanism results in loss of energy each time the scan is performed. Methods are proposed to reduce the duration of searching for global MPP in order to increase the efficiency [7, 8]. In this paper we propose a new scanning MPP approach that changes the time-interval between scans adaptively based on the probability of a shift of operating point having occurred. The problems associated with the constant interval approach are summarized as follow:

1. If the interval between scans is too short, scans will occur even when the MPP voltage $V_{MPP}$ has not changed. Section 2 of this paper shows that $V_{MPP}$ may not change as a result of partial shading.

2. If the interval between scans is too long, the algorithm may fail to detect a partial shading condition that has resulted in a change in the global $V_{MPP}$

Section 2 of this paper provides an analysis and discussion of the characteristics of a PV-system under partial shading conditions. This discussion provides the background for the proposed MPPT operating principles presented in section 3.

2 CHARACTERISTICS OF A PV SYSTEM

Figure 1 shows the simulation model of a conventional PV module that consists of 36 cells in series and two-bypass diodes. At the Standard Test Condition (STC), the short-circuit current is 5A whereas the open-circuit voltage is 22.3V. The solar cell model with single diffusion diode is used. This results in 36 diodes for the model of the module, shown as $D_{PV1-36}$. In order to simplify the discussion, solar cells that share the same bypass diode, $D_{BP}$ are assumed to have identical irradiance. As a result, only two photocurrent sources, $I_{PV1}$ and $I_{PV2}$ are needed in the models. The components, $D_{PV1-36}$, $D_{BP1}$ and $I_{PV1}$ are referred to as “GROUP 1” whereas $D_{PV17-36}$, $D_{BP2}$ and $I_{PV2}$ are referred to as “GROUP 2” in the discussions below. A partial shading condition is simulated by assigning different irradiance in GROUP 1 and GROUP 2 i.e. $I_{PV1}$ and $I_{PV2}$ have different magnitudes.
Figures 2 and 3 show that there is only one MPP on the characteristic power curve if there is not any difference in irradiance. Multiple MPPs occur when the irradiance differs between the GROUPs. In Figure 2, $I_{PV1}$ is kept constant at a high value while $I_{PV2}$ is varied below $I_{PV1}$. This simulates a possible situation where the irradiance on the PV cells of GROUP 1 remains constant whereas the sunlight on GROUP 2 varies due to a changing shade pattern. Three cases are shown corresponding to 40%, 56% and 80% difference between $I_{PV1}$ and $I_{PV2}$. It can be seen that the MPP stays at the vicinity of $V_{MPP0}$ as long as the difference of photocurrent is less than 56% but shifts to $V_{MPP1}$ when the difference is higher than this. $V_{MPP1}$ is approximately half of $V_{MPP0}$ due to the configuration with two bypass diodes. It is important to note that, in this case, one of the photocurrents needs to be less than half of the other for a large shift in the maximum power point voltage to occur.

In Figure 3, $I_{PV2}$ is kept constant at a low value while $I_{PV1}$ varies above $I_{PV2}$. This simulates a possible situation where the PV cells of GROUP 1 remains shaded while the sunlight on GROUP 2 varies due to moving cloud. The curves show that the global $V_{MPP}$ may occur at both voltage levels. However, the global $V_{MPP}$ will never occur at $V_{MPP1}$ if the photocurrent in GROUP 2 is at least half of the maximum, since this will prevent the difference between the two currents to every be large enough to shift the maximum power point voltage away from $V_{MPP0}$.

Figure 4 shows a simulated situation where only one of the panels is partially shaded. The photocurrent in the shaded module has been reduced by between 10% and 30%. Since there are 10 bypass diodes all connected in series in this configuration, $V_{MPP0}$ becomes a local maximum voltage when the reduction in photocurrent is more than 20%.

The observations from the curves presented are summarized as follow:

1. The global $V_{MPP}$ corresponds to the peak in the power-voltage curve that is closest to $V_{OC}$ (i.e. equals $V_{MPP0}$) unless the difference in irradiance is large enough. Figure 4 shows that, in this case, the global $V_{MPP}$ is not equal to $V_{MPP0}$ only when one module has its photocurrent reduced by more than 20% as compared to others.

2. This also implies that the global MPP is at $V_{MPP0}$ if the power output of the array is close enough to the rated value. For the case of a single module, Figures 2 and 3 show that the
The MPPT strategies are based on the analysis in section

1. The interval between SCANNING is reduced when the instantaneous power drops to a level where multiple MPPs may possibly occur. INC is an integer larger than one. If \( P(X) \) is smaller than \( P_{\text{MEAN}}(Z) \), the conditional box 4 is not satisfied hence increment of the counter \( M \) is larger than one.

2. The interval between SCANNING is reduced if the maximum power is not at \( V_{\text{MPP0}} \). If the conditional box 11 is satisfied, decremented of the counter \( N \) is one instead of \( N \) being reset in box 13.

The variables are defined as follow:
1. \( M \) is the counter for the main inner loop that consists of orange boxes
2. \( N \) is the counter for the main outer loop that consists of blue boxes (and orange boxes as the inner loop)
3. \( I_{\text{MAX}} \) is the highest PV current that is constantly updated after P&O is completed in box 3
4. \( P(X) \) is PV power that is measured after P&O is completed in box 3
5. \( P(Y) \) is PV power that is measured after SCANNING is completed in box 9
6. \( P_{\text{MEAN}}(Z) \) is the average power of \( P(Y) \) for \( V(Y) \) does not equal to \( V_{\text{MPP0}} \).
7. \( V(Y) \) is the global \( V_{\text{MPP}} \) that is measured after SCANNING is completed in box 9
8. \( V(Z) \) is the lowest possible voltage level where global MPP may occur given the equation, \( V(Z) = P(X) / I_{\text{MAX}} \).

3 PROPOSED MPPT STRATEGY

The proposed MPPT strategy combines both real-time tracking and scanning MPP approaches. The real-time tracking approach utilizes P&O algorithm, which is a popular yet simple MPPT technique that provides fast response [9-11]. P&O algorithm is able to continuously track MPP under rapidly changing atmospheric conditions but it does not necessarily detect global MPP, as they only move the operating point to the nearest local maximum. To overcome this shortcoming, we propose to start the SCANNING function occasionally in order to check whether the P&O tracking algorithm is in the vicinity of global \( V_{\text{MPP}} \) and correct as necessary.

Figure 5 shows the flowchart of the proposed strategy. It consists of two main loops that vary the interval between the SCANNING functions. The SCANNING function starts the sweep by increasing the voltage from \( V(Z) \) and it stops when the power approaches zero. The duration of SCANNING function can be reduced by skipping parts of the voltage range [7]. The MPPT strategies are based on the analysis in section 2:

1. The interval between SCANNING is reduced when the instantaneous power drops to a level where multiple MPPs may possibly occur. INC is an integer larger than one. If \( P(X) \) is smaller than \( P_{\text{MEAN}}(Z) \), the conditional box 4 is not satisfied hence increment of the counter \( M \) is larger than one.

Assuming that the constants are assigned as follow: \( \text{MAX} = 30, \text{NMAX} = 4 \) and \( \text{INC} = 2 \). P&O in box 3 requires 10 seconds for completion whereas the SCANNING function requires less than 1 second. Consider a hypothetical situation where the converter is tracking single PV module similar to that shown in Figure 2:

1. The operating point is initially at \( V_{\text{MPP0}} \) and counters \( M, N \) are reset to 0. The PV power measured is consistently low hence conditional box 4 is not satisfied. The algorithm always steps through box 5 and it starts SCANNING function after 10 minutes \( (\text{MAX} / \text{INC} \times \text{NMAX} \times \text{P&O} = 30 / 2 \times 4 \times 10 = 600 \text{ seconds}) \).

2. The operating point is now at \( V_{\text{MPP1}} \) after the SCANNING function is completed. The conditional box 11 is not satisfied. If the power at \( V_{\text{MPP1}} \) is consistently lower than \( P_{\text{MEAN}}(Z) \), it will start SCANNING function after 5 minutes \( (\text{MAX} / \text{INC} \times 2 \times \text{P&O} = 30 / 2 \times 2 \times 10 = 300 \text{ seconds}) \). However, if the power at \( V_{\text{MPP1}} \) is consistently higher than \( P_{\text{MEAN}}(Z) \), it will start...
SCANNING function after 10 minutes ($MAX \times 2 \times P&O = 30 \times 2 \times 10 = 600$ seconds).

3. If PV module receives high irradiance, the conditional box 4 is always satisfied. The algorithm will step through box 6 and start SCANNING function after 20 minutes ($MAX \times NMAX \times P&O = 30 \times 4 \times 10 = 1200$ seconds).

4 CONCLUSIONS

This paper provides a detailed analysis on the characteristic power curve of a partially shaded PV system. The proposed MPPT approach varies the time-interval between scans adaptively based on the probability of a shift of operating point having occurred. The interval between scans reduces if the instantaneous power drops to a level where multiple MPPs may possibly occur or if maximum power is not at the nominal $V_{MPP}$.

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5 REFERENCES


