A Partial Shading Detection Technique for MPPT Algorithms in PV systems

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Abstract. In this paper, a simple algorithmic enhancement for MPPT methods is introduced, which mathematically determines if the PV system is shaded, thus avoiding unnecessary curve scanning to locate the global maximum if it is unshaded. The proposed technique improves the overall efficiency and applies to any PV system at any irradiance distribution, using only a common temperature sensor.

1. Introduction

Multiple power peaks are presented on the *P-V* curve of a photovoltaic (PV) array under partial shading conditions, hindering the effectiveness of maximum power point tracking (MPPT) algorithms. Conventional MPPT methods, such as P&O, INC etc., often fail to locate the global maximum power point (MPP) and converge to a local suboptimal MPP. Several methods are proposed in literature to tackle this problem, such as in [1]-[2], but still the tracking of the global maximum under any illumination conditions cannot be guaranteed. Therefore, the strategy usually adopted in commercial inverters employs periodic scanning of the entire *P-V* curve, by linearly varying the duty cycle of the converter, and re-localization of the global and local MPPs. However, during the scanning procedure the output power deviates from the maximum, thus leading to fluctuations on the output power and energy losses.

In this paper, a simple algorithm is proposed that determines whether the PV array is partially shaded or not, thus performing curve scanning only when there is a need and not at uniform illumination that only a single MPP exists. The technique only needs information given in the PV modules' datasheet and measurements of the actual operating voltage and temperature, readily provided by the converter and a temperature sensor respectively. Furthermore, applies to multiple irradiance levels and any PV structure (PV array, string etc.) or temperature, while it is not susceptible to measurement inaccuracy of the latter. Moreover, the calculations performed are entirely mathematical, not affecting the operating point and the output power, rendering the proposed algorithm a useful enhancement to any conventional MPPT method.

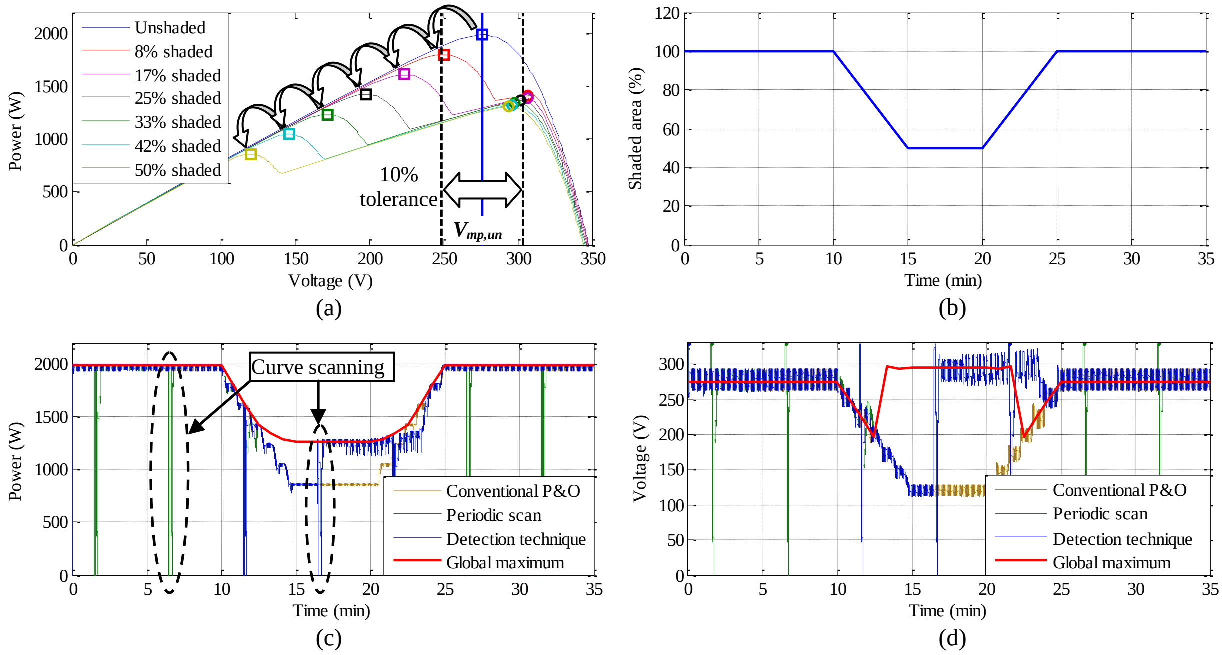

Fig. 1. Partially shaded PV string at variable extent and 60% intensity of shade. (a) *P-V* curve at various shaded areas, (b) variation of shaded area, (c) power output with different MPPT methods, and (d) voltage with different MPPT methods.

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2. Partial Shading Detection Algorithm

A comprehensive analysis of the partial shading phenomenon in PV strings and arrays is presented in [3] and [4]. According to these studies, each MPP that appears on the *P-V* curve has specific properties and is denoted by the term MPP1, MPP2, MPP3 etc., depending on the irradiance level. To facilitate understanding, the simplified scenario of a PV string comprising 12 PV modules is examined in Fig. 1, gradually shaded over time, up to 50% of its area (one shade level). In Fig. 1(a), the variation of the *P-V* curve as the shading pattern changes is illustrated with different colour, presenting one or two MPPs. The square marker corresponds to MPP1, in which the shaded part of the PV string is bypassed (due to the conducting bypass diodes) and only the unshaded part produces power, and the circle marker to MPP2. A conventional MPPT algorithm operates constantly at the MPP1 even if it is not the global maximum, as illustrated with the arrows in Fig. 1(a).

Therefore, given that the MPP1 voltage, V_{mp1}, is linearly dependant on the shaded area, as discussed in [3], the extent of the shade can be estimated by comparing the actual operating voltage V_{mp1} to the MPP voltage of the unshaded PV system $V_{mp,un}$. The calculation of the latter involves the nominal MPP voltage of the PV module, V_{mp0}, the number of modules connected in series, N_m, and the temperature coefficient, bV_{oc}:

$$V_{mp,un} = N_m V_{mp0}(1+bV_{oc}\Delta T_c) \quad (1)$$

The flowchart of the proposed algorithm is shown in Fig. 2. Initially, the system is considered *unshaded* and $V_{mp,un}$ is calculated by (1). If the measured voltage V_{meas} deviates from $V_{mp,un}$ more than 10%, then the curve scanning is performed and all local MPPs are determined, otherwise this process is avoided. If multiple MPPs are found, the system's status changes to *shaded*, otherwise remains *unshaded*, and the process is repeated.

The tolerance is set to 10%, since this is typically the maximum error in $V_{mp,un}$ estimation. In particular, if a measurement inaccuracy of 10˚C is assumed in temperature, this would lead up to 4% error in $V_{mp,un}$ for typical temperature coefficients (0.3-0.4%/˚C). In addition, the dependence of irradiance on $V_{mp,un}$ which is neglected in (1), is less than 5% for practical irradiance. The same algorithm applies to multiple irradiance levels and PV arrays, as well, since the properties of MPP1 remain the same [3]-[4].

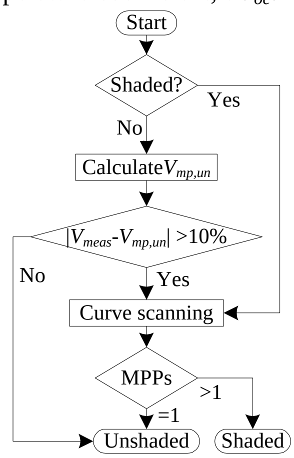

Fig. 2. Flowchart of the partial shading detection technique.

3. Simulations

In order to evaluate the contribution of the proposed detection technique, the shading scenario of Fig. 1 is examined. A *conventional P&O* is implemented as the standard approach, as well as, two variants employing the periodic scanning procedure: with and without the detection technique (Fig. 1(c)-(d)). Apparently, the *conventional P&O* (brown line) stays stuck at MPP1 the whole time, which significantly deviates from the global maximum (red line) the time period 12-23 min (Fig. 1(c)). On the contrary, the *periodic scan* alternative (green line) performs a curve scanning every 5 min, enclosed in dashed line frames in Fig. 1(c), which re-localizes the global MPP at the 17th min. However, the resulting power fluctuation is unnecessary at the time instants of 2, 7, 27 and 32 min, when there is no shading. This is where the *detection technique* (blue line) shows its potential, since no curve fitting is performed in those time instants and the relevant power reduction is avoided. Consequently, the efficiency of the *conventional P&O* is 94.7%, of the *periodic scan* 93.8% and of the *detection technique* 96.2% for this particular simulation. It is worth noting that the loss of power during the curve scanning is not negligible and surpasses the gain of the accurate global maximum determination in the simple *periodic scan* technique. On the other hand, the proposed *detection technique* yields the best results, since it performs this procedure only when there is the need.

4. Conclusion

In this paper, a simple algorithm to determine if a PV system is partially shaded is presented, and it is shown that it may improve the MPPT efficiency of any PV system, using only a temperature sensor.

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