



Analysis of current and voltage indicators in grid connected PV (photovoltaic) systems working in faulty and partial shading conditions



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ABSTRACT

To ensure the optimization of the energy generated by grid connected PV (photovoltaic) systems is necessary to plan a strategy of automatic fault detection. The analysis of current and voltage indicators have demonstrated effectiveness in the detection of permanent faults in the PV array in real time as short-circuits or open circuits present in the system. In this paper, the analysis of the evolution of these indicators is focused on the detection of temporary faults due to partial shade on the PV array or disconnection of the inverter in case of grid fluctuations of voltage or frequency to prevent islanding. These situations can be identified by observation of the evolution of both indicators and power losses due to these effects can be evaluated from them. The analysis and experimental validation were carried out in two grid connected PV systems in Spain and Algeria.

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1. Introduction

Grid connected PV (photovoltaic) systems are becoming an important part of the electricity system all around the globe, especially in most developed countries. A vigorous growth of the global PV market is still expected due to the strong PV technology price decreases and rise of electricity prices produced by conventional sources together with the clear advantages of green and renewable energy sources as PV on delivering safe and clean energy.

Monitoring, automatic supervision and fault detection of grid-connected PV systems are absolutely necessary to ensure an optimal energy harvesting, minimize the cost of the energy produced by the system and to ensure reliable power production.

The identification of failures in grid connected PV systems can be based on evaluation of the system yields and comparison with forecasted values of these parameters [1–4] or on the analysis of

power losses present in the PV system in real operation [4–9]. Once a failure in the PV system operation is observed the source of the fault must be identified by means of a specific diagnostic procedure. Monitored parameters are the key to develop a successful diagnostic procedure [10–12].

Most common faults in PV arrays use to be the apparition of short circuits in PV modules, mainly due to hot spots, the activation of bypass diodes and earth faults [13–16], overcurrent and voltage disturbances [17], and open circuits that disconnect some strings of the array [15,18,19]. Accurate simulations of the PV system behaviour have demonstrated good results in fault detection and diagnostic of faults in PV systems [20–23]. However, these techniques require sophisticated simulation software environments and high computational cost.

In a previous work we have presented a procedure for automatic fault detection in grid connected (PV) systems based on the evaluation of current and voltage indicators [24]. The described procedure can be integrated into the inverter without using simulation software or additional external hardware and minimizing the number of sensors present in the monitoring system. Moreover, the indicators of current and voltage used as benchmarks can be

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calculated by the inverter itself in real time. This approach was experimentally validated and other researchers have followed this way to identify the kind of fault present in the PV system [25].

In the present work we analyse the effects of partial shading of the PV array on current and voltage indicators and how this condition of work and power losses associated to it can be clearly identified by means of these indicators.

The rest of this paper is organized as follows: First, the methodology and calculations are introduced in Section 2. Section 3 presents the experimental validation carried out in two different grid connected PV systems. Finally, the conclusions are made in the last section.

2. Methodology

2.1. Current and voltage indicators for fault detection

Silvestre et al. [24] defined two indicators of current, NR_c , and voltage, NR_v , for automatic supervision and fault detection of PV systems as follows:

$$NR_c = \frac{I_m}{I_{sc}} \quad (1)$$

$$NR_v = \frac{V_m}{V_{oc}} \quad (2)$$

where V_m and I_m are the voltage and current of the MPP (maximum power point) at the DC output of the PV generator respectively and I_{sc} and V_{oc} the short circuit current and V_{oc} the open circuit voltage of the PV array respectively.

The inverter is able to calculate both NR_c and NR_v indicators through MPP coordinates available at the inverter input, and the values of I_{sc} and V_{oc} , obtained for actual conditions of irradiance and temperature by the inverter itself internally in real time. For this purpose, the inverter must have MPP tracking and monitoring capabilities. Two more parameters can be also calculated in real time: I_{mo} and V_{mo} , the current and voltage at the maximum power point of the output of the PV array in absence of faults [24]. Then, the ratios: NR_{co} and NR_{vo} , the expected values of NR_c and NR_v , in normal operation of the PV system are given by:

$$NR_{co} = \frac{I_{mo}}{I_{sc}} \quad (3)$$

$$NR_{vo} = \frac{V_{mo}}{V_{oc}} \quad (4)$$

The definition of thresholds for current, TNR_{cfs} , and voltage, TNR_{vbm} , allows detecting both, short circuits and open circuits in the PV array [24]. These thresholds were defined by the following equations:

$$TNR_{cfs} = 1.02 \alpha NR_{co} \quad (5)$$

$$TNR_{vbm} = 1.02 \beta NR_{vo} \quad (6)$$

where α and β are the relationship between the ratios of current in case of one faulty string and fault-free operation and the ratio between the voltage ratios in case of one bypassed PV module and fault-free operation respectively given by Equations (7) and (8). On the other hand, the constant included in Equations (5) and (6) was fixed by means of statistical procedures in order to avoid false fault detections as an offset of a 2% respect the NR_{co} and NR_{vo} values [24].

$$\alpha = \frac{NR_{cfs}}{NR_{co}} = 1 - \frac{1}{N_p} \quad (7)$$

$$\beta = \frac{NR_{vbm}}{NR_{vo}} = 1 - \frac{1}{N_s} \quad (8)$$

In case of permanent faults in the PV array, short circuits or open circuits, the corresponding current or voltage indicators always remains below its threshold.

2.2. Partial shading of the PV array

Unavoidably, the partial shading is a condition that affects the operation of PV systems at some point and leads to reduction of the output power [26–31]. However, most times partial shading has a dynamic behaviour depending on the cloud evolution and on the position of surrounding obstacles near the PV array [32].

The output current of the PV generator is reduced by the number of PV modules affected by shading. The most shaded PV module in a chain limits the total current in that chain. Moreover, there is also a reduction in the output voltage of the PV array due to shadow. The overall decrease in the output voltage depends on the number of bypass diodes that are activated in the PV modules that form the PV generator [33].

Both effects, current and voltage reduction, can be observed at the same time or separately depending on the shadow profile and the configuration of the PV array. Furthermore, in most cases these effects disappear quickly due to the dynamic behaviour of the irradiance profile on the PV field unless a PV module has been completely damaged. So, it is possible to identify that situation by means of the current and voltage indicators described in the previous section.

The total percentage of reduction in output voltage, ΔV , can be expressed as follows:

$$\Delta V = \left(\frac{V_{mo} - V_m}{V_{mo}} \right) = \left(1 - \frac{NR_v}{NR_{vo}} \right) \quad (9)$$

Considering a number of N_s PV modules connected in series by string in the array, the number of PV modules bypassed, BP_{mod} , because of the shadow effects are given by:

$$BP_{mod} = \Delta V N_s \quad (10)$$

Similarly, the normalized reduction of output current, ΔI , varies according to the following expression:

$$\Delta I = \left(\frac{I_{mo} - I_m}{I_{mo}} \right) = \left(1 - \frac{NR_c}{NR_{co}} \right) \quad (11)$$

If the PV array is formed by N_p strings of PV modules connected in parallel, the output current losses can be translated to number of equivalent strings in open circuit. The number of equivalent faulty strings, Efs , is given by:

$$Efs = \Delta I N_p \quad (12)$$

So, the presence of partial shadows on the PV array can be detected by means of current and voltage indicators when they present values below their respective thresholds for short periods of time. Moreover, Equations (10) and (12) allow identifying the number of bypassed modules and the equivalent number of faulty strings in the PV array respectively in case of partial shading.

The proportion of DC power losses due to the shadowing effect, P_{loss} , can also be evaluated from Equations (9) and (11) as follows:

$$P_{loss} = \left(1 - \frac{NR_c}{NR_{co}} \frac{NR_v}{NR_{vo}} \right) \quad (13)$$

The accuracy of the method depends on the errors in the estimation of main parameters involved in the equations, mainly: I_{sc} , V_{oc} ,

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