FAULT DETECTION AND AUTOMATIC SUPERVISION METHODOLOGY FOR PV SYSTEMS

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ABSTRACT: In this work, we show a new methodology for automatic supervision and fault detection of PV Systems, based mainly on the analysis of the power losses. This methodology includes parameter extraction techniques to calculate main PV system parameters from monitoring data [1-2], taking into account the real irradiance and module temperature, allowing simulation and evaluation of the PV system behaviour in real time.
Keywords: PV System, System Performance

1 INTRODUCTION

Some experiences have been carried out trying to introduce remote monitoring and fault detection in PV systems [3-4]. These experiences use climate data from satellites observation. From these data, and with the complete information of the PV system design, is possible the calculation of the expected system's energy yield. Finally, the fault analysis is based in the comparison of predicted yields with the real measured ones in the monitoring process. The calculated system's energy yields have not the same accuracy than yields calculated from real monitored data; values of RMSE about 10 % have been reported for irradiance estimated using these methods [5]. Other authors have developed new simulation tools for the diagnostic and fault detection of PV systems. Most of these approaches are not based on the use standard software tools and are just been focused in the detection of determinates incidences [6]. In this work we present a new methodology able to detect most faults that may occur in PV systems. The proposed method has been implemented in Matlab&Simulink, one of the most popular and standardized simulation environments in engineering fields. The losses in the PV system are evaluated by means of comparison between the monitored data with simulation results. Mismatch losses can be evaluated by our method, greatly reducing the false detection of failure of operation. The main PV module parameters used in our simulations are obtained from a new PV module extraction parameter technique that allows a more realistic simulation of the PV array in real conditions of work. None of the procedures presented so far used parameter extraction techniques to improve the adjustment of the simulation results of system operation.

2 METHODOLOGY DESCRIPTION

2.1 Photovoltaic array output modelling and Parameter extraction.

Output current and voltage of the PV generator are calculated by the simulation model using the following nonlinear implicit equation:

$$I = I_{PH} - I_o\left[\exp\left(\frac{V+R_s I}{nV_t}\right)-1\right] - \left(\frac{V+R_s . I}{R_{sh}}\right) \tag{1}$$

Where main parameters are: Photocurrent I_{PH}, ideality factor n; diode reverse saturation current Io; Rs and Rsh the series and shunt resistances respectively, I and V, are the output PV module current and voltage, and Vt is the thermal voltage.
The effects of temperature in output voltage and current are also considered by the model. The simulation model applies a nonlinear regression algorithm to both data sets; measured I-V data from the PV system and data generated by the simulation model, in order to minimize the following quadratic function [2]:

$$S(\theta) = \sum_{i=1}^{N} \left[I_i - I(V_i, \theta)\right]^2 \tag{2}$$

Where: $\theta = (I_{ph}, I_0, n, R_s, R_{sh})$

is the vector containing main PV module parameters. This parameter extraction technique gives a set of parameters that will be used later in the simulation of the PV system to supervise.
As shown in Fig. 1, the results of the simulation for the output DC power very well approaching the actual measured values of that parameter. Values of RMSE about 3% have been obtained in all cases of study made. Using this parameter extraction technique allows realistic simulation of system behaviour and provides supervision to increase reliability in predicting poor performance of the PV system.

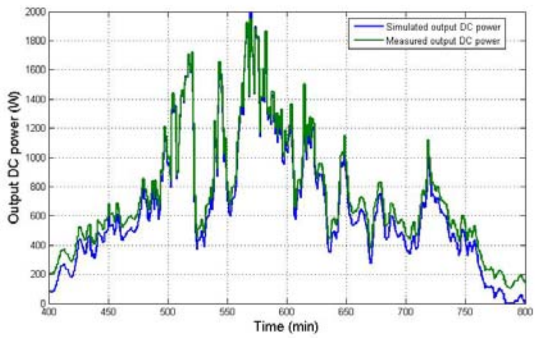

Figure 1: Output power, measured & simulation results

2.2 Automatic Supervision Methodology

The automatic supervision procedure is based in the observation of the miscellaneous capture losses, LC, which comprises all possible causes of power losses. Two values of this parameter can be obtained from the monitoring data (LC_meas) and simulation results (LC_sim). The simulated capture losses, LC_sim, are the reference inherent losses without faulty operation, and can be calculated by the following expression :

$$L_{C\_sim} = Y_r - Y_{a\_sim} \qquad (3)$$

Where Yr is the reference yield defined as:

$$Y_r = \frac{H_i}{G_{ref}} \quad [Hours] \qquad (4)$$

and Ya_sim is the array yield obtained from simulation results :

$$Y_a = \frac{E_{dc}}{P_{ref}} \quad [Hours] \qquad (5)$$

Being : Hi the total plane of array irradiation in (Wh/m^2), Gref the reference irradiance at STC (1000 W/m^2), Pref the maximum power output of PV array (kWp), and Edc the energy produced by PV array (kWh) obtained in simulation results.

The measured capture losses, LC_meas, are the real losses obtained from the monitored data, and calculated by the following expression:

$$L_{C\_meas} = Y_r - Y_{a\_meas} \qquad (6)$$

Where Ya_meas can be calculated from equation (5), using the real measured value of energy produced by the PV system, Edc.

The fault detection and Automatic Supervision Methodology proposed is based on the continuous check of the measured capture losses. We established theoretical boundaries in which the measured capture losses don't exceed any of them; otherwise the system is working in faulty operation, so the error signal is activated. These upper and lower boundaries are calculated by means of statistical approach and in case of PV system normal operation; the measured capture losses remain into the theoretical boundaries as given by the following expression:

$$LC\_sim - 2d < LC\_meas < LC\_sim + 2d \qquad (7)$$

Where the standard deviation, d, is calculated from simulated capture losses for clear sky conditions.

We define two indicators of the deviation of the DC variables respect to the simulated ones to identify the detection of malfunctions and isolate the type of the error. These indicators are the current and voltage ratios shown in the following expressions:

$$R_C = \frac{I_{PV\_sim}}{I_{PV\_meas}} \qquad R_V = \frac{V_{PV-sim}}{V_{PV\_meas}} \qquad (8)$$

Analyzing these parameters, the error signal and current / voltage relations, the type of fault is identified. The most probably failure or malfunction is found following the flowchart that appears at Fig. 2.

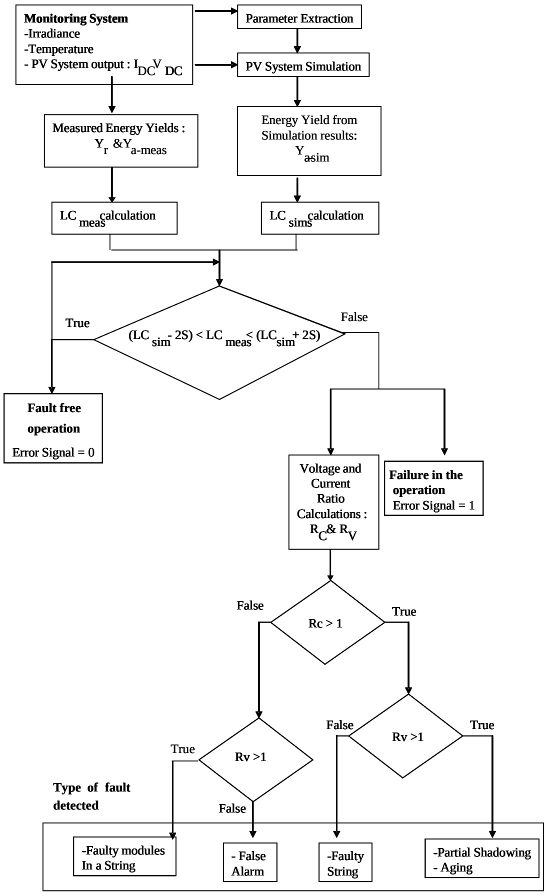

Figure 2: Flow chart for the Automatic system Supervision and for Fault detection

3 RESULTS OBTAINED

Specific tests and evaluations of the presented methodology have been carried out successfully in a 3.2kWp grid connected PV system. The PV array is formed by 30 PV, two strings of 15 PV modules of 106 Wp, from Isofotón, connected in parallel, including a monophasic inverter of 2.5 kW.

Results obtained in three case studies are presented in this work: Fault free operation, Faulty modules in a String and faulty string operation.

3.1 Fault Free Operation

In case of fault free operation the measured capture losses don't exceed the established theoretical boundaries, as is shown in Fig. 3, and the error signal is not activated.

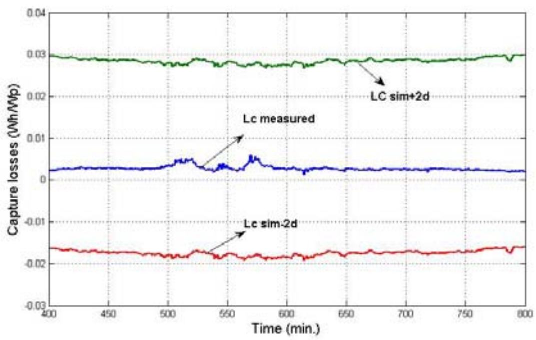

Figure 3: Capture Losses

The values of current and voltage ratios are always close to the unity, as Fig. 4 shows below.

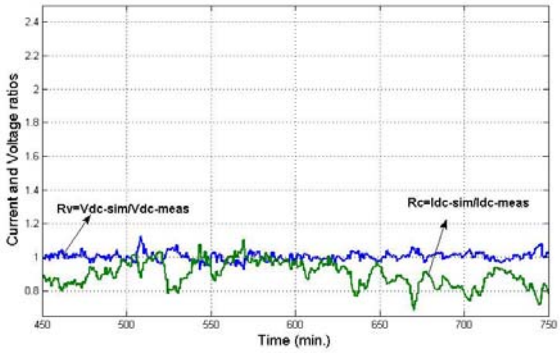

Figure 4: Current and Voltage ratios

3.2 Faulty modules in a String

In case of disconnection of five modules in one of the strings forming the PV array, the measured output power is lower than the simulated one, as Fig. 6 shows. The value of the measured capture losses exceeds the theoretical boundaries and the error signal is activated. The measured output voltage is lower than the obtained by the simulation, so the voltage ratio exceeds unity, as is shown in Fig.5, while the current ratio follows near unity.

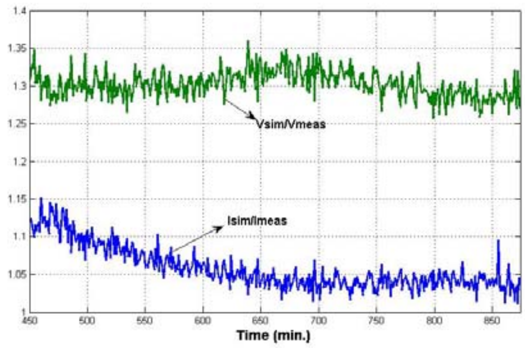

Figure 5: Current and Voltage ratios

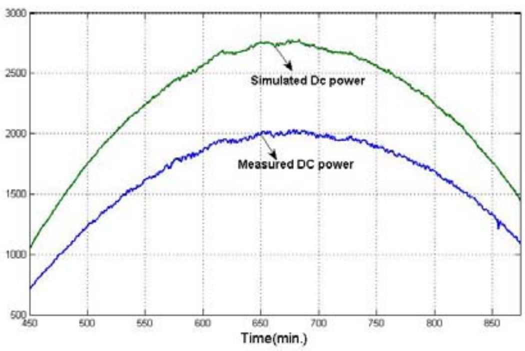

Figure 6: DC output power

3.3 Faulty string operation

If one of the strings forming the PV array is in open circuit the measured DC power is lower than the simulated output of the PV system, as Fig. 8 shows, the value of the measured capture losses exceeds the theoretical boundaries and the error signal is activated. The measured current value is about half the current value obtained in the simulation, so the current ratio goes to a value close to two, as is shown in Fig. 7, while the voltage ratio still follows near unity.

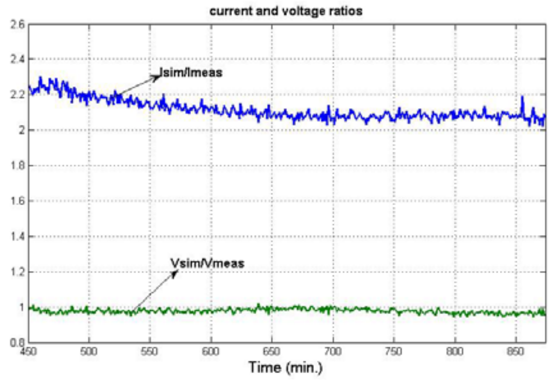

Figure 7: Current and Voltage ratios

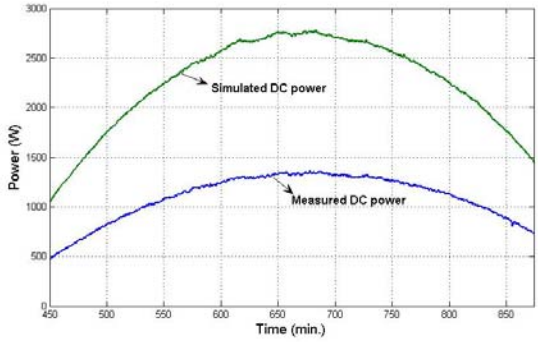

Figure 8: DC output power

4 CONCLUSIONS

The automatic supervision methodology presented in this work starts with the analyses of the output power losses, presents in the DC side of the PV generator: Measured capture losses and simulated capture losses. Treatment of these indicators allows the monitoring system to generate an error signal as an indicator of failure detection in the PV system performance. Analyzing the error signal and the current/voltage ratios is possible the identification of the type of fault present in the PV system. The automatic supervision system has been successfully tested experimentally.

4.1 References

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