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Remote supervision and fault detection on OPC monitored PV systems

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ABSTRACT

This paper presents a new approach for automatic supervision and remote fault detection of grid connected photovoltaic (PV) systems by means of OPC technology-based monitoring. The use of standard OPC for monitoring enables data acquisition from a set of devices that use different communication protocols as inverters or other electronic devices present in PV systems enabling universal connectivity and interoperability. Using the OPC standard allows promoting interoperation of software objects in distributed-heterogeneous environments and also allows incorporating in the system remote supervision and diagnosis for the evaluation of grid connected PV facilities. The supervision system analyses the monitored data and evaluates the expected behaviour of main parameters of the PV array: Output voltage, current and power. The monitored data and evaluated parameters are used by the fault detection procedure in order to identify possible faults present in the PV system. The methodology presented has been experimentally validated in the supervision of a grid connected PV system located in Spain. Results obtained show that the combination of OPC monitoring along with the supervision and fault detection procedure is a robust tool that can be very useful in the field of remote supervision and diagnosis of grid connected PV systems. The RMSE between real monitored data and results obtained from the modelling of the PV array were below 3.6% for all parameters even in cloudy days.

1. Introduction

One of the main difficulties involved in monitoring systems is the inability to add new devices or new ways of evaluating the performance of these systems without significantly changing the topology of the monitoring system. Firstly, the incorporation of new devices, in the absence of standard communication protocols, requires the development of software for acquiring data from these devices and it is also necessary to add the functionality of each of the data that are acquired. Moreover, in photovoltaic (PV) plants connected to the grid each inverter has its own communication protocol and issues its own program online or locally to access data and plant information. These programs do not allow the inclusion of data from other inverters or for other plants even in the case of inverters from the same manufacturer. Also, it is not possible to incorporate any functionality to them in order to make a diagnosis and evaluation of the operation of facilities, beyond including the system supplied by the manufacturer of the inverter, who usually simply presents the information of the recorded data. Therefore, it is possible to ensure that one of the most important problems when it comes to monitoring and supervising solar energy plants is the communication between devices due to the different types used. It is common to find many devices of different types and manufacturers who use different ways of communication. In order to obtain a generic system, a general mechanism is needed to communicate with any devices, irrespective of their characteristics or of the manufacturer.

To address these limitations, it has been proposed to use the OPC standard for monitoring PV systems (Martinez-Marchena et al., 2010, 2014). OPC was originally based on OLE (Object Linking and Embedding) for Process Control (Alan Gordon, 2001; Liu et al., 2005). However, OPC is now available on other operating systems. It is a standard and consistent communication system for exchanging information and it allows defining the rules of handshaking between different devices using the client-server paradigm; this system has been used in industry to connect supervisory systems and data acquisition and man-machine interfaces with the physical control systems (Holley, 2004). Moreover, it allows the development of components for interconnecting

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disperse systems providing interoperability efficiently. This technology enables software components developed by experts in one sector to be used by applications in any other sector. The design of OPC interfaces supports distributed architectures.

The Data access OPC and Historical Data Access specifications are compatible with client-server and publisher-subscriber communication models. The use of the Distributed Component Object Model (DCOM) from Microsoft makes possible the access to remote OPC servers. DCOM extends Microsoft's object-oriented Component Object Model (COM) to promote interoperation of software objects in a distributed-heterogeneous environment.

Using this OPC standard, an automatic assessment model for solar energy plants was proposed in Martínez-Marchena et al., (2014). The model for each installation is built using different data sources. Various daily parameters were proposed to evaluate the performance of a photovoltaic system:

- The daily output energy of the photovoltaic plant, that is, the daily energy supplied by the installation, E_{day}.
- The daily yield, Y_{a_day}, defined as the daily output energy per kW_p installed.

The daily evaluation model is treated as an element of the system. The container used for the model behaves as an OPC client with access to all data.

The operation of each plant is evaluated using a statistical analysis of the differences between the measured parameters and the estimated parameters. These differences are checked using the Jarque-Bera test (Jarque et al., 1987) that informs whether these differences follow a normal distribution. This proposal allows an initial daily evaluation of the performance of the PV system. However, for a complete diagnosis of the detected problems generally related to the DC side of the PV system, it is necessary to use additional methods based on a detailed analysis of monitored data.

A list of fault detection methods for grid connected PV systems was reported in the past. Some of these methods are based on power losses analysis (Chouder and Silvestre, 2010; Drews et al., 2007; Firth et al., 2010) or on theoretical concepts of descriptive and inferential statistics (Vergura et al., 2009; Leloux et al., 2014). Bayesian (Coleman and Zalewski, 2011) and neural networks (Wu et al., 2009) were also used in fault detection procedures. However, these techniques require sophisticated software environments and have a high computational cost. In this work a procedure for automatic fault detection in grid connected PV systems is used. This procedure is based on a technique for the evaluation of current and voltage indicators recently reported that was experimentally validated and can work in real time without using sophisticated software tools (Silvestre et al., 2014, 2015; Chine et al., 2014). The integration of this fault detection procedure along with OPC monitoring, results in a powerful tool for automatic supervision and fault detection of grid connected PV systems. The present work shows the results obtained in the remote supervision of a grid connected PV system with a nominal power of 14.08 kW located in Spain by using diagnosis tools in combination with OPC monitoring.

2. Methodology

2.1. Description of the OPC-based monitoring

The following parameters were monitored: Current, voltage and power (DC and AC), cosine (ϕ), frequency, irradiance, partial energy and module temperature. The irradiance received was measured using a calibrated solar cell installed in the plane of the modules. Module temperature was measured using a Pt100 sensor fitted to the back of the module, in the middle of a cell, near its geometric center. Both parameters are recorded by the data acquisition of the inverter.

All data were supplied by the inverters. For data collection it was used OPC Historical Data Access (OPC HDA) specifications which provide access to information already stored in inverters and allow retrieving this information in a homogeneous and uniform way. A VPN and IP were used to connect with the facilities. The data collection interval was 5 min. Data are directly retrieved from the inverter. When the inverter is disconnected data are not recorded, but data previously stored in the inverter will be transmitted when the inverter is connected.

Several elements are used in the monitoring process: The client software using OPC HDA technology for downloading data from the devices, the device and the OPC HDA server that knows the protocol and the procedure to download data from the device (Martínez-Marchena, 2015).

Data were stored in a PostgreSQL DBMS compatible with the SQL92 standard. Daily evaluation and fault detection algorithms were implemented with OPC.

2.2. PV system modelling

The model of the PV array is mainly based on the Sandia PV array performance model (SAPM) King et al., 2004. This model is an empirical model described by the fundamental Eqs. (1)–(7). The model contains several coefficients and parameters that are unknown and not provided by the PV module's manufacturer, by knowing these model parameters as well as the solar radiation and the PV modules operating temperature, the output power of the PV array can be predicted by using the following equations:

$$Ee = G/G_n \tag{1}$$

$$Iscg = N_{pg}[Isco \cdot Ee \cdot \{1 + \alpha_{Isc} \cdot (Tc - To)\}] \tag{2}$$

$$Impg = N_{pg}\left[Impo \cdot \left\{C_0 \cdot Ee + C_1 \cdot Ee^2\right\} \cdot \{1 + \alpha_{Imp} \cdot (Tc - To)\}\right] \tag{3}$$

$$\delta(Tc) = n \cdot k \cdot (Tc + 273.15)/q \tag{4}$$

$$Vocg = N_{sg}[Voco + N_s \cdot \delta(Tc) \cdot ln(Ee) + \beta_{Voc}(Ee) \cdot (Tc - To)] \tag{5}$$

$$\begin{aligned} Vmpg = N_{sg}\Big[&Vmpo + C_2 \cdot N_s \cdot \delta(Tc) \cdot ln(Ee) + C_3 \cdot N_s \cdot \{\delta(Tc) \cdot ln(Ee)\}^2 \\ &+ \beta_{Vmp}(Ee) \cdot (Tc - To)\Big] \end{aligned} \tag{6}$$

$$Pmpg = Impg \cdot Vmpg \tag{7}$$

where Ee is the effective solar irradiance; G is the measured irradiance (W/m^2); G_n is the reference irradiance (1000 W/m^2) at standard conditions (STC); To is the reference cell temperature (25 °C) at STC; Tc is the measured cell temperature inside module (°C); $Isco$ is the PV module short-circuit current at STC (A); α_{Isc} is the normalized temperature coefficient for Isc, (°C^{-1}); $Iscg$ is the PV array short-circuit current (A); N_{pg} is the number of modules connected in parallel; $Impo$ is the PV module current at the maximum power point at STC (A); $Impg$ is the PV array current at the maximum power point (A); α_{Imp} is the normalized temperature coefficient for Imp, (°C^{-1}); C_0 and C_1 are empirically determined coefficients which relate Imp to the effective irradiance, $C_0 + C_1 = 1$, (dimensionless); $\delta(Tc)$ is the thermal voltage per cell at temperature Tc; q is the elementary charge, $1.60218 \cdot 10^{-19}$ (coulomb); k is the Boltzmann's constant, $1.38066 \cdot 10^{-23}$ (J/K); n is the diode ideality factor; $Voco$ is the PV module open circuit voltage at STC (V); β_{Voc} is the temperature coefficient for module Voc at standard irradiance, (V/°C); N_s is