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Fault detection method for grid-connected photovoltaic plants

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ABSTRACT

In this work, an automatic fault detection method for grid-connected photovoltaic (GCPV) plants is presented. The proposed method generates a diagnostic signal which indicates possible faults occurring in the GCPV plant. In order to determine the location of the fault, the ratio between DC and AC power is monitored. The software tool developed identifies different types of faults like: fault in a photovoltaic module, fault in a photovoltaic string, fault in an inverter, and a general fault that may include partial shading, PV ageing, or MPPT error. In addition to the diagnostic signal, other essential information about the system can be displayed each 10 min on the designed tool. The method has been validated using an experimental database of climatic and electrical parameters regarding a 20 kWp GCPV plant installed on the rooftop of the municipality of Trieste, Italy. The obtained results indicate that the proposed method can detect and locate correctly different type of faults in both DC and AC sides of the GCPV plant. The developed software can help users to check possible faults on their systems in real time.

1. Introduction

The number of photovoltaic (PV) systems is increasing rapidly all over the world. Grid-connected PV plants – with sizes varying from a few kW_p (domestic plants) to several MW_p (utility-scale plants) – represent world-wide the power technology with the highest rate of growth. This is due to the simplicity of installation, high reliability, zero fuel costs, very low maintenance costs, and the lack of noise due to the absence of moving parts [1].

The energy produced by a grid-connected PV (GCPV) plant depends on various factors such as the nominal characteristics of the components of the PV system, electrical and geometrical configurations, weather conditions of site of installation mainly with respect to solar radiation availability, the local horizon and the near-field shading, availability of the plant, failures that may occur during its operation [2], and other factors which are not very important. A number of different issues can cause the loss of energy in the plant. Some losses are related to the PV array, these include maximum power point tracking error, module parameters dispersion (mismatch), wiring losses and ageing [3]. Others are influenced by environmental characteristics such as operating temperature, and solar irradiance level. In addition, others losses are referred to the power conditioning units (DC–DC and DC–AC converters).

Nowadays, many diagnostic techniques are developed for possible faults detection in PV systems. Some of these do not require climate data (solar radiation and module temperature) such as the earth capacitance measurement (ECM) developed by Takashima et al. [4] that consists of an electrical method for detecting where a photovoltaic module in a string has been disconnected, the time-domain reflectometry (TDR) that measures the electrical characteristic of a transmission line developed by Schirone et al. [5] which can detect not only the disconnection in the string, but also the impedance change due to degradation, and a statistical approach based on the ANOVA (Analysis of Variance) test and non-parametric Kruskal–Wallis test that shows a high level of accuracy and is fast in fault diagnosis [6].

Additionally, a remote monitoring and fault detection method of small GCPV systems [7] used climate data from satellites observation that replaces on-site measurements. Then, the expected energy yield is calculated and compared with the measured one. The expected system's energy yields do not have the same accuracy than yields calculated from real monitored data and values with root mean square error (RMSE) of about 10% have been reported for irradiance estimated using these methods [8]. This type of analysis allows four different types of failures to be distinguished: constant energy losses (for example due to degradation, soiling, module

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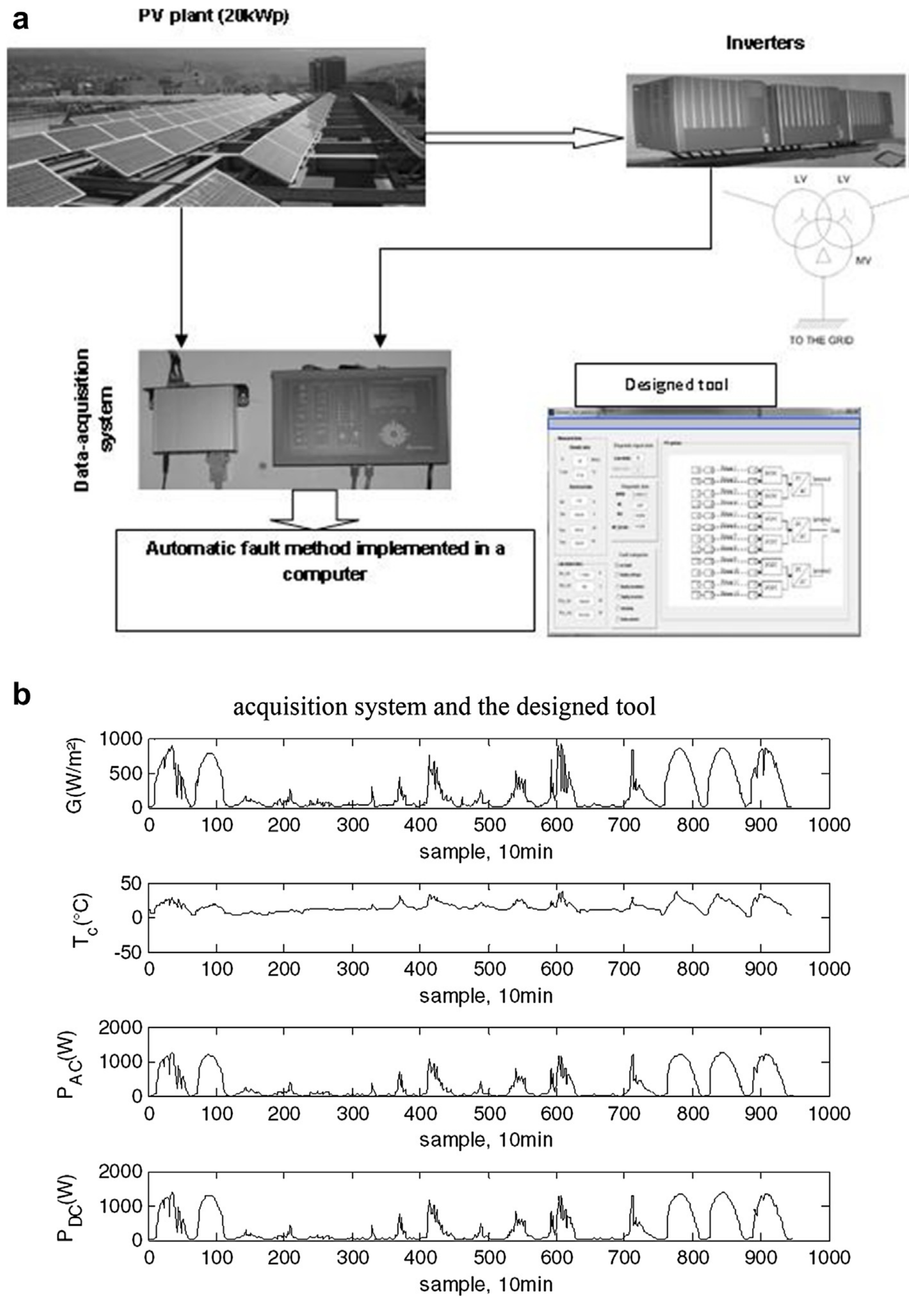

Fig. 1. a. The GCPV plant installed on the rooftop of the Trieste local government, data-acquisition system and the designed tool. b. Example of the monitored data (G_i: irradiance, Tc: cell temperature, output DC and AC power) for a few days (SQ_3).

defect, string defect, etc.), variable energy losses (for example due to shading [9], grid disconnections, power limitation of the inverter, MPP tracking failures, temperature, etc.), and losses due to the presence of snow (blackout).

Other researchers used climate data measured by local sensors on the plants. This category includes the intelligent based approaches, as an example the method proposed by Syafaruddin et al. [10] that used a three layered feed forward neural network, which allows the identification of the short-circuit location of PV modules in one string. Another intelligent system for automatic detection of faults in PV fields based on a Takagi–Sugeno–Kahn Fuzzy Rule-Based System (TSKFRBS) was described in Ref. [11]. The results show that the system can recognize more than 90% of fault conditions, even when noisy data are introduced.

Some other techniques are based on learning methods and take into account the specific condition of the plant under monitoring [12]. This type of monitoring system simplifies the operation and maintenance of the PV systems, even though it needs many measurement sensors. Two types of faults were identified by this method: shading and inverter failure. Firth et al. [13] have developed a technique that used only few measurement sensors, which can classify the energy losses in four different categories: sustained zero efficiency faults, brief zero efficiency faults, shading, and non-zero efficiency non-shading faults. Moreover, the loss of energy can be quantified. Nevertheless, this technique does not detect any type of fault leading to possible loss of energy without any alarm given.

Gokmen et al. [14] developed a simple diagnostic method to determine the number of open and short-circuited PV modules in a