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Parallel fault detection algorithm for grid-connected photovoltaic plants

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ABSTRACT

In this work, we present a new algorithm for detecting faults in grid-connected photovoltaic (GCPV) plant. There are few instances of statistical tools being deployed in the analysis of PV measured data. The main focus of this paper is, therefore, to outline a parallel fault detection algorithm that can diagnose faults on the DC-side and AC-side of the examined GCPV system based on the *t*-test statistical analysis method. For a given set of operational conditions, solar irradiance and module's temperature, a number of attributes such as voltage and power ratio of the PV strings are measured using virtual instrumentation (VI) LabVIEW software.

The results obtained indicate that the parallel fault detection algorithm can detect and locate accurately different types of faults such as, faulty PV module, faulty PV String, Faulty Bypass diode, Faulty Maximum power point tracking (MPPT) unit and Faulty DC/AC inverter unit. The parallel fault detection algorithm has been validated using an experimental data climate, with electrical parameters based on a 1.98 and 0.52 kWp PV systems installed at the University of Huddersfield, United Kingdom.

1. Introduction

In recent years the photovoltaic market has developed rapidly throughout the world. A significant factor leading to this large growth in the PV industry is the reduction of PV generation costs. In addition, most developed countries have implemented specific governmental strategies to encourage the introduction of grid connected PV plants. Successful examples can be seen in Germany, Japan and Kenya [1]. This important growth has not, however, been accompanied by similarly significant improvements in the field of PV system fault diagnosis and detection. Most PV systems, currently in use, operate without any supervisory mechanism. These tend to be PV systems with power outputs below 25 kWp [2]. However, following the fast growth of PV installations, fault detection techniques nowadays are important to be deployed in smaller scale PV systems which do tend to be 25 KWp or less.

The need for higher performance, efficiency and reliability for grid-connected PV (GCPV) systems has led to a recent interest in fault detection algorithms. Different factors can be responsible for the production losses in a PV system, including; maximum power point tracking (MPPT) error [3,4], wiring losses and ageing [5], shading effect [6,7], dust effect [8], snow accumulation on the surface of the solar panels [9] and faulty dc-ac inverters [10].

There are existing techniques which have been developed for fault detection in grid connected PV plants. Some use satellite data [11] for fault detection using GITEL approach which facilitate the detection of several faulty conditions in PV systems such as partial shading effect, faulty PV modules and faulty PV string. However, some algorithms do not require any climate data (Solar irradiance and module temperature) but instead use earth capacitance measurements in a technique established by Takashima et al. [12], this approach follows three PV performance diagnosis layers, starting with passive diagnosis part, then fault separation method and ending with active layer which contains the fault location in a PV string.

Other fault detection algorithm techniques are based on a diagnostic signal which indicates a possible fault occurring in the GCPV plant such as short circuit fault in any bypass diodes in PV string, shunted bypass diode fault and connection resistance fault between PV modules [13]. In Ref. [14], the authors proposed a reliable fault detection method for grid-connected PV plants. The method was developed using two algorithms based on artificial neural network (ANN) and I-V characteristics of the examined PV system.

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The development of a fault detection algorithm which allows the detection of seven different fault modes on the DC-side of a GCPV system is presented by M. Dhimish & V. Holmes [15]. The algorithm uses the *t*-test statistical approach for identifying the presence of system fault conditions. However in Ref. [16], the fault detection algorithm focuses on the AC-side of the GCPV system. The approach uses the ±3 standard deviation statistical analysis technique. Hot-spot detection in photovoltaic substrings using AC parameters characterization was developed by Ref. [17], this approach is used to detect the number of shaded modules in a PV string, moreover, and the algorithm proves that the hot spot detection can be achieved with two frequency measurements: one for the higher frequency capacitive region and one for the low frequency dc impedance region. Nevertheless, the analysis of the current and voltage indicators in a GCPV system operating in partial shading faulty conditions is created by Silvestre et al. [18], this approach is using the relationship between the ratios of the current in case of one faulty string and fault-free operation mode. In addition to the ratio between the voltage ratios in case of one bypassed PV module and fault-free operation mode.

In this work, we present the development of a fault detection algorithm which allows the parallel detection of faults occurring on both the DC and AC sides of the examined GCPV plant. The algorithm uses the theoretical and measured power outputs from the GCPV plant. Initially, the measured output power is compared with the theoretical power. Subsequently, a statistical *t*-test technique is used to check the location of the fault which has occurred on the system. Two parameters are calculated and used in order to determine the type of fault: The power ratio between the simulated and measured power (PR); and the ratio between the simulated and measured voltage (VR).

The algorithm was developed and validated using online and historical field measurements from a 1.98 kWp PV plant located in Huddersfield, United Kingdom. The parallel fault detection algorithm was validated with data that include measurements taken during the faulty operation of the GCPV plant. Fig. 1 shows all types of faults which can be identified by the proposed parallel fault detecting algorithm. It can be observed that faults occurring in GCPV plants can be classified into three main categories:

- Faults in the data acquisition
- Faults in the DC-side of the GCPV system
- Faults in the AC-side of the GCPV system

A software tool is designed using Virtual Instrumentation (VI) LabVIEW to automatically display and monitor the possible faults occurring within the GCPV plant. A LabVIEW VI is also used to log the measured power, voltage and current data for the entire GCPV system.

The main contribution of this work is the development and implementation of a simple, fast and reliable fault diagnosis algorithm for GCPV plants. The statistical *t*-test method is used to determine the location of the fault in the PV system, there is, therefore, no requirement to compare the measured data with a specific simulation threshold as described in Refs. [13,14and16]. In practice, the parallel detection algorithm is capable of localizing and identifying faults occurring in: A PV module in a PV string; Two PV modules in a PV string; A faulty PV string; A Faulty MPPT; Shading effect with faulty bypass diodes; A faulty DC/AC inverter unit and; Data acquisition errors. Fault data analysis is performed using two algorithms operating in parallel:

- Algorithm 1, is implemented to detect faults in the DC-side of the GCPV plant
- Algorithm 2, is implemented to detect faults in the AC-side of the GCPV plant

This paper is organized as follows: Section 2 presents the data acquisition in the GCPV plant. Section 3 describes the methodology used, Fault detection algorithm and diagnosis rules are presented, while section 4 lists the results and discussion of the work. Finally, section 5 describes the conclusion and future work.

2. GCPV plant and data acquisition

The PV system used in this work comprises a grid-connected PV

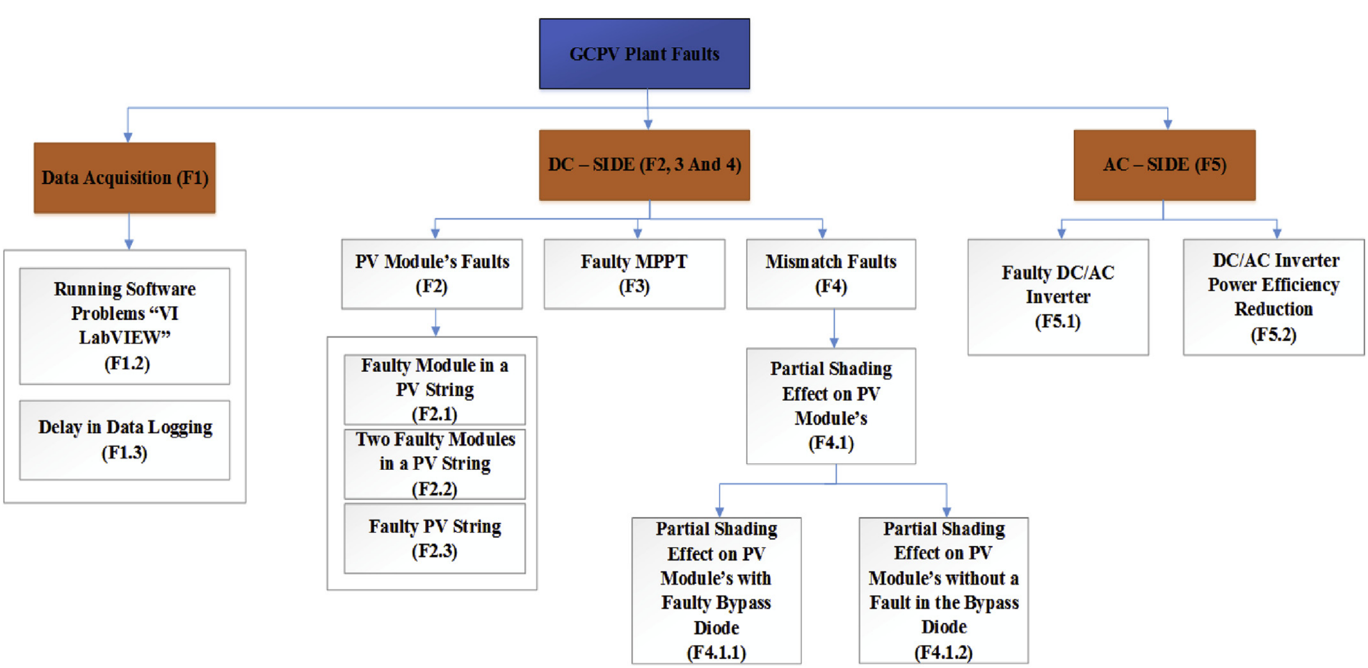

Fig. 1. Different Type of Faults Occurring in the examined GCPV Plant.