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Diagnostic architecture: A procedure based on the analysis of the failure causes applied to photovoltaic plants

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ABSTRACT

Analysis of failure modes and causes and diagnostic architectures are fundamental aspects for plants based on photovoltaic (PV) panel. In fact, for these plants, high level of reliability is necessary in order to operate, without failures, in the time taking into consideration also the typical lifetime of these plants. To this aim the monitoring of both plant parameters and plant performances is a very important task that can be obtained, as presented in this paper, by means of a well-designed diagnostic and monitoring system. This approach allows to improve complex system maintenance policies and, at the same time, to achieve a reduction of unexpected failure occurrences in the most critical components.

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1. Introduction

The problems related to the electrical energy production are becoming more and more important, in particular, in recent years. A more rational use of energy resources or the use of energy production from renewable sources are the strategies typically adopted worldwide, to obtain both the goal of reducing emissions of pollutants and a lower environmental impact. Among the available technologies that play a key role, particularly interesting are: photovoltaic (PV), wind, biomass and fuel cells. In particular, among these photovoltaics had the greatest spread throughout the country. In fact, photovoltaic systems can also be made in small size, can be easily connected to the national grid thus creating a network of Distributed Generation (DG) or used for the production combined with high efficiency, even local, thermal and electrical energy.

The basic element of these systems is the photovoltaic panel, PV panel in the following. This item is definitely very reliable but despite its performance is highly dependent on many factors, it may fail or degrade in several ways. This consideration leads to the necessity to study in detail the performance in terms of both reliability and availability of the plants that are characterized by a return on investment on the time horizon of at least 20 years which not consider the possible operational errors. Already in the early stages of design, reliability problems and potential failures should be suitably considered in order to ensure appropriate countermeasures in a more rapid and less expensive way. The *reliability* can be defined as the capacity of the PV panel to maintain its functionality over time, under specified environmental conditions and use [1]. Indeed, the *maintainability* is the capacity of the PV panel, in given conditions of use, to maintain an operating state in which it can perform the required function, when maintenance is performed in the given conditions and with

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Table 1
Failures frequency [9].

#	Failure subsystem	Frequency, %
1	Inverter	43
2	AC subsystem	14
3	External	12
4	Support structure	6
5	DC subsystem	6
6	Modules	2

appropriate procedures and resources [1]. It can be stated that the assessment of the reliability and maintainability can be made only if the failure modes of the PV panel are known and taken into account in a correct way. The evaluation of PV system long term reliability is mandatory and it should include both a complete and partial outage of the system. In fact, a system working at a level below expectations can be considered in partial outage. For example, a small power loss due to damaged single cell can be considered a failure in PV system. In literature several papers consider the reliability of PV components and in particular that of PV modules [2–8]. A fewer number of publications consider the failures of the overall PV system. In [9], for example, a failure analysis shows that inverters, AC subsystems, support structure, DC subsystems and modules contribute in important but in different way to the PV system failures. Golnas in [9] presents a very interesting analysis of the system reliability starting from the operator's perspective and Pareto's table concerning the frequency of the abnormal state of the failures.

In Table 1 is shown the frequency of failures to be attributed to the subsystems before mentioned [9].

In this paper a detailed review of the most important failure causes of a photovoltaic plant is proposed in order to identify the parameters that have to be monitored. This analysis can be used for the design of a more efficient diagnostic system. The paper deals with topics included in a long term research concerning PV plants composed by set of PV panels, their reliability and modelling as far as the prevision of the energy production [10–23]. This paper is a part of broader research activities carried out by the authors in recent years [10–24].

The paper is organized in the following manner. In Section 2 a PV systems overview is presented. In Section 3 the possible failure causes are discussed. The diagnostic architecture is presented in the following Section 4. Section 5 reports the experimental results and the discussion of the experimental results. Conclusions are finally drawn in Section 6.

2. PV systems overview

The system under study is a grid-connected photovoltaic system with one main inverter. As well written in [9] a PV system can be seen as *"a compilation of systems and components, ranging from simple hardware like wire interconnects to complex units like tracker controllers and inverters, which makes the rigorous treatment of the overall system reliability a challenging task, but one that is essential to the on-going maturation of the industry"*.

It consists, as depicted in Fig. 1 in a simplified way, of three main subsystems, photovoltaic modules connected in series and parallel, power conditioning subsystem that includes inverters and BOS (Balance Of System) subsystem that is composed by generator and module junction box, solar cable connectors, fuses, DC and AC wires, DC and AC switches.

Module junction boxes connect solar cells to the outside world by joining the connection cables of the cell strings and interconnecting them with the bypass diodes. On the other hand, generator junction box consolidates the multiple string cables of the PV generator. Moreover, it includes DC switching contactors and performs protection functions against over voltages by employing string fuses and against lightening through surge suppressors. Mounting structure failures are excluded from the considered system as their contribution to PV plant outages is very small, less than 1% [8]. Besides, string diodes will be out of our scope as well, since grid connected PV are recently built without string diodes to avoid losses associated to their forward bias current. Therefore, current modules, nowadays, can withstand reverse current up to seven times the short circuit one.

3. Failure causes analysis

The reliability model of PV plant can be obtained by dividing the whole system into different functional subsystems, each of which fulfills its respective function. Afterwards, the potential failure causes and sub causes in each subsystem have been identified and described in the following part of this section. Failure causes can be derive from PV modules (as described in Section 3.1), from inverters (as discussed in the following Section 3.2) and, finally, from BOS (as presented in the Section 3.3).

3.1. PV module failure causes

The core of every photovoltaic system is the array of PV modules. The PV modules represent the power generation subsystem and any failure associated with their operation

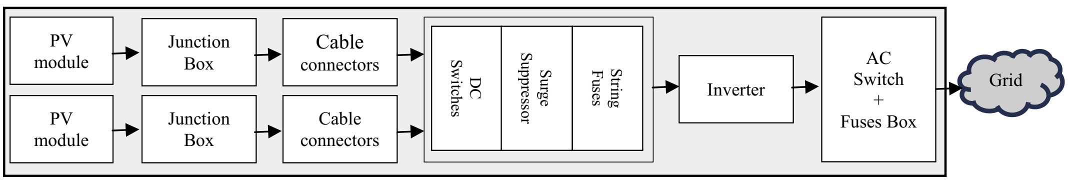

Fig. 1. Simplified schematic diagram of photovoltaic plant.

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