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Optimization of photovoltaic maintenance plan by means of a FMEA approach based on real data

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ABSTRACT

There have been many scientific advances in the improvement of renewable energy systems. Recently, considerable interest has been given to their optimized management during their service life due to a large increase in the number of new renewable energy source power plants. High reliability levels are as important as high yields in order to maximize the useful green energy produced. Solar energy has been one of the most popular and exploited renewable sources in the market and therefore improvements in its efficiency and reliability have had a considerable impact. All energy systems require an increase in their conversion efficiency to reduce the consumption of primary energy. Moreover, the optimization of the performance of photovoltaic systems has increased their incidence as renewable sources in global power generation and has boosted their profitability. A failure of the components and sub-components of a working energy system cause two main issues; the first direct implication for the plant is the damage of the components and sub-components, and the second indirect implication is the consequent lack of energy production due to the plant being out of order. Furthermore, unforeseen failures of the components increase the uncontrollability of photovoltaic power systems, which worsens electric grid dispatching.

The work presented here provides, for the first time, a complete and new assessment of Reliability Centered Maintenance carried out using a failure mode and effect analysis approach to photovoltaic systems. We use a large volume of data derived from a database of real maintenance activities carried out by a multinational company. These data were interpreted by the opinions of experts with specialist experience in the installation, operation, and maintenance of photovoltaic power systems, from small to multi-megawatt size. The present work here has advantages over many previous studies since the information was derived from real experiences of photovoltaic systems which allowed for a more realistic risk analysis and, especially, this information was also used to revise the maintenance plan of photovoltaic installations and to optimize their effectiveness, concentrating on various failure modes which mostly affect production or which can be easily removed/reduced.

1. Introduction

In 2015, 50 GWs of new photovoltaic (PV) systems were installed globally and by the end of 2015, the total installed capacity was 227 GW connected to the electric grid [1]. There has been an increase in the popularity of power systems based on renewable energy sources, especially PV, due to the supporting policies [2,3] and strategies [4] and their feed-in-tariff incentives, with important implications for the investments [5], regarding wind energy [6], biomasses [7,8] solar thermoelectric [9] and, especially, solar photovoltaic [10] using various installations and technologies as integrated in greenhouses [11], large-scale ground-mounted [12], building integrated [13,14] and floating [15]. More importantly, European countries, such as Italy and Germany, now have large enough PV capacities to produce 8% and 7.1% of their annual electricity demands, respectively. PV systems provide approximately 1.3% and 3.5% of the electricity demands of the World and Europe, respectively. Furthermore, the significance of PV technology is not only reflected in the achieved goals but also in the 25% growth rate of the PV market. This has the potential to continually increase the generation of energy and requires additional working energy systems to be connected to the electric grid, including their management and maintenance.

The large size of the power capacity requires functioning plants that will begin to have an even larger impact on the global energy balance in the coming years. The long-term performance of a PV system, with an expected 20–25 years of operation, is one of the most valuable aspects

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Nomenclature

Abbreviations

PV	photovoltaic
IPP	independent power producer
LCOE	levelized cost of energy
t	time
R(t)	reliability (as a function of time)
f(t)	failure density function
h(t)	hazard rate
RCM	reliability centered maintenance
MBS	machine breakdown structure
FMEA	failure modes and effect analysis
RPN	risk priority number
D	detection
O	occurrence
S	severity
CM	corrective maintenance
CMMS	computerized maintenance management system
PID	potential induced degradation

of this sort of energy system, and since commercial contracts are based on assumptions regarding efficient life cycles, these systems are even more appealing [16]. Therefore, the reliability of PV power systems is becoming increasingly important and requires closer examination. In the present work, we will address this issue, and use the opportunity to analyze the risk of failure using the opinions of experts with experience in the maintenance of many PV systems. Furthermore, there is a need in this industry, to find a suitable balance between the savings in the construction of the PV components, such as the modules, and the creation of a reliable power system. It is becoming more apparent to the participants of the PV sector, that increasing the reliability is the most effective way to reduce the LCOE of PV technology.

The Reliability Centered Maintenance (RCM) applied here to the PV systems uses a Failure Modes and Effect Analysis (FMEA) reliability analysis approach which allows the processing of each individual analysis of a system's sub-component. This analysis identifies the various failure modes affecting each part, along with the causes and consequences, and the entire system.

Until recently, the common approach for analyzing the reliability of a PV system was to concentrate on the separate failures of single components or sub-components, with considerable attention given to the modules [17–22] and inverters [23]. However more recently, the reliability of the overall system has been considered [24]. In the previous analyses, the opinions of engineers have been sought who are experts in PV projects and theory, but are not knowledgeable in the operation of PV systems. In the present paper, we consider the opinions of technicians who are experts in the functioning of a PV system. In this study we use data from Solarig, a multinational Spanish company [25] present in 12 countries which has developed and constructed over 300 PV MW globally and with 1.3 GW under operation. The present study uses plants that are installed and under maintenance in Italy, i.e. 18 solar plants which are property of Solarig as IPP and 39 plants which are the property of the customers of Solarig. Therefore, it will be possible to discover new aspects, issues, and solutions observing these

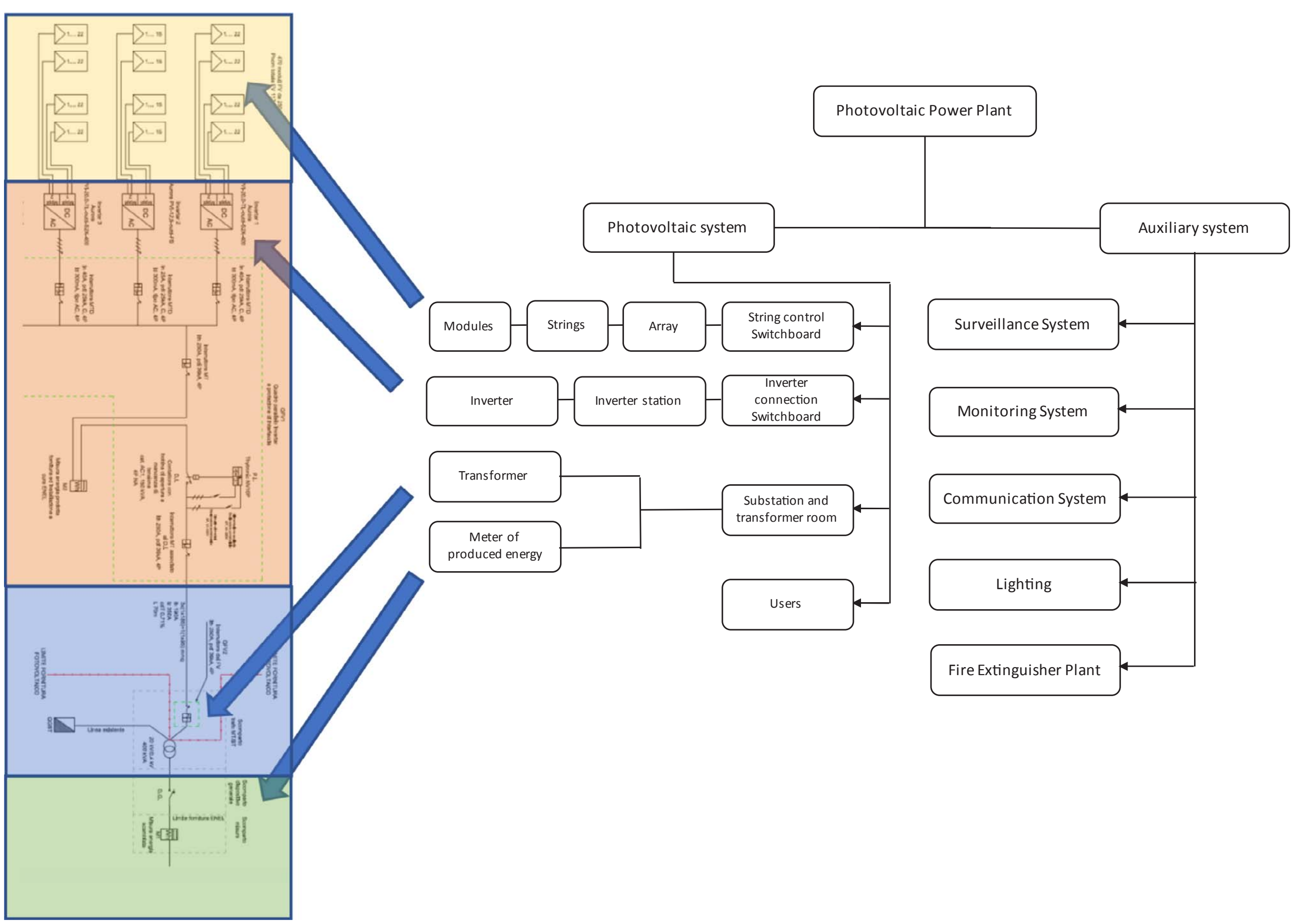

Fig. 1. PV Machine breakdown structure.