

PHOTOVOLTAIC INVERTER: THERMAL CHARACTERIZATION TO IDENTIFY CRITICAL COMPONENTS

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Abstract: The renewable energy industry has been growing remarkably over the last years and the recent Fukushima nuclear crisis has given a further incentive worldwide. In this context, solar radiation represents one of the most accessible and clean energy resources thus the number and scale of photovoltaic (PV) systems installed grows, so does the size of the associated investments, and the related opportunities and risks. It therefore becomes increasingly important for developers and investors the assessment of the quality, reliability and electrical performances of their PV plants. PV systems are highly reliable, but like any complex system, they may fail. Neglecting the effects of those failures may lead to unreasonably optimistic performance and life cycle cost predictions.

In this paper a study of the thermal characterization of a PV inverter is proposed in order to individuate its critical components. The final aim is a proposal of a reliable design solution considering the real condition of use for the plant and, consequently, an improvement of the PV inverter yield. At the same time, the study allows to optimize both the availability and the maintainability of the inverter hence of the whole PV plant.

Keywords: Photovoltaic inverter, reliability, diagnostic, thermal tests, power electronics.

1. INTRODUCTION

Nowadays, energy-related aspects are becoming extremely important. They involve, for instance, a rational use of resources, the environmental impact related to the pollutants emission and the consumption of non-renewable resources. For these reasons there is an increasing worldwide interest in sustainable energy production and energy saving. Among the technologies that could play a role in the generation of sustainable and widespread energy, actually interesting solutions are represented by photovoltaic (PV), wind generators, biomass and fuel cells. In particular, photovoltaic can be considered one of the most widespread

with significant margins of improvement while ensuring the generation of energy with low environmental impact.

To this aim, for the photovoltaic (PV) plant developer, the assessment of the quality, reliability and electrical performances of these equipments is becoming more and more important.

Although the PV system, shown in Figure 1 [1], is considered as a reliable source of electrical energy, field results pointed out that the modules can fail or degrade in a number of ways [1-3].

Looking for the failure data we can deduce that the most widespread of PV system faults are attributed to inverter failures [4–7]. Although a single inverter failure will not typically bring down an entire commercial PV plant, their reliability has a direct effect on plant economics because system availability is a multiplicative factor in energy harvest, just like power conversion efficiency.

In this scenario it's fundamental to guarantee the functionality, the reliability and maintainability performances of the whole plant assuming the central role covered by the inverter. In fact, reliability is an important issue considering also large-scale grid-connected PV systems as their operations rely on business plans developed over periods of time of at least twenty years which often assume fault-free functioning [1]. Already, at the early design steps, reliability issues and potential failures should be addressed. Based on these considerations, it's important to note that recognition of reliability, availability and maintainability (RAM) as factors in the early development of today's complex systems, as a PV inverter, has placed greater emphasis on the application of design analysis procedures to logistics management. By understanding equipment behavior in the intended operating environment, any needed part improvement or review effort can be identified prior to the expensive test, analyze and fix phase of equipment development. The design analysis, also, defines spare parts requirements and allocation of logistics resources to assure that specified RAM requirements will be met in the equipment's actual operating environment.

Taking into account this issues [8-9], the paper focuses the analysis of the critical components of a PV inverter in order to identify a reliable design solution with respect to the

real thermal condition of use. As result, it's possible to achieve an improvement of the PV inverter yield and, also, to optimize both the availability and the maintainability of the equipment-inverter as well as the whole PV plant.

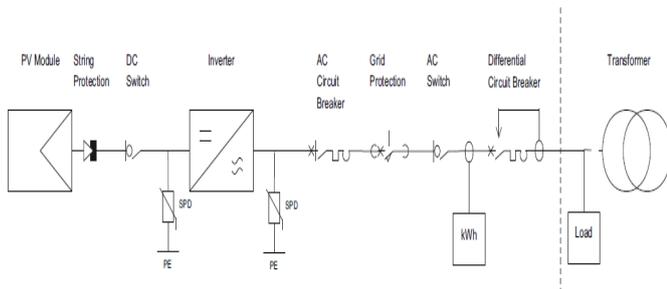


Figure 1. Example of an architecture of a PV system.

2. PV INVERTER RELIABILITY

Electronic devices are characterized by different values of lifetime in function of the environmental conditions of use.

PV plant and, therefore, the inverter are located in some of the harshest environments: wide temperature range, high humidity level (up to 95%) and, often, salty and corrosive conditions (installation in seaside and/or industrial sites).

Reliability performances are correlated to such conditions and the temperature is one of the most important factor. For this reason, a proper thermal distribution on printed circuit board (PCB) is required to provide adequate heat-sinking for the power stage circuitry. Critical heat sensitive circuitry should be relocated to cooler areas on the PCB. In fact, in the PV inverter thermal design and heat extraction mechanisms of the switching components and capacitors have to be analyzed in detail, being such components highly sensitive to temperature.

For a more detailed identification of the critical components of the PV inverter from both the thermal and reliability point of view, the reliability prediction of the system was carried out. The components failure rates are evaluated by means of a reliability prediction handbook and are then optimized by using field data. In particular, for electromechanical and mechanical elements, the Handbook of Reliability Prediction Procedures for Mechanical Equipment [10] are taken into consideration and OREDA Offshore Reliability Data Handbook [11]. For electrical parts, instead, the MIL-HDBK 217 [12] and IEC 62830 [13] have been used. As result, the reliability prediction puts in evidence that the most critical components are the DC capacitors and the insulated-gate bipolar transistors (IGBT), confirming the above notice about thermal design. Thus such components have to be monitored with particular attention in the thermal tests. In Figure 2 the trend of the MTBF (Mean Time Between Failures) for the PV inverter versus the temperature is shown; it highlights the negative effect that it has on the life of the system. In Figure 3 the of the MTBF versus the system electrical stress is presented: it is possible

to see that also in this case the inverter life decreases when the stress increase.

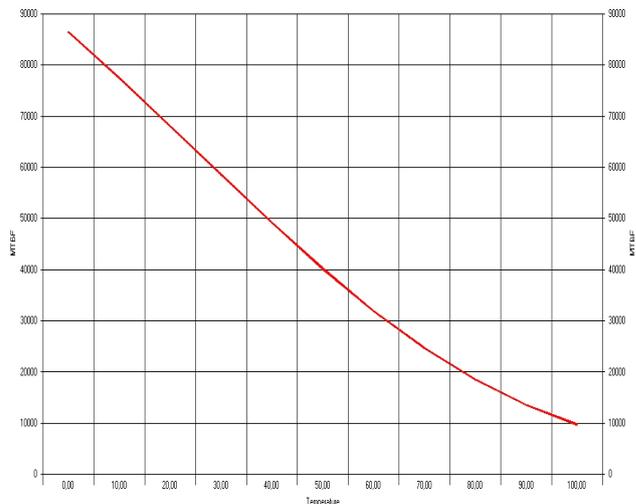


Figure 2. PV inverter MTBF vs temperature.

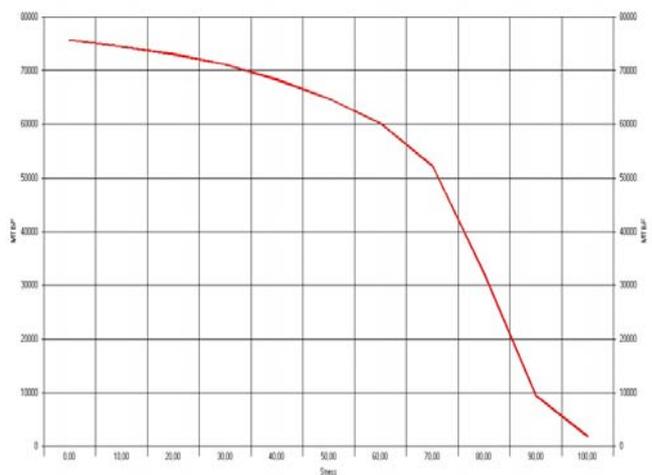


Figure 3. PV inverter MTBF vs stress.

3. THERMAL CHARACTERIZATION OF PV INVERTER

The measurement system used in this work for monitoring the thermal tests is shown in Figure 4. It is carried out using a custom thermal chamber with twenty-five type K thermocouples connected to a Data Logger HP 34470A. The thermal data are acquired and stored by a PC via RS 232. The PV inverter under test is powered and functioning during the test. Also the inverter is controlled by a PC via RS 232.

The custom thermal chamber is self-made and it allows to reproduce the real condition of use of a PV inverter enclosed in a shelter. In this way it's possible to reproduce the stresses in terms of temperature, humidity and heat air flux present in

a real field installation. Only reproducing the real inverter operative conditions is possible to study in detail the device and its components behavior and the data so obtained can be successfully used to optimize the design.

By means of a dedicated thermocouple is possible to monitor the internal temperature that is also acquired by PC.

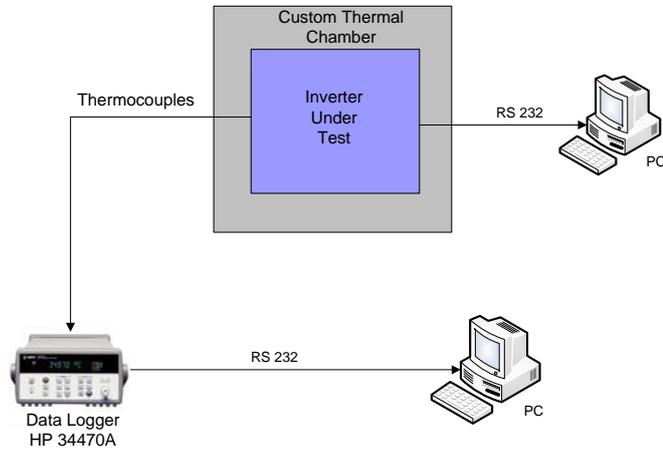


Figure 4. Measurement set-up.

A first thermal test phase was carried out with an internal temperature of the chamber of 50°C. The inverter under test is at the maximum operative temperature with maximum output power in order to put in evidence the behavior of the critical components. In fact, the more significant aspect of the thermal stability of the components is the capability to guarantee a large immunity to over-current operation at high temperatures. Moreover, reliability could be further enhanced by constraining the electrical and thermal stress on components, and protecting critical components from environmental noise and contaminants.

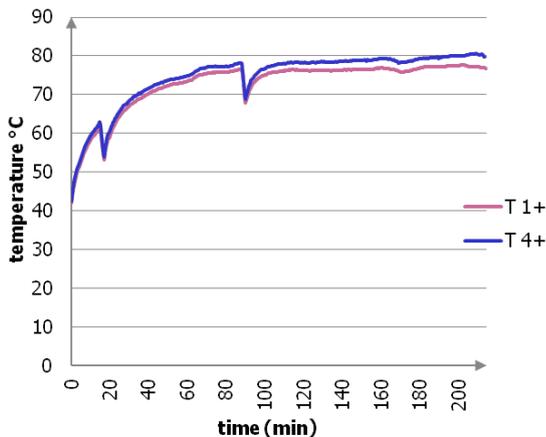


Figure 5. IGBTs temperatures vs time.

In Figure 5, the temperature of IGBTs is plotted. It's possible to observe that no problems are present in the

functioning of the IGBTs but the temperature 80°C could lead to an increase of the temperature of the other internal components.

Figure 6 shows, instead, the temperature trend in function of time of some DC capacitors. It's possible to observe a constant increase of the temperature without a stabilization due to an anomalous behaviors of such devices. This trend represents the typical case of an uncorrected functioning of the inverter with the presence of a thermal escape that could leads to a rupture of the device.

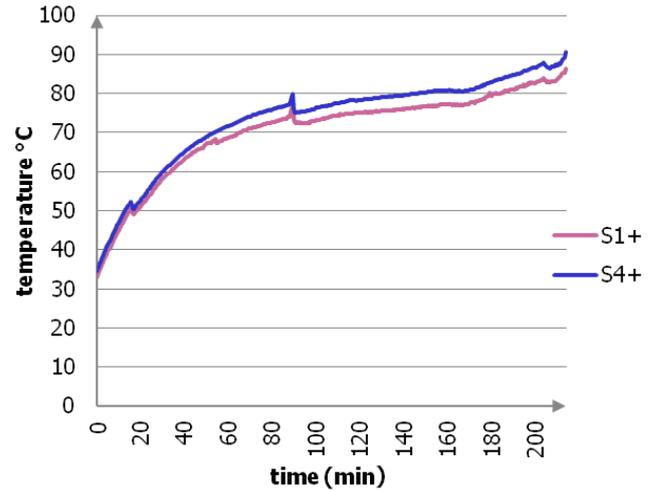


Figure 6. Capacitors temperatures vs time.

Therefore, a design upgrade is necessary to avoid the particular temperature trend in the PCB area where the S-phase capacitors are allocated. In particular, two cooling fans are added and a new hot air paths is provided, as shown in Figure 7.

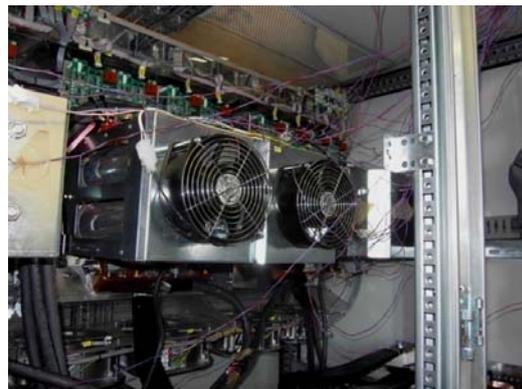


Figure 7. A picture of the new cooling fans.

In Figure 8 the temperature trends of the DC capacitors after the design review is shown. Now it's possible to note a normal trend in function of the time and the temperature is stabilized below 70 °C. In this case the PV inverter is working properly.

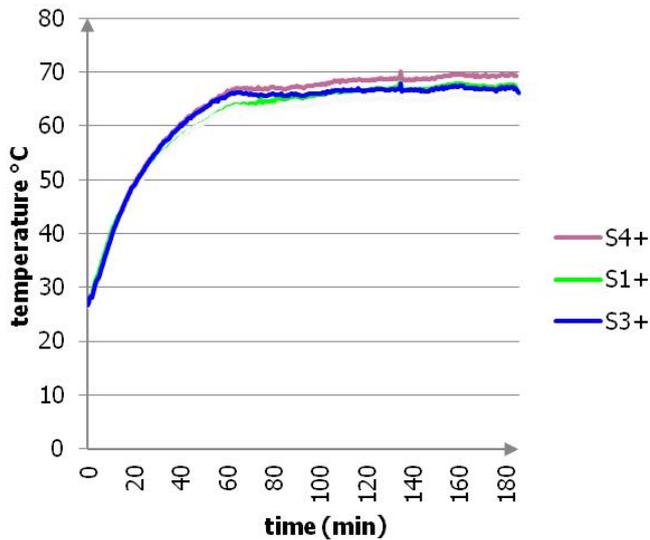


Figure 8. Capacitors temperature vs time after the design modifications.

In Figure 9 the temperature trends of the components present in the logic control unit that controlled the PV inverter is shown. Also in this case the temperature doesn't show any anomalous increase and it is stabilized below 70 °C.

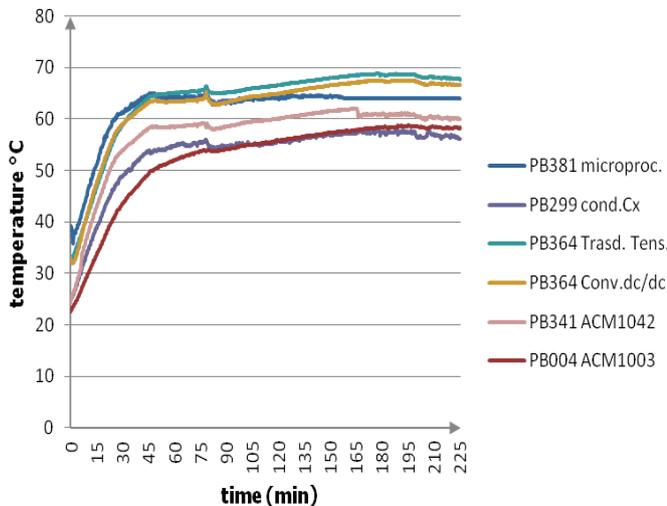


Figure 9. Control Logic Unit boards temperatures vs time.

By using the data obtained from the thermal tests it is also possible to improve the inverter maintainability. This is possible thanks to the combination between the reliability prediction results and the electrical stresses measured taken into account the real operative condition of the inverter. In this way it is possible to provide a preventive maintenance based on a well-defined condition in order to minimize an eventual stop of the PV plant. It would be highlighted that the maintenance is, sometimes, a very expansive operation both from economical point of view therefore any effort to contain these costs is desirable.

4. CONCLUSIONS

Photovoltaic power generation is increasingly contributing to the energy market. PV systems are typically characterized by a long pay-back periods therefore reliability is a fundamental parameter that must be analyzed in detailed. The overall PV system performance penalty due to inverter failures depends on several factors, such as the reliability characteristics of the inverter, inverter configuration and repair time.

The inverter is still considered the weakest link in modern photovoltaic systems. Inverter failure can be classified into three major categories: manufacturing and quality control problems, inadequate design, and electrical component failure.

For the reasons presented above, in this paper a deepened study, from the thermal point of view, of the critical components of a photovoltaic inverter is proposed. In particular, the thermal analysis of the inverter is presented and a series of thermal tests were carried out in order to individuate the most critical components. The aim is to optimize the inverter design and therefore its energy yield taking into account the real operative condition presents when it is installed on the field. In this way, it will be also practicable to optimize the design of the diagnostic system of the PV inverter. Finally, by means of the data obtained with this study it is also possible to improve the maintenance policy of the PV inverter hence its availability and that of the whole PV plant.

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