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Enhancement of the survival probability of a photovoltaic converter–An optimization approach☆

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ABSTRACT

Maximizing the return on investment of a photovoltaic array requires a power electronics converter with the longest possible operational life. This paper is aimed at presenting a heatsink optimization approach to enhance the survival probability of a high-efficiency 1 kW DC/DC converter, specifically designed for PV applications. A main feature of the enhancement is that it takes into account the meteorological characteristics of the intended installation site: a coastal area with high humidity and cloudiness throughout the year.

As a first step, the converter reliability is estimated according to the FIDES procedure, yielding a mean time between failures MTBF = 98.15 FIT. The numerical results pinpoint the diodes as the most failure-prone components, and temperature as the dominant stressor, clearly suggesting that the performance can be improved by resorting to better heatsinks. As a second step, a heatsink optimization problem is established, involving three objective functions: minimization of heatsink thermal resistance and weight, and maximization of the cooling system performance index, The problem is solved using a genetic algorithm, which yields MTBF = 74.09 FIT. The approach takes advantage of the computer tools currently available: mathematical toolboxes to implement the optimization algorithm, user-friendly reliability prediction software, and software packages capable of simulating the thermal behavior of heatsinks with good accuracy.

1. Introduction

Nowadays, the world is becoming more electrified, and the number of renewable energy sources connected to the electric grid is increasing at an accelerated pace. The fast growth in the use of renewable energies has fostered the development of new electronic devices and novel converter topologies, resulting in remarkable efficiency and reliability improvements. In the case of photovoltaic (PV) power plants, a few years ago it was reported that, depending on the installation site and the technology, the energy payback time could range from 0.5 to 2 years. In dire contrast, new technologies, such as fracking, can provide inexpensive natural gas to utilities. This represents a difficult challenge to PV power plants because, in order to be viable, they must generate energy at competitive cost.

One way to achieve competitiveness is by providing lower installation costs, and nowadays the cost of a PV panel is a third of what it was five years ago. A second way is to minimize the losses in PV generation. either by enhancing the efficiency of the

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maximum power point tracking device, or by reducing the losses in the power electronics stage. A third way is to manufacture long-life PV generators. Panels customarily offer operational lives in excess of 25 years, but the same is not true for the power electronics stages. Although several micro-inverters offer 25 years guaranties, many others offer much shorter times.

A common figure of merit in the industry is the mean time between failures *MTBF*. This parameter, however, might be somewhat misleading. If the failure rate λ of an electronic converter is assumed to remain constant throughout the operational life, then $MTBF = \lambda^{-1}$. Reliability as a function of time can be expressed as:

$$R(t) = exp\left(-\frac{t}{MTBF}\right) \quad (1)$$

Therefore, if $t = MTBF$, then $R(MTBF) = 0.37$, meaning that there is a 37% probability that the converter will survive long enough to reach the *MTBF*. A complementary criterion to assess the performance of the converter is the probability that it will survive a desired operation life L_{OP}. From (1), this probability (in percent) is given by:

$$R\ (\%) = \frac{100}{\exp\left[\frac{L_{OP}}{MTBF}\right]} \quad (2)$$

In order to accurately predict the survival probability for a desired L_{OP}, it is necessary first to estimate the *MTBF* of the converter, also as accurately as possible. Once the MTBF has been properly estimated, it is possible to change or adjust the components of the converter in such a way that the survival probability is enhanced.

The first issue is which prediction methodology to use. Many reliability analyses have been reported in the technical literature, following different prediction methodologies (e.g. Mil-Hdbk-217 [1], Bellcore [2], Telcordia [3], RDF 2000 [4], IEC TR 62380 [5], FIDES [6], etc.) and applied to different converters. In most cases, power semiconductors switches (MOSFETs, IGBTs, diodes, etc.) are identified as the most fragile components [7–12], its reliability being greatly affected both by high junction temperatures, and severe thermal cycling related to environmental conditions.

The second issue relates to the environment in which the converter is expected to operate. Power converters in PV applications are exposed to harsh environmental conditions which degrade the useful life of the electronic components. It has been found that, in order to achieve the highest possible availability from power converters aimed at renewable-energy applications, it is essential to define an accurate mission profile [12,16–18]. The mission profile is a representation of all the relevant conditions (including non-operating phases) to which an electronic assembly will be subject to throughout its entire life cycle, taking into account all the stress factors in the application [13]. These include operational stresses such as voltage, current, and switching frequency, and environmental stress factors such as temperature swings, temperature profile, humidity, vibration, etc. For each of the stressors involved in the application, it is important to specify their nature, intensity and duration of exposure. With these details it is possible, within specified accuracy, to calculate the failure rate of each component, and hence the overall MTBF of the converter.

This paper carries out a heatsink optimization procedure to improve and assess the survival probability of a DC/DC converter aimed at PV applications, rated at 1 kW. The converter is intended to be installed in a coastal area where cloudiness and high humidity are prevalent throughout the year. The failure rate is calculated following the FIDES procedure, because it explicitly takes mission profile into account, and includes a step-by-step description of the reliability calculations required for electronic assemblies.

Once the individual failure rates for all the components in the assembly are calculated, those with the highest values are singled out for improvement. The improvement depends on the stress factor with the highest impact on the failure rate, and is treated as a multi-objective problem, which is solved by taking advantage of a metaheuristic algorithm. The performance of the modified converter is afterwards assessed, assuming operational lives from 5 years, and up to 30 years.

The approach takes advantage of the computer tools currently available: mathematical toolboxes to implement the optimization algorithm, user-friendly reliability prediction software, and software packages capable of simulating the thermal behavior of heatsinks with good accuracy.

The design of a power converter is a complex task, usually involving conflicting goals such as efficiency, reliability, weight, size, and price. The design can be treated as a multi-objective optimization problem, and solved using metaheuristic methods, which provide a set of optimal solutions to choose from. Afterwards, the designer selects the solution that best satisfies the requirements of the application [14].

The rest of the paper is organized as follows. Section 2 contains a brief description of the environmental condition in the planned installation site, and the corresponding mission profile. Section 3 lists the electrical and operational characteristics of the converter used as case study. Section 4 includes the reliability prediction results, obtained according to the FIDES guide. The description of the optimization problem, and the algorithm used to solve it, are located in Section 5. The impact of the heatsink optimization on reliability is assessed in Section 6. Finally, the conclusions are presented in Section 7.

2. Mission profile

A mission profile consists of a series of operational phases, and there should be as many as required by the behavior of the stresses on the assembly: chemical, mechanical, humidity, electrical, thermo-mechanical and thermal related. At each phase, the level of each stressor must be properly quantified.

It is assumed that the converter will be located at Ciudad del Carmen (N 18.65, W 91.82, 8 MASL), a coastal city with high saline pollution, and a maximum measured irradiance of 1093 W/m^2. The mechanical stress is null because the converter is permanently