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A study into the impact of the choice of Maximum Power Point Tracking Technique on the Reliablilty of the Power Electronics Interface for Photovoltaic Systems

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Abstract— **Photovoltaic (PV) systems are becoming increasingly common as residential distributed generators, however these systems can be severely limited by the presence of partial shading conditions (PSC). When bypass diodes are installed in the system to mitigate the impact of PSC, the Power-Voltage (P-V) characteristics become more complex and multiple maxima are observed. This has necessitated the development of advanced Maximum Power Point Tracking (MPPT) techniques. Advanced MPPT techniques can increase power capture under PSC, however their impact on the reliability of power electronics interfaces is not yet fully understood. This paper will present a preliminary study into the reliability implications of the choice of MPPT method on diodes in a power electronics interface. The preliminary results indicate that the choice of MPPT method may affect the reliability of the power electronics interface as evidenced through large changes in the simulated junction temperature of the diode due to power losses.**

Keywords—photovoltaic, maximum power point tracking, reliability

I. INTRODUCTION

As consumers become more aware of the environmental implications of conventional means of generating electrical energy and seek to reduce their power costs, residential Photovoltaic (PV) system installations have become more common all around the world. PV systems installed as residential distributed generators often experience partial shading conditions (PSC) due to the presence of obstacles such as trees, other houses and structures in the local environment [1], [2].

PV modules have a non-linear Power-Voltage (P-V) and current-voltage (I-V) characteristic which becomes increasingly complex under PSC when bypass diodes are included across the modules. PSC increase the complexity in identifying the point that corresponds to maximum power as there may now be multiple possible maxima. Maximum Power Point Tracking (MPPT) techniques are developed to enable PV systems to operate at their optimal power under changing environmental conditions. The PV system is incredibly sensitive to environmental conditions including incident irradiance on the panels and panel temperature [3]. Incident irradiance can change very quickly with the shadow from cloud speed varying greatly and having an average speed of 13 m/s [4]. The shading phenomena from objects around the PV system is much slower [5] with the shadow projection for static objects changing with the movement of the sun in the sky of, on average, 15°/hour (or 0.00417 °/second).

Most PV systems need to have a power electronics interface between the PV modules and associated load/grid in order to ensure that sufficient voltage is provided to the load and also to control the power available from the PV modules. This can include DC-DC converters and inverters and is where MPPT techniques are implemented.

Conventional MPPT techniques are usually based on a hill climbing method where samples are taken in sequential steps to a maximum [6]. These techniques however, are unable to identify if a located maximum is in fact the global maxima or a local maxima. Advanced MPPT techniques have been designed to distinguish between local and global maxima. Where conventional techniques involve small sequential steps in the duty cycle of the system, the techniques designed for PSC often involve an initially rapidly changing system duty cycle as the method searches the space, such as that involved in Particle Swarm Optimization (PSO) [7] and Simulated Annealing (SA) [8]. These techniques have good performance in locating a global maximum quickly, however rely on widely searching the P-V space.

This paper explores the interaction between the choice of MPPT technique and the reliability of the converter. The application of how the duty cycle changes in the applied technique and any potential impacts this has on the elements of the converter are of interest.

The reliability of the diode is considered in this paper extending work that has been done previously in considering the capacitor reliability and the implication of the choice of MPPT method [9]. In the study of the capacitor reliability the concept of mission profiles [10] was applied and extended to include the MPPT method as a kind of mission profile [9]. Mission profiles describe the conditions experienced by an element and can include temperature and irradiance. The diode has been selected as an element of interest as it will have a longer conduction time than the IGBT in a DC/DC boost converter and so will potentially experience more stress due to the mission profile [11]. PV modules are shown to have a long life-time, typically 20 to 25 years with a mean time between failures (MTBF) of 520 years [12], while the power electronics interfaces have a much shorter lifetime of 5 to 10 years with MTBF of 1 to 16 years [12]. Improving the reliability of the converter or understanding the impact of the choice of MPPT method on the converter is an important step in understanding the full system operation.

The remainder of the paper is organized as follows. Section II will further introduce MPPT including key techniques utilized in this study, Section III will explore the reliability concepts utilized in the study, Section IV will present the simulation model and method of the study. Results and analysis are presented in Section V, while conclusions and recommendations for future work are given in Section VI.

II. MAXIMUM POWER POINT TRACKING TECHNIQUES

MPPT has been extensively studied in the literature with over 30 distinct techniques proposed ranging from simple techniques to complex techniques designed for PSC [13]–[15]. Among these techniques a simple classification strategy is to split the techniques into:

1. Simple techniques – often referred to as conventional MPPT, these techniques are designed to work quickly and efficiently under uniform conditions. Some common examples include Perturb and Observe (P&O), Incremental Conductance (IncCond), Fractional Open-circuit voltage and short-circuit current [16], [17].
2. Complex techniques – techniques with increased complexity are often designed to handle the case of PSC on the PV modules and could involve hybrid techniques where the performance of a conventional technique is improved (such as two-stage implementations [18]), or techniques designed specifically for PSC, such as PSO, Grey Wolf optimization, firefly optimization and SA [19]–[22].
3. Power electronics-based approaches – where changing the system configuration such as using distributed converters on each module with simple MPPT techniques can reduce the impact of PSC across the system but not within modules. Common approaches include Distributed MPPT (DMPPT), differential power processing (DPP) and reconfigurable arrays [23]–[25].

The approaches of interest in this study are simple and complex MPPT techniques. Power electronics based approaches to improve energy capture are outside of the scope of this paper. The characteristics of simple and complex MPPT techniques with respect to their searching process is quite different. In a simple P&O based technique the duty cycle is progressively increased by small increments until it starts to oscillate around a local optimum point. When an advanced technique such as PSO or SA is implemented the duty cycle is no longer changed in small regular steps but has irregular changes in step size based on the progress of the search. Assuming the same frequency is applied in both cases to the change in duty cycle, this paper seeks to explore the impact that the application of different techniques has on the reliability of the diode.

The two techniques implemented in this paper are P&O and SA, a brief description of each follows.

P&O is a conventional MPPT method which involves progressively taking steps in the voltage (or duty cycle) of the converter and observing the change in power [26]. If the change in power continues to increase, steps will continue to be applied in the same direction. In the case that a power decrease is observed then the step direction will be reversed. Depending on the step size chosen in P&O it may either quickly track to the MPP and then oscillate around this point or track slowly and have minimal oscillation around the MPP. P&O in its standard implementation cannot distinguish between global and local peaks.

SA is a more complex MPPT method which is designed to achieve global MPPT. This approach is based on emulating the process of annealing in metals in finding a particular energy state [22]. SA is implemented by sampling points and keeping a record of the best point, whether or not to accept a new sampled power as the best point is largely determined by whether it has larger power than the previous best point, however it may also be accepted in some cases with lower power based on the acceptance probability threshold. In searching the SA method is guided by a simulated temperature parameter, and can also be enhanced with adaptive neighbourhood sizes or different cooling functions [27].

These two techniques represent very different approaches to achieve MPPT and will present to the converter in terms of duty cycle in quite different ways. For this purpose, these techniques have been selected for investigation in this study in order to assess if the choice of MPPT method has any influence on the reliability of the diode in the DC/DC power converter.

III. RELIABILITY CONCEPTS

The concept of a mission profile being applied to the power electronics interface to establish the reliability of that interface is a common approach for studying the reliability [10]. Common mission profiles studied include temperature and irradiance. In this paper we extend the idea of mission profiles to include the type of MPPT technique as a type of mission profile in a similar approach to that adopted in [9].

Considering a simple DC-DC converter shown in Fig. 1 (boost converter), there are a number of elements including capacitors, inductor, switch and diode. This project investigates the impact of the choice of MPPT technique as a mission profile on the reliability of the diode. The results

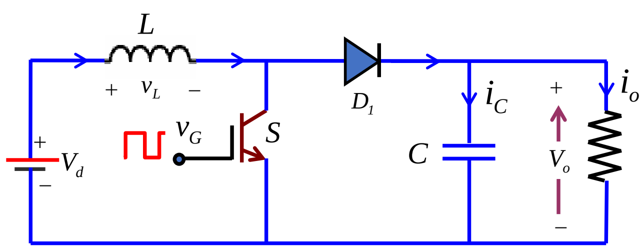


Fig. 1. DC-DC boost converter circuit

explore if the diode is susceptible to damage from the choice of MPPT technique and the possible implication this has on converter lifetime.

An element will fail when a situation occurs that causes the loading on the element to exceed the designed strength. This could be related to voltage, cyclic load and temperature [28]. For a diode, the temperature is the main factor which affects the reliability [29]. This diode temperature can be related to the mission profiles that the diode is exposed to.

The junction temperature of the diode can be calculated from [30]:

$$Tj(t) = Z_{(j-c)}(t)P_{D_{loss}} + T_{c-a}(t) + T_a(t) \qquad (1)$$

Where, $T_{c-a}(t)$ can be assumed to be constant at 15°C, $T_a(t)$ is the ambient temperature, and $Z_{j-c}(t)$ is the junction to case thermal impedance. Diode power loss can be calculated from [29]:

$$P_{D_{loss}} = i_D^2(t)r_D + i_D(t)v_F \qquad (2)$$

Diode resistance of 0.001 Ω and forward voltage of 0.8 V are used in the analysis.

IV. SIMULATION MODEL

To assess the reliability implications of the choice of MPPT technique a simulation model has been constructed in Matlab/Simulink. This simulation model contains PV modules connected to a DC/DC converter and then into a constant source representing a connection to the larger utility grid. A block diagram of the system is shown in Fig. 2.

The irradiance input to the model is based on idealized conditions. Voltages and currents across and through the diode are monitored throughout the simulation to enable the reliability to be calculated. P&O and SA-based MPPT techniques are implemented in the simulation for the same environmental conditions enabling the impact of the MPPT technique on the junction temperature of the diode to be observed.

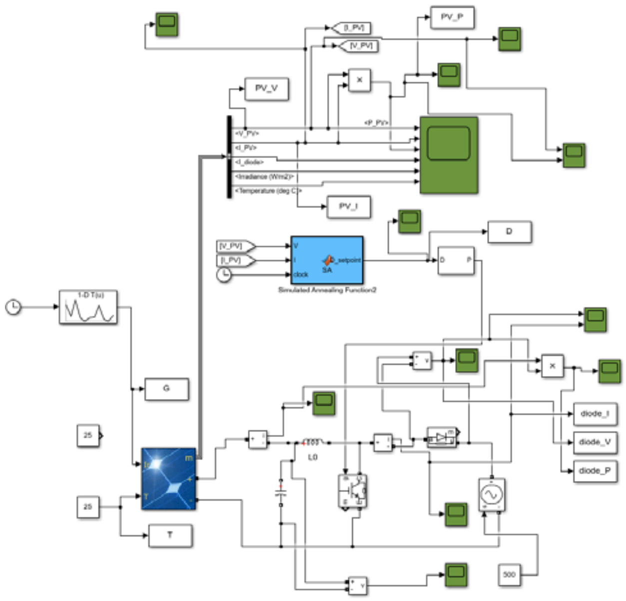


Fig. 2 Simulation model with the SA-based MPPT method

The simulation executes the operation of the PV system with MPPT techniques for given environmental conditions and then calculates the power loss over a switching period using (2). The power loss is then used in (1) to determine the junction temperature. Peaks and valleys in the junction temperature are then evaluated and ΔT_j can be determined. For each instance, the histogram of ΔT_j, average, minimum and maximum values of T_j are recorded enabling comparison between the potential impact on reliability that the choice of MPPT method will have on the diode.

V. RESULTS AND ANALYSIS

Twenty different irradiance profiles have been applied in the simulation model. These vary from uniform conditions, to linearly varying irradiance which is both increasing and decreasing. Cases 1-4 involve uniform irradiance across the full 10 seconds of simulation, Cases 5-10 represent linearly decreasing and increasing irradiance profiles which have been manually generated, and cases 11-20 involve randomly generated irradiance profiles.

Fig. 3 shows the average power loss in the diode recorded for each simulation case for the SA based MPPT and P&O MPPT. These results show that on an average basis the P&O method typically had greater power loss in the diode for the cases considered.

The changes in the junction temperature for each method and each case are shown in Fig. 4. These results show that the SA-based MPPT experiences much more significant variations in the junction temperature due to the searching nature of the method. This suggests that advanced techniques such as SA which search the P-V characteristic extensively and that are designed for application in PSC may cause additional stress on converter elements, including the diode, leading to reduced reliability of the power electronics interface.

An example of the histogram plots produced for one case study is shown in Fig. 5 (linearly decreasing irradiance from 1000 W/m2 to 600 W/m2). This shows that the change in ΔT_j between peaks is typically smaller in the P&O implementation than the SA implementation.

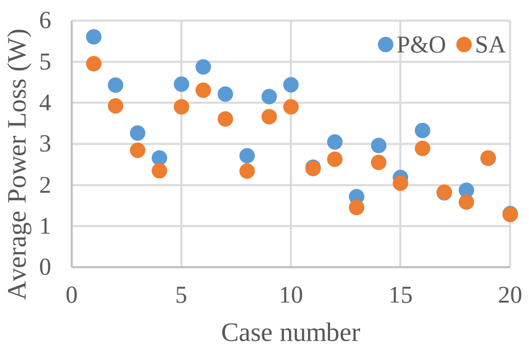
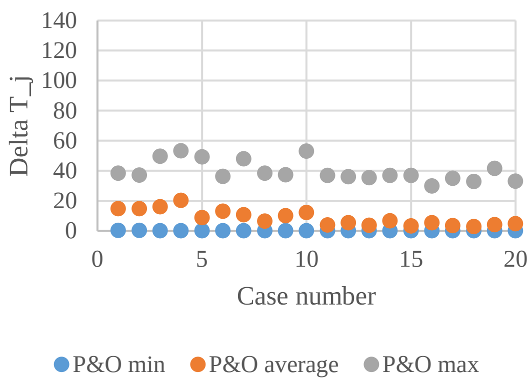
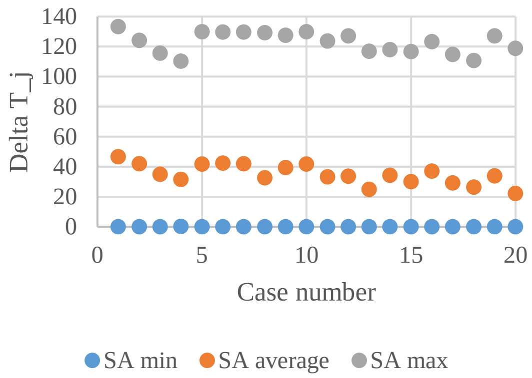


Fig. 3 Average power losses in the diode for each case with the two MPPT methods



(a) P&O



(b) SA

Fig. 4 ΔT_j characteristics for the two MPPT methods tested

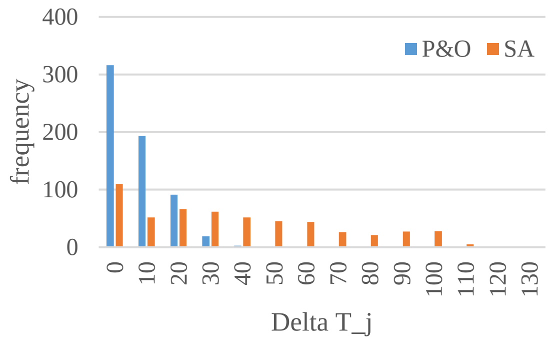


Fig. 5 Example histogram plot showing difference in characteristics of ΔT_j for P&O and SA-based implementations

VI. Conclusions and Future Work

The preliminary results presented show that the reliability of the diode as indicated by the variation in the junction temperature is affected by the choice of MPPT method. Future work will involve extending the analysis to lifetime prediction and considering the effect of a wider variety of MPPT techniques.

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