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Mission Profile-based Accelerated Testing of DC-link Capacitors in Photovoltaic Inverters

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***Abstract*—The dc-link capacitor is considered as a weak component in Photovoltaic (PV) inverter system and its reliability needs to be evaluated and tested during the product development. Conventional reliability testing methods do not consider the real operating conditions (e.g., mission profile) of the dc-link capacitor during the test. Therefore, the validation of the reliability performance of the dc-link capacitor under its mission profile is still a challenge. To address this issue, a new reliability testing concept for the dc-link capacitor in PV inverters is proposed in this paper. In contrast to the conventional method, the proposed reliability testing method realizes the test profile through the modification of the original mission profile (e.g., solar irradiance and ambient temperature) in order to maintain the test condition as close to the real application as possible. A certain acceleration factor is applied to the solar irradiance amplitude and the ambient temperature level during the mission profile modification in order to increase the thermal stress of the dc-link capacitor during test, and thereby effectively reduce the testing time. The results show that the testing time can be reduced to 2.5 % of the real field operation lifetime, if the solar irradiance amplitude is increased by 20 % and the ambient temperature is elevated to 75 °C.**

***Index Terms*—Reliability, accelerated testing, mission profile, capacitors, PV inverters.**

I. Introduction

Reliability is one of the key performance metrics of inverters for Photovoltaic (PV) applications, and the demand has been continuously increasing, e.g., from the current lifetime expectation of 10-15 years to 20-30 years in the near future [1]. Some field experiences have indicated that PV inverters are responsible for a large share of failure events and being one of the weakest components in a PV system [2]–[4]. Such failure events can contribute to a significant loss of revenue for the PV system owner, which is mainly due to the loss of energy yield during the downtime period of the PV power plants, but also due to the cost of inverter replacement. In order to ensure the reliability performance and to avoid unexpected failures of the PV inverters, the reliability evaluation and testing are vital during the product design and the development of them.

Among other components in PV inverters, the dc-link capacitor is one of the reliability-critical components that is highly stressed during the operation and thus it has been witnessed a high failure rate [5]–[7]. Typically, the aluminum electrolytic capacitors are adopted for the dc-link application due to their high capacitance [4], which usually gives a lower cost and volume compared to the other capacitor technologies. During the operation, the ripple current in the capacitor will inevitably induce power loss, leading to an increase in the core temperature of the capacitor (i.e., hotspot temperature) [8], [9]. Besides, the environmental condition of the installation site such as the ambient temperature can also affect the hotspot temperature of the capacitor during the operation, especially for the PV inverter with an outdoor installation (e.g., micro-inverter and string-inverter applications). The increase of the internal hotspot temperature of the aluminum electrolytic capacitor is one of the major stress factors that leads to electrolyte evaporation and contaminant. This will accelerate the wear-out of the capacitor, and thus decrease the capacitor lifetime and its reliability [10], [11]. Therefore, the reliability of the dc-link capacitor in PV inverters have been investigated in several aspects such as design for reliability [12], lifetime analysis [13]–[15], as well as testing [16].

Conventionally, the reliability testing of the dc-link capacitor in the PV inverter is done at the component level under a constant loading condition, e.g., constant high temperature and voltage [11], [17]. Afterwards, the lifetime model of the capacitor with respect to the stress factors (e.g., temperature and voltage) can be obtained, and this information is normally given by the capacitor manufacturer [10], [11]. Then, the reliability of the dc-link capacitor under real operating condition, referred to as mission profile (e.g., solar irradiance and ambient temperature), is evaluated through analytical calculations [6]. However, in this approach, the validation of the reliability performance of the dc-link capacitor under the mission profile is very challenging. Since the lifetime expectation of the PV inverter is relatively long (e.g., more than 10 years) compared to the product development cycle, testing the PV inverter under the real mission profile is usually not possible, as the testing time can be very long until a certain degradation can be observed. Accordingly, there is a gap between the reliability evaluation and the validation of the dc-link capacitor considering the mission profile. To the authors best knowledge, this issue has not been solved yet.

In previous studies, several testing concepts have been proposed for evaluating the reliability of the component in the power converter (e.g., capacitors and power devices) through experiments under operating conditions close to the real application (e.g., mission profile). One of the early attempts to test and evaluate the reliability of the dc-link

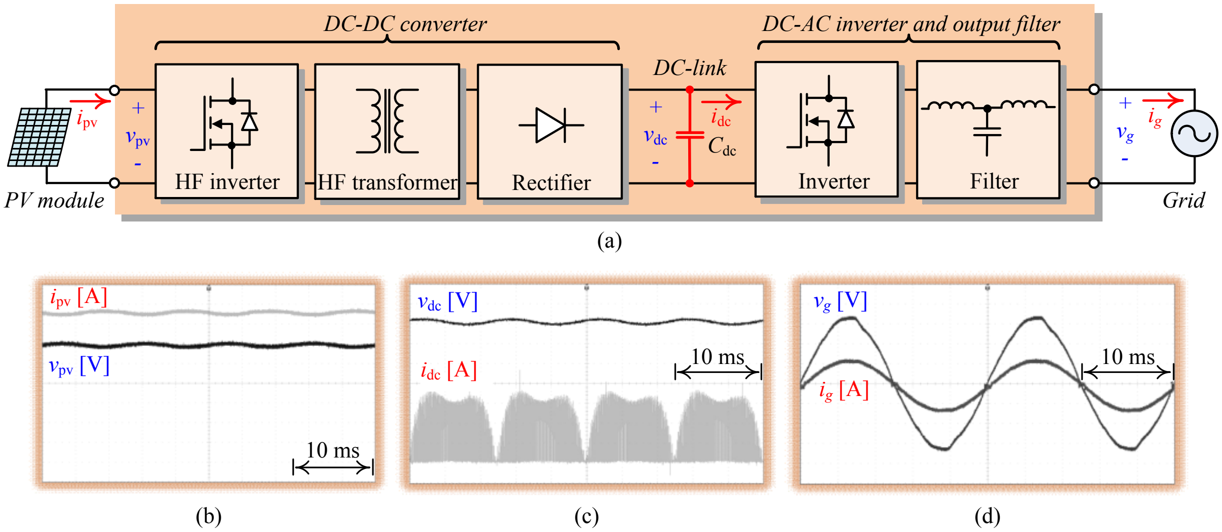

Fig. 1. A two-stage PV inverter where the dc-link capacitor C_{dc} acts as an energy buffer between the dc-side and the ac-side: (a) system diagram, (b) PV output voltage v_{pv} and current i_{pv}, (c) dc-link voltage v_{dc} and current i_{dc}, (d) grid voltage v_g and current injected to ac grid i_g.

capacitor by considering the real application was discussed in [16], where the dc-link capacitor is stressed by operating the power converter with pulse-width modulation. However, the loading condition of the power converter during the test has been simplified (e.g., constant ripple current), which does not closely represent the mission profile of the PV application (e.g., dynamic loading condition). Recently, a reliability testing method has been applied to the PV inverters in [18], where standard accelerated testing methods (e.g., thermal cycling, damp heat, high temperature, and grid transient) are applied. Nevertheless, the mission profile of the PV system was not considered during the test. In [19], a mission profile-based accelerated test method has been applied to the power devices in PV inverters. However, the correlation between the real mission profile and the testing profile is not clearly discussed. In other words, a method to design the test profile from the real mission profile is still not yet defined.

In order to address the above challenges, a mission profile-based accelerated testing of the dc-link capacitor in PV inverters is proposed in this paper. The proposed testing concept modifies the real mission profile of the PV system (e.g., solar irradiance and ambient temperature) in a way to accelerate the degradation process of the dc-link capacitor while maintaining the operating condition close to the real application. The rest of this paper is organized as follows: A system description of the PV inverter employed in the test is provided in Section II. Then, the thermal modeling and reliability evaluation methods of the dc-link capacitor are discussed in Section III. Afterwards, the proposed mission profile-based accelerated testing concept is presented in Section IV, where the possibilities for modifying the solar irradiance and ambient temperature during the test are explored. A guideline for designing the test profile is provided in Section V, where the results show that the required testing time can be reduced to 2.5 % of the real field operation lifetime, if the solar irradiance amplitude is increased by 20 % and the ambient temperature is elevated to 75 °C. Finally, concluding remarks are given in Section VI.

TABLE I
PARAMETERS OF THE TWO-STAGE PV INVERTER (FIG. 1).

Input voltage range v_{pv}	10-60 V
Rated power	300 W
Switching frequencies	DC-DC converter: 105 kHz, DC-AC inverter: 20 kHz
DC-link capacitor C_{dc}	150 μF, 500-V electrolytic capacitor
LCL-filter	L_{inv} = 2.6 mH, L_g = 1.8 mH C_f = 470 nF
Grid nominal voltage (RMS)	V_g = 230 V
Grid nominal frequency	ω_0 = $2\pi\times50$ rad/s
Peak efficiency of power circuit	96.2 %
Peak MPPT efficiency	99.5 %

II. PHOTOVOLTAIC INVERTERS

A. System Description

A PV inverter is used to convert the dc power generated by PV module into the ac power and deliver it to the grid [20]. One of the commonly used system architecture is the two-stage PV system as shown in Fig. 1, where the two power conversion stages are used: 1) the dc-dc converter and 2) the dc-ac inverter. In this configuration, the dc-dc converter is responsible for extracting the power generated by the PV module with the Maximum Power Point Tracking (MPPT) operation. It is also required to convert the PV module output voltage v_{pv} (e.g., 10-60 V) to a regulated dc-link voltage level v_{dc} (e.g., 400 V). Then, the dc-ac inverter converts the extracted dc power into the ac power and delivers it into the grid. The system parameters of the two-stage PV inverter used in this paper are given in Table I.

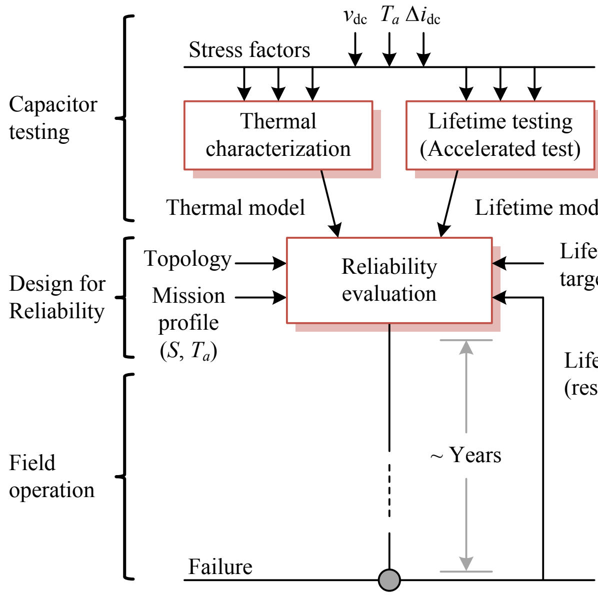

Fig. 2. Conventional method to evaluate the reliability of the dc-link capacitor (e.g., aluminum electrolytic capacitor) during the design phase of PV inverters.

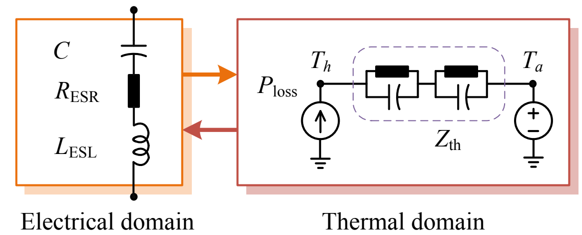

Fig. 3. Electro-thermal model of the electrolytic capacitor, where C is the capacitance, R_{ESR} and L_{ESL} are the equivalent series resistance and inductance, P_{loss} is the power loss, T_h and T_a are the hotspot and ambient temperature, and Z_{th} is the thermal impedance.

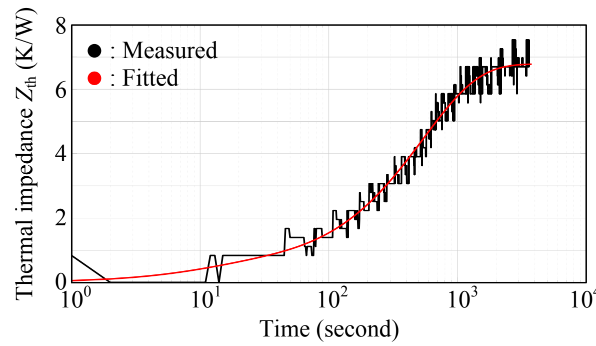

Fig. 4. Thermal impedance of the dc-link capacitor Z_{th} characterized by applying a current ripple of 2 A (RMS) with the frequency of 100 Hz.

B. Design of DC-link Capacitor

Between the two power conversion stages, the dc-link capacitor is required to maintain a relatively constant dc-link voltage. Inevitably, the instantaneous power from the single-phase ac grid induces the double-line frequency (e.g., 100 Hz) power fluctuation to the dc-side. This double-line frequency power oscillation needs to be suppressed at the dc link to ensure the tracking performance of the MPPT algorithm [7]. Therefore, the dc-link capacitor of the single-phase system is normally designed according to the dc-link voltage ripple Δv requirement as

$$\begin{aligned} C_{\mathrm{dc}} &= \frac{P_{\mathrm{pv}}}{\omega_0 \cdot \Delta v \cdot v_{\mathrm{dc}}} \\ &= \frac{300}{(2\pi \cdot 50) \cdot (0.04 \cdot 400) \cdot 400} \approx 150\ \mu\mathrm{F} \end{aligned} \tag{1}$$

where P_{pv} is the rated output power, ω_0 is the grid nominal frequency, and v_{dc} is the nominal dc-link voltage [12].

III. Reliability Modeling of DC-link Capacitors

In this section, a conventional method to evaluate the reliability of the dc-link capacitor in a PV inverter is discussed. A general diagram of the assessment procedure is illustrated in Fig. 2, which includes the characterization of the capacitor in terms of thermal and lifetime modeling as well as reliability evaluation based on the mission profile.

A. Thermal Modeling of DC-link Capacitors

Since the thermal stress is one of the dominant factors that accelerates the degradation process of the electrolytic capacitor, it is necessary to model the thermal characteristic of the dc-link capacitor in order to assess its reliability. The thermal behavior of the dc-link capacitor can be modeled with a thermal network as it is illustrated in Fig. 3. During the operation, the ripple current in the capacitor Δi_{dc} will inevitably induce power loss P_{loss} due to the equivalent series resistance R_{ESR}, causing the internal temperature T_h to rise according to the thermal impedance [12]. The thermal impedance of the capacitor Z_{th} can be measured from an experiment for a given power loss (e.g., dissipated in the equivalent series resistance) and ambient temperature T_a as discussed in [21]. When the supply of the power loss (e.g., the ripple current injection) is removed, the cooling behavior of the dc-link capacitor will represent the thermal impedance. The thermal impedance of the dc-link capacitor used in this paper is obtained as

$$Z_{\mathrm{th}} = 6.3 \cdot (1 - e^{(-t/543.3)}) + 0.483 \cdot (1 - e^{(-t/10.06)}) \tag{2}$$

which is based on fitting the measurement result in Fig. 4 with the Foster's thermal network.

B. Lifetime Modeling of DC-link Capacitors

In general, the hotspot temperature and the applied voltage are the two main stress factors that accelerate the degradation process of the electrolytic capacitor [8]. These stress factors lead to the acceleration of the chemical process (e.g., electrolyte evaporation), which consequently results in the decrease of the capacitance C and increase of the equivalent series resistance R_{ESR}. For the electrolytic capacitor, the reliability testing is normally done by applying a relatively high constant operating temperature and voltage [17] in order to

TABLE II
PARAMETERS OF THE LIFETIME MODEL OF A CAPACITOR [24].

Parameter	Symbol	Value
Rated lifetime (at V_0 and T_0)	L_0	5000 hours
Rated operating voltage	V_0	500 V
Rated operating temperature	T_0	85°C

accelerate the degradation process of the capacitor. Afterwards, the lifetime model of the capacitor with respect to these stress factors can be obtained as given in the following

$$L_f = L_0 \times 2^{\frac{T_0 - T_h}{10}} \times \left(\frac{V}{V_0}\right)^{-5} \quad (3)$$

where L_f is the lifetime under the thermal and electrical stresses T_h and V (e.g., real operating condition), L_0 is the lifetime under the reference temperature T_0 and the nominal voltage V_0 [22]–[24]. The lifetime model parameter of the capacitor used in this paper is specified in Table II.

For the dynamic operating condition (e.g., mission profile), the Miner's rule can be employed to accumulate the damage occurred during the operation [25], which is calculated as

$$D = \sum_i \frac{l_i}{L_{\text{fi}}} \quad (4)$$

in which l_i is the time duration when the capacitor operates at a specific hotspot temperature T_h and voltage V while L_{fi} is the time-to-failure calculated from (3) at that specific stress condition. The lifetime of the capacitor is then determined when the damage is accumulated to D = 1.

C. Design for Reliability of DC-link Capacitors

Once the thermal model and the lifetime model of the dc-link capacitor have been obtained, the design for reliability approach can be applied in order to ensure the reliability performance of the dc-link capacitor under a given mission profile. Normally, the mission profile needs to be converted into the loading condition of the capacitor (e.g., power losses). This calculation requires the knowledge of the topology and operation of the PV inverter, as discussed in Section II. Then, the obtained power loss profile is applied to the thermal model in order to estimate the hotspot temperature of the capacitor during the operation. Afterward, the lifetime of the dc-link capacitor can be estimated from the lifetime model together with Miner's rule for accumulating the damage during the entire operation (e.g., mission profile). If the estimated lifetime is below the lifetime target, either the capacitor or the overall PV inverter needs to be re-sized.

However, the validation of the design for reliability approach discussed above is very challenging. More specifically, it is very difficult to experimentally validate if the lifetime of the dc-link capacitor can be achieved in the real operation according to the estimation, especially with a limited testing time. Typically, the reliability-related tests after the design phase are more relevant to the qualification of the PV inverter. Thus, very limited information about the wear-out lifetime can

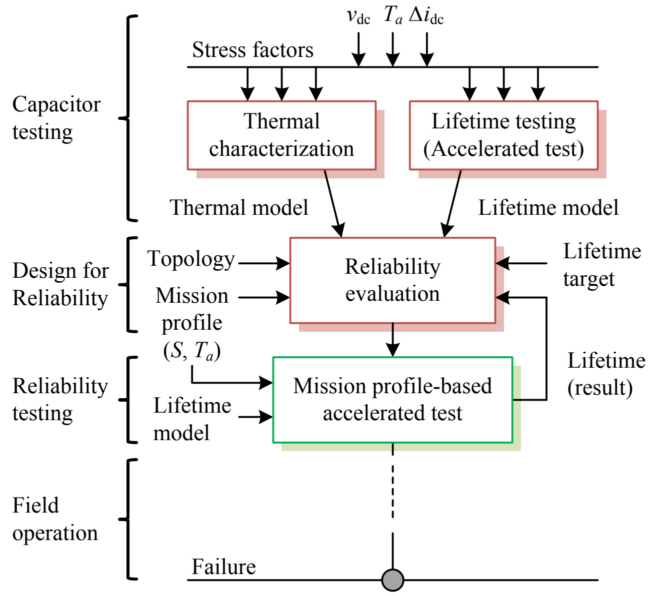

Fig. 5. Proposed method to evaluate the reliability of the dc-link capacitor in PV inverters through the mission profile-based accelerated testing.

be obtained, especially when considering the operation under the specified mission profile. In many cases, the failure from field operation is the only indicator of the real lifetime of the component, but this information can normally be obtained after certain years of operation while the product development cycle is typically limited to a few months.

IV. PROPOSED MISSION PROFILE BASED ACCELERATED TESTING METHOD FOR CAPACITORS

To address the challenge discussed previously, a new reliability testing method for the dc-link capacitor in the PV inverter is needed. The requirements of such test method are

- The degradation process of the dc-link capacitor should be accelerated during the test
- The dc-link capacitor should be stressed under the operating condition close to the real mission profile

If the above targets are achieved, the reliability performance of the dc-link capacitor in the PV inverter can be validated, and the obtained results can be used for improving the design during the product development cycle, as it is shown in Fig. 5. In the following, the mission profile-based accelerated testing of the dc-link capacitor in the PV inverter is discussed.

A. Methodology

One possibility to maintain the stress condition of the dc-link capacitor during the test similar to that in the real application is by realizing the test profile through the modification of the original mission profile. Afterwards, the modified mission profile can be applied to test the prototype of the PV inverter, and the degradation of the dc-link capacitor can be measured. The concept of the proposed mission profile-based accelerated testing of dc-link capacitor is illustrated in Fig. 6.

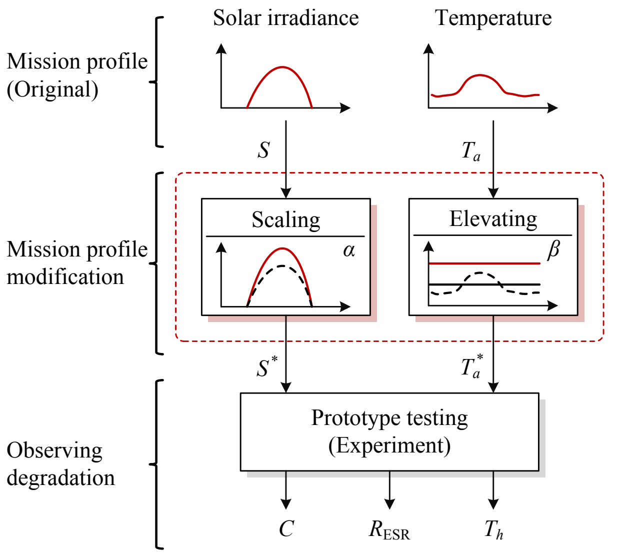

Fig. 6. Mission profile-based accelerated testing of the dc-link capacitor in PV inverters, where (S, T_a) and (S^*, T_a^*) are the original and the modified mission profiles, respectively.

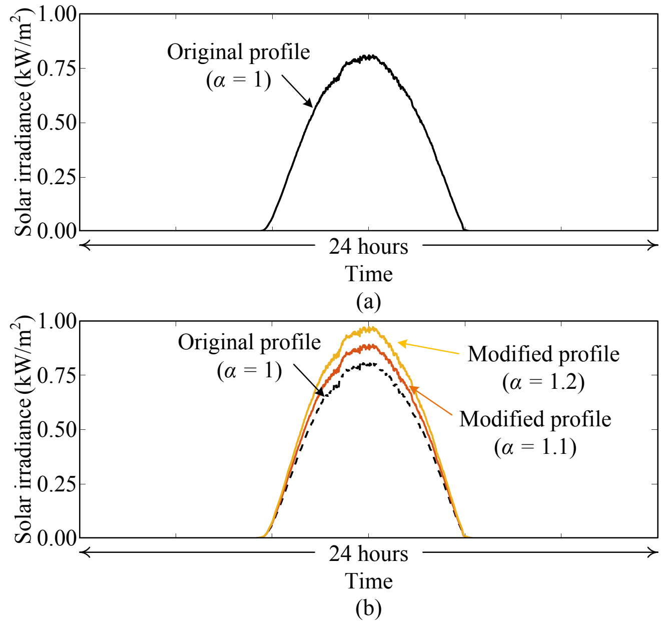

Fig. 7. Daily solar irradiance profile: (a) original profile and (b) modified profile with different amplitude scaling factors α.

Clearly, the original mission profile needs to be modified with a certain acceleration factor in a way to accelerate the degradation process of the dc-link capacitor during the test and thereby reduce the testing time. For PV systems, the solar irradiance and ambient temperature are considered as the mission profile parameters, as they strongly affect both the electrical and thermal loading conditions of the components in the PV inverter. The modification of these two parameters needs to consider both the impact on the degradation of the dc-link capacitor and the testing facility requirements.

B. Modifying the Solar Irradiance Profile

In general, the solar irradiance is the mission profile parameter that strongly affects the dynamic of the PV power production, and thereby the loading of the dc-link capacitor. Thus, it has a direct impact on the power losses P_{loss}, which in turn contributes to the hotspot temperature of the dc-link capacitor T_h according to the thermal model in Fig. 3.

In order to accelerate the degradation of the dc-link capacitor during the test, the solar irradiance profile needs to be modified in a way to increase the loading and thereby the power losses in the dc-link capacitor. This can be achieved by multiplying the original solar irradiance profile with a certain amplitude scaling factor α, which is defined as

$$\alpha = \frac{S^*}{S} \tag{5}$$

where S and S^* are the original solar irradiance and the modified solar irradiance, respectively.

An example of the solar irradiance amplitude modification is illustrated in Fig. 7, where the original daily solar irradiance profile (e.g., collected from the field operation) is modified with different amplitude scaling factors α (e.g., increase the solar irradiance amplitude by 10 % and 20 % for α = 1.1 and 1.2, respectively). By doing so, the loading condition of the dc-link capacitor during the test is increased while its dynamic operation (e.g., shape) remains the same as the original one. As a result, the dc-link capacitor will degrade with a faster rate compared to the original mission profile, and thereby reduce the testing time. Notably, the maximum amplitude scaling factor is limited by the rated power of the PV inverter. When the solar irradiance is over-scaled, the loading of the PV inverter will be limited to its rated power and thus the dynamics (e.g., shape) of the mission profile will be affected.

C. Modifying the Ambient Temperature Profile

According to the thermal model of the dc-link capacitor in Fig. 3, the ambient temperature T_a has a direct influence on the hotspot temperature of the dc-link capacitor T_h. Thus, increasing the ambient temperature for the test is an effective way to accelerate the degradation process of the capacitor.

Normally, the ambient temperature profile varies to a certain extent during the day, as it is demonstrated in Fig. 8(a). However, the realization of a dynamic ambient temperature during the test can be challenging concerning the testing facility (e.g., response time of the oven). Seen from a reliability testing perspective, using a constant ambient temperature to simplify the test is a reasonable assumption for the dc-link capacitor, as its degradation mechanism is related to the average value of the hotspot temperature [8]. The initial value of the ambient temperature can be obtained from the average value of the original profile, as it is shown in Fig. 8(b).

In order to reduce the testing time, an ambient temperature level should be elevated during the test in order to accelerate

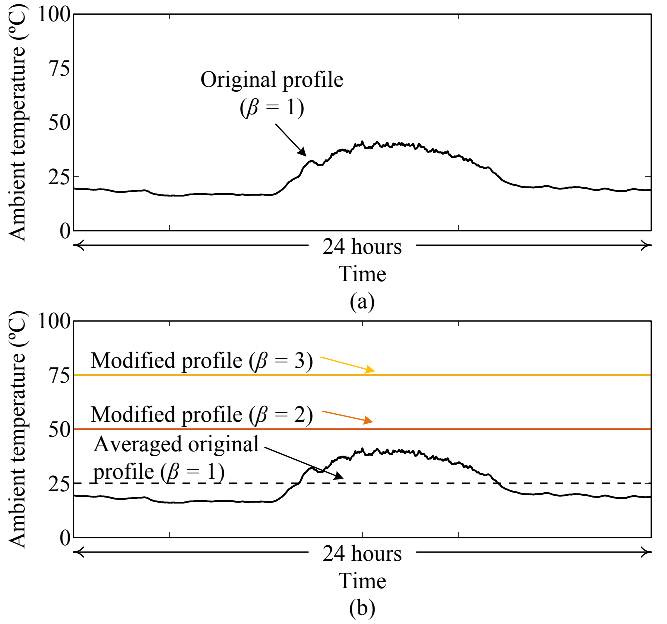

Fig. 8. Daily ambient temperature profile: (a) the original profile and (b) the modified profile with different temperature scaling factors β.

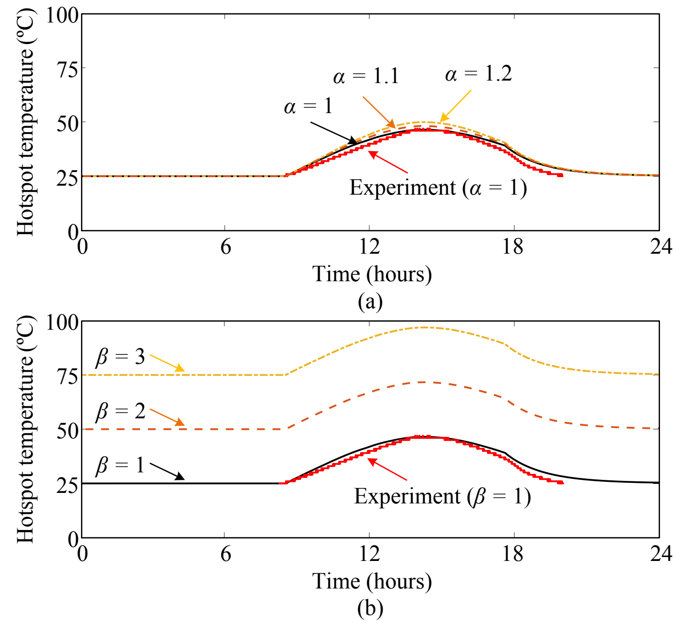

Fig. 9. Daily hotspot temperature of the dc-link capacitor with different: (a) amplitude scaling factors α and (b) temperature scaling factors β.

the degradation process of the capacitor [16]. A scaling factor for the ambient temperature during the test is defined as

$$\beta = \frac{T_a^*}{T_a} \tag{6}$$

where T_a and T_a^* are the original averaged ambient temperature and the modified ambient temperature, respectively.

An example of the modified ambient temperature with different scaling factors β is shown in Fig. 8(b), where the original averaged ambient temperature of 25 °C is elevated to 50 °C (i.e., β= 2) and 75 °C (i.e., β= 3). By elevating the ambient temperature during the test, the testing time of the dc-link capacitor until failure can be reduced significantly compared to the original mission profile. Notably, the maximum temperature scaling factor is limited by the maximum operating temperature of the dc-link capacitor (and also the surrounding components). Applying an ambient temperature higher than the maximum limit should be avoided, as it may trigger other failure mechanisms that are not related to the wear-out failure of the capacitor in real application and thereby introduce erroneous in the reliability evaluation.

V. Design Guideline

In this section, a guideline for designing a test profile according to the proposed mission profile-based accelerated testing is provided. The selection of scaling factor parameters for a certain required testing time is discussed, where the original mission profile in Figs. 7(a) and 8(a) is considered.

A. Thermal Stress Analysis

The thermal stress of dc-link capacitor during the test is an indicator to demonstrate the effectiveness of the proposed testing method. According to the test requirements discussed in Section IV, the thermal stress of the dc-link capacitor should be increased in a way to accelerate the capacitor degradation, while its dynamics should be maintained close to the real operation (e.g., the original mission profile).

The hotspot temperature of the dc-link capacitor under the original mission profile is shown in Fig. 9(a) (for the case of β = 1), where the result obtained from the simulation is closely aligned with the experiments (under similar operating conditions) and validating the thermal modeling. It can be seen from the same figure that the hotspot temperature of the dc-link capacitor reaches a higher peak value as the amplitude scaling factor increases to α = 1.2, which is the maximum limit where the peak PV output power reaches the PV inverter rated power during midday. In this case, the modification of the solar irradiance only affects the thermal stress of the dc-link capacitor during the day (e.g., from 8.00 to 18.00). On the other hand, the modification of the ambient temperature can effectively elevate the hotspot temperature of the dc-link capacitor during the entire testing period, as it can be seen in Fig. 9(b). In both cases, the dynamics of the hotspot temperature is similar to that in the original profile.

B. Parameter Sensitivity Analysis

To quantify the impact of the mission profile acceleration on the required testing time of the dc-link capacitor, the sensitivity analysis of the two scaling factors is necessary. In this case, the accumulated damage of the dc-link capacitor under daily mission profile with different scaling factors (e.g., α and β) are evaluated and compared, since it is a reliability metric that indicates the time to failure of the capacitor during the test. More specifically, the required testing time

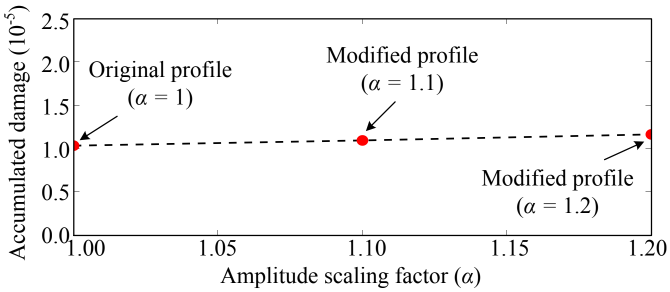

Fig. 10. Accumulated damage of capacitor under daily mission profile with different solar irradiance amplitude scaling factors (ambient temperature of T_a = 25 °C).

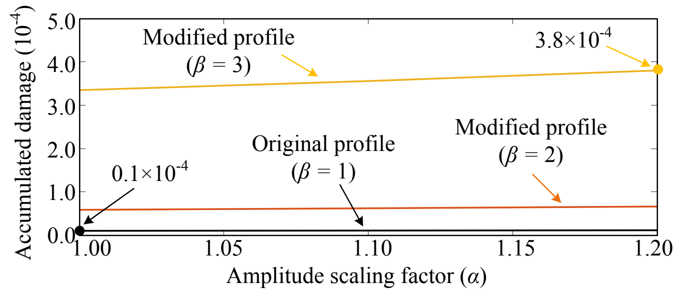

Fig. 12. Accumulated damage of capacitor under daily mission profile with different solar irradiance amplitude scaling factors α and ambient temperature scaling factors β.

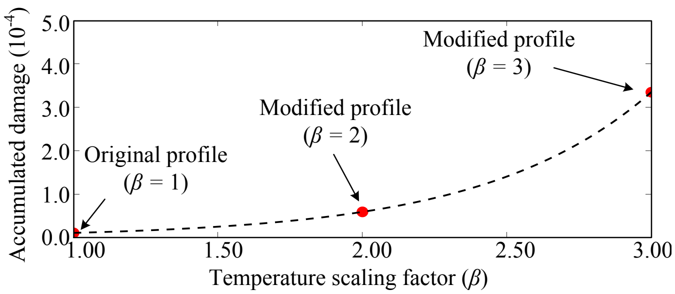

Fig. 11. Accumulated damage of capacitor under daily mission profile with different ambient temperature scaling factors (original solar irradiance profile).

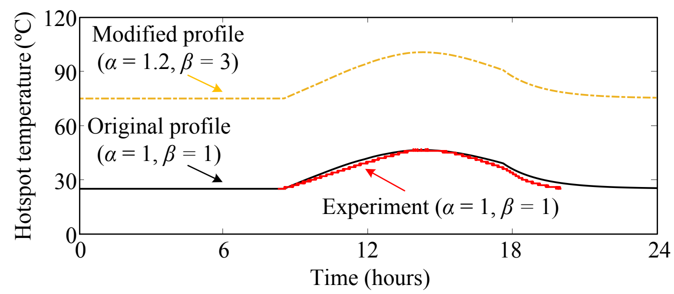

Fig. 13. Daily hotspot temperature of the dc-link capacitor with the amplitude scaling factors of α = 1.2 and temperature scaling factors of β = 3.

(i.e., number of days) is inversely proportional to the damage accumulated during the test. Therefore, the test condition with high accumulated damage indicates a shorter testing time.

The accumulated damage of the capacitor under different amplitude scaling factors α is shown in Fig. 10, which is obtained by applying the thermal stress profile in Fig. 9(a) to the lifetime model and the damage model in (3) and (4), respectively. It can be seen from the results in Fig. 10 that the amplitude scaling factor has a small impact on the accumulated damage of the capacitor. Thus, its effectiveness to reduce the testing time is limited. In contrast, the accumulated damage of the capacitor increases significantly as the temperature scaling factor β increases, as it is shown in Fig. 11. In fact, the increase in the accumulated damage follows an exponential function. Therefore, elevating an ambient temperature can effectively accelerate the reliability testing of the dc-link capacitor.

C. Scaling Factor Design

In order to design the scaling factor for the test profile, the impact of both solar irradiance amplitude and temperature scaling factors need to be considered together. The accumulated damage of the dc-link capacitor when considering both solar irradiance and ambient temperature modifications are shown in Fig. 12. Similarly to the sensitivity analysis, the ambient temperature elevation is more effective than the solar irradiance amplitude modification in terms of reducing the testing time. Nevertheless, the impact of the solar irradiance amplitude scaling factor is more pronounced at the high ambient temperature, as it can be seen from the slope of the accumulated damage at different temperature scaling factors. Therefore, at the elevated ambient temperature condition, the impact of the modified solar irradiance cannot be neglected.

The results in Fig. 12 can be used for designing the scaling factors considering the required testing time. For instance, by applying the scaling factor of α = 1.2 and β = 3, the dc-link capacitor is highly stressed during the test compared to the original mission profile, as it can be seen in Fig. 13. This test condition results in the accumulated damage of D = 3.8×10^{-4}, which is 38 times higher than the case of the original mission profile (D = 0.1×10^{-4}). This also implies that the testing time for this operating condition is only 1/38 ≈ 2.5 % of the real field operation lifetime. For instance, if the dc-link capacitor is designed to achieve lifetime target of 10 years in the real operation, the required testing time for the proposed testing method is around 3 months.

Notably, the testing time may be further reduced by applying a higher temperature scaling factor (since the maximum value of α is 1.2) as long as it is within the maximum operating temperature of the capacitor (e.g., 85 °C at the rated voltage) and also other components in the system. For the different testing time requirements, the other combination of the scaling factors (e.g., α and β) can be selected following the results shown in Fig. 12. It is also worth mentioning that in the case of long-term mission profile (e.g., one year), a representative short-term operation (e.g., one day) is needed. The representative mission profile can be chosen from a daily average solar irradiance and ambient temperature of the entire mission profile in order to simplify the test profile.

VI. Conclusions

In this paper, a new reliability testing concept based on the real mission profile seen in the field is proposed for the dc-link capacitor in PV inverters. In contrast to the conventional reliability testing method, the proposed one realizes the testing conditions through the modification of the original mission profile in order to be more close to the real application. More specifically, the solar irradiance profile is modified by introducing an amplitude scaling factor while the ambient temperature is elevated for the test. This leads to an increase in the thermal stress (e.g., the hotspot temperature) of the dc-link capacitor, and thereby accelerate the degradation process. A design guideline for selecting the scaling factors is also provided, where the results indicate that the testing time can be reduced to 2.5 % of the real field operation lifetime, if the solar irradiance amplitude is increased by 20 % and the ambient temperature is elevated to 75 °C during the test.

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