# A Stress Emulation Method for Concurrent Testing of AC and DC Capacitors

Yao, Bo; Wang, Haoran; Wang, Huai

*Published in:*
2022 International Power Electronics Conference (IPEC-Himeji 2022- ECCE Asia)

*DOI (link to publication from Publisher):*
10.23919/IPEC-Himeji2022-ECCE53331.2022.9807254

*Publication date:*
2022

# A Stress Emulation Method for DC and AC capacitors concurrently testing

Bo Yao[1]*, Xing Wei[1], Haoran Wang[1], Huai Wang[1]
1 Department of Energy, Aalborg University, Aalborg, Denmark
*E-mail: ybo@energy.aau.dk

***Abstract*—The parameter characterizations and degradation testing of both AC capacitor banks and DC capacitor banks should be considered for high power converter applications such as railway and wind power systems. Based on this, this paper proposes a stress emulation method for DC and AC capacitors. Compared with existing solutions, the proposed test method can concurrently emulate realistic voltage and current stresses for DC and AC capacitors, thereby reducting the test time and cost. The circuit architecture and testing ability of the proposed testing method are provided in this paper. Meanwhile, this paper illustrates the practicability and convenient for laboratory and industrial implementation of this method through application-oriented cases in railway and wind power systems. Finally, the experimental results are given to verify the feasibility and effectiveness of the proposed test method.**

***Keywords*—Stress emulation, DC capacitors, AC capacitors, degradation testing.**

## I. Introduction

Capacitor is one of the highest failure rate components in power electronic systems [1]. The degradation and failure of capacitors could lead to worse filtering capability and over-stresses as well as severe catastrophe to the power converters [2]. The realistic stress testing of capacitors is significant part in the performance characterization and lifetime prediction of capacitors [3] [4].

With the development of power electronics, both DC capacitors and AC capacitors are widely used in power converter systems. The circuit architecture of the typical railway traction system is shown in Fig. 1 [5]. In this system, the DC capacitors are located between the converters for energy exchange and filtering and the AC capacitors are located between the converter and the load to filter out the harmonics of the AC signal. The parametric characteristics and reliability testing of both AC capacitor banks and DC capacitor banks cannot be ignored for high power converter applications such as railway and wind power [6] [7]. Therefore, how to cost-effectively simulate electrical stresses for AC and DC capacitors has become an emerging demand for capacitor testing in high power converter applications.

In the last two decades, extensive efforts have been made for capacitor testing stress conditions. In [8] and [9], a voltage source and a current source converter are connected in parallel to apply the DC voltage and ripple current, while the converter has to process the full-scale voltage and current of the voltage soucre. The test stresses level and test frequency of this test method

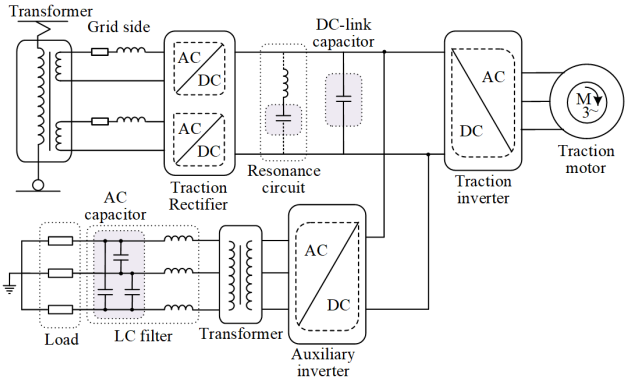


Fig. 1. Circuit architecture of the typical railway traction system.

are limited by the power supply capability and cannot be extended, which are only suitable for low-power aluminum electrolytic capacitors and ceramic capacitors testing. The commercial ripple current tester Chroma 11800 and 1120 can simulate different ripple voltage and current according to different extension components [10] [11]. But limited by the size of the hardware, its output ripple current and ripple voltage are only kilowatts. The [12] and [13] use a circuit structure in which a power converter is connected in series with CUTs, and the ripple current can be configured according to the converter parameters. However, the converter needs to directly withstand the DC voltage component of the CUTs in this method, which cannot be tolerated in the high power capacitor testing with kilovolt DC voltage. Due to the power converters are used in the voltage sources with fixed 120 °C three phase symmetrical voltage, it can improve the test range for electrical stresses, where the ripple voltage, ripple current, and DC voltage of the CUTs can be expand according to test requirements [14] [15]. However, only independent stresses condition of DC capacitors or AC capacitors can be emulated in this testing method.

In general, existing capacitor testing methods still lack the strategy that can cost-effectively test the multiple capacitors including AC and DC capacitors for high power applications. This paper propose a method for capacitor characterizations and degradation testing. This method has the unified testing capability, in which DC capacitors and AC capacitors can be concurrently testing, thereby reducing the test time and cost. In additon, this paper provides a few examples of typical testing scenarios for different power electronics applications, such as wind

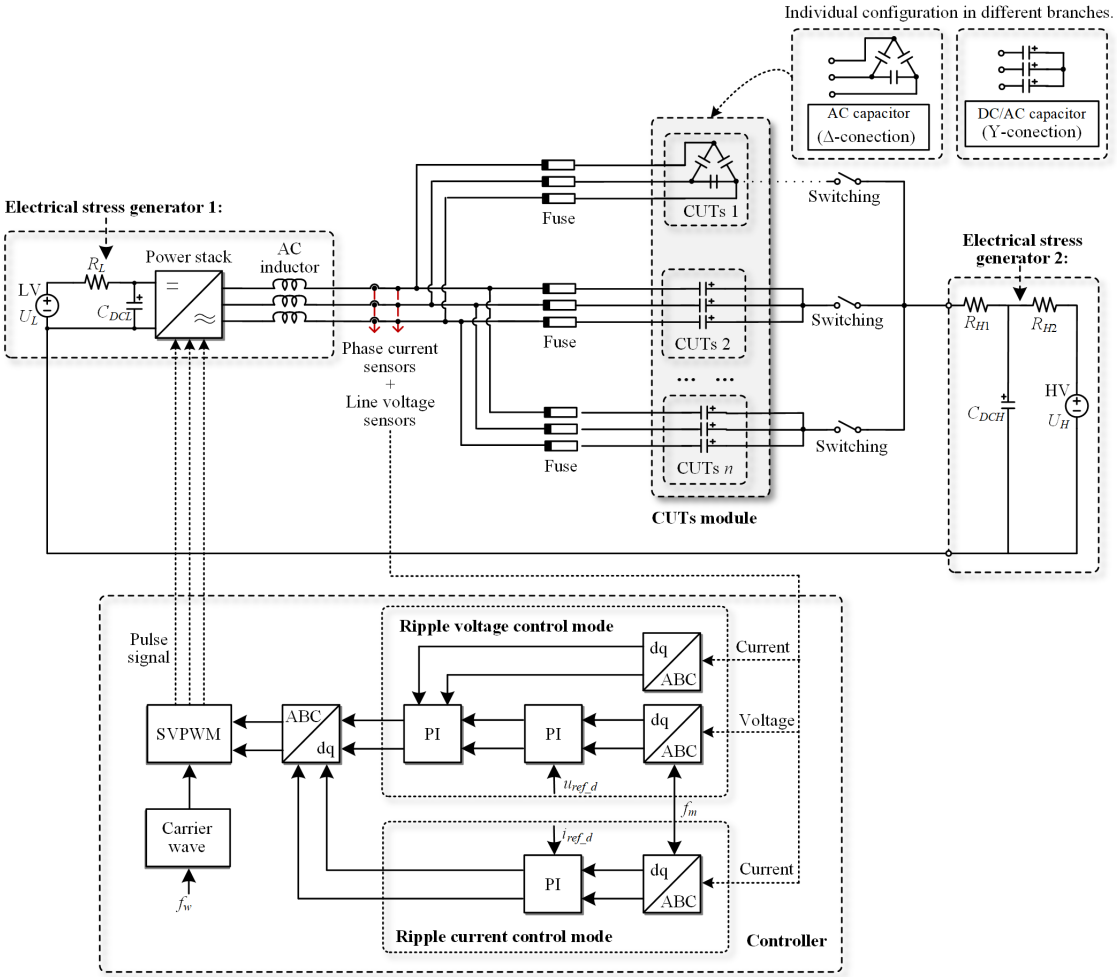


Fig. 2. Circuit architecture of the unified reliability test method.

power converters and railway traction systems.

The structure of this paper is as follows: Section II presents the structure of the test method; Section III gives the test parmeters and cases analysis; Experimental verification is given in Section IV, followed by the conclusions.

## II. Concept of Proposed Stress Emulation Method

The circuit architecture of the proposed unified stress emulation method is shown in Fig. 2. It is achieved by decoupling the DC voltage bias generation and AC ripple voltage generator, by the HV supply and LV supply plus the PWM inverter, respectively.

The AC ripple voltage generator mostly consists of the LV power supply that generates ripple voltage and ripple current, the power stack, the AC-side inductor $L$, the CUTs, the stack resistors $R_L$ and the filter capacitors $C_{DCL}$. The structure can apply sinusoidal current to the CUTs through the LV power supply and the power stack. The power is circulated in the system, so that the LV supplies the power losses only of the testing system and the DUTs only, implying a minimum current rating.

The HV power supply that generates DC voltage component, the filter capacitors $C_{DCH}$, and the stack resistors $R_H$ are added for the DC capacitor test setup. By setting the stack resistors $R_H$, the current flowing into the circuit of the HV power supply is limited in the DC capacitor test setup. The HV is used to generate DC bias voltage for DC capacitor testing, which supplies typically mA current only.

The CUTs module realizes the function of concurrent AC and DC capacitor testing for different branches. The CUTs can be configured into Y- or Δ-connection for AC capacitors, and Y-connection for DC capacitors, with single or multiple such connections in parallel. The tested ripple voltage and ripple current of the CUTs are provided by the electrical stress generator 1. In DC capacitors testing, the DC component voltage of the CUTs are provided by the electrical stress generator 2. Meanwhile, the fuses are used for short-circuit protection and the switchings are used for turning on or turning off the DC capacitors testing circuit in different branches.

The three-phase SVPWM vector control model is used in the test method, which can be divided into voltage mode to control ripple voltage and current mode to control ripple current. The control system is to modulate the three-phase current with low-frequency sinu-

TABLE I. EXAMPLES OF TYPICAL TESTING SCENARIOS FOR DIFFERENT POWER ELECTRONICS APPLICATIONS

| | | Reqirement | | | Design (Minimum required value) (RMS value) ($\eta$=96.6%) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CUTs | Application | Capacitor parameter (Capacitance/frequency/ Ripple/DC volatege) | Test Number | Scaling factor for rated ripple voltage (RMS) | Power stack output voltage | Power stack and inductor current | Inductance value | Required power (LV) | Power source voltage (HV) | Power source current (HV) |
| AC | Wind power | 75μF/50Hz/730V | 9 | m=1.4 (1022V) | 530V | 375A | 2.40mF | 6830W | - | - |
| | Railway | 416μF/50Hz/600V | 4 | m=1.4 (840V) | 530V | 761A | 0.75mF | 22080W | - | - |
| DC | Wind power | 645μF/50Hz/1250V | 24 | m=1.4 (280V) | 530V | 448A | 0.15mF | 8100W | 1250V | <100mA |
| | Railway | 750μF/50Hz/3000V | 6 | m=1.4 (1189V) | 530V | 560A | 2.5mF | 10050W | 3375V | <100mA |
| AC+DC | Railway | 416μF/50Hz/600V<br>750μF/50Hz/3000V | 4 (AC)<br>6 (DC) | m=1.4 (840V)<br>m=1.0 (840V) | 530V | 1161A | 0.72mF | 20850W | 3375V | <100mA |

TABLE II. EXPERIMENTAL PLATFORM PARAMETERS.

| CUTs setup | AC capacitor (Δ-conection) | DC capacitor (Y-conection) |
|---|---|---|
| AC-side inductor $L$ | 2.5mH | |
| Ripple frequency $f_R$ | 50Hz / 60Hz | |
| Switch frequency $f_w$ | 5000Hz | |
| LV source voltage $U_L$ | 750V | |
| HV source voltage $U_H$ | 0V | 3375V |
| Capacitance of CUTs | 75μF*3*(9 / 7) | 220μF*2 |
| Given ripple voltage (RMS) | 730V*1.0/1.2/1.4 | 730V/√3 |
| Testing Ripple voltage (RMS) | 1013V | 424V |
| Testing Ripple current (RMS) | 363.2A | 58.1A |

1. HV source voltage:3375V (3000V DC voltage for DC capacitors + ½ LV voltage)


Fig. 3. Photo of experimental test rig.

soidal waveforms. Through the Park's transformation of ($ABC \Rightarrow dq$), the ripple voltage $u_{Ref_d}$ or ripple current $i_{Ref_d}$, and the modulation frequency $f_m$ are set in the controller. Then performing the Park's inverse transformation ($dq \Rightarrow ABC$), thereby getting the switch signal.

Base on this structure, the proposed method can test the following CUTs:

- Separate AC capacitors testing (Δ / Y-connection);
- Separate DC capacitors testing;
- AC capacitors and DC capacitors concurrently testing.

All of the above testing setup can adopt voltage control mode or current control mode.

## III. TEST PARAMETERS AND CASES ANALYSIS

In AC capacitor test setup, the RMS (root mean square) value of ripple volatge $U_{ripple}$ and ripple current $I_{ripple}$ of CUTs can be shown as:

$$\begin{cases} U_{ripple} = U_{line} \\ I_{ripple} = I_{AC} = U_{ripple} \times 2\pi f_R C_{test} \end{cases} \tag{1}$$

where $U_{line}$, $I_{AC}$, and $C_{test}$ represent the line voltage between the inductor and CUTs, the AC-side current, and the capacitance of the CUTs, respectively. The $f_R$ of the CUTs is ripple frequency of CUTs.

In DC capacitor test setup, the $U_{ripple}$, $I_{ripple}$, and the DC component voltage $U_{DC}$ of CUTs can be shown as:

$$\begin{cases} U_{DC} = U_{HV} - \frac{1}{2}U_{LV} \\ U_{ripple} = \frac{1}{\sqrt{3}}U_{line} \\ I_{ripple} = I_{AC} = U_{ripple} \times 2\pi f_R C_{test} \end{cases} \tag{2}$$

where $U_{HV}$ and $U_{LV}$ respectively represent the output voltage of HV power supply and LV power supply.

The RMS value of ripple current $I_{ripple}$ of the DC capacitors and AC capacitors are given by:

$$I_{ripple} = \frac{U_m}{\sqrt{3} \mid \frac{1}{2\pi f_R \times C_{test}} - 2\pi f_R \times L \mid} \tag{3}$$

where $L$ is the inductance of the AC-side inductor, and $U_m$ is the RMS value of the output voltage in the power stack.

The AC-side inductor can boost the output voltage of the power stack, and its minimum value can be given as:

$$L = \left(1 - \frac{U_m}{U_{ripple}}\right) \times \frac{1}{4\pi^2 f_R^2 C_{test}} \tag{4}$$

The power requirement of the LV power supply $P_{LV}$ can be given as:

$$P_{LV} \approx I_{ripple}^2 R_{total} + (1-\eta) I_{ripple} U_m \tag{5}$$

where the $\eta$ is the efficiency of the power stack and inductors at the specific operating condition of interest, and the $R_{total}$ represents the ESR of the CUTs.

Based on the above analysis, according to the test requirements of capacitors in different high power applications, the design parameters of the power stack, the AC-side inductor, and the power supplies in this testing method can be obtained. A few examples of typical testing scenarios for different power electronics applications are given in Table I [5] [7] .

## IV. EXPERIMENTAL VERIFICATION

### A. Settings and parameters of the experiment

In order to verify the rationality of the proposed test method, this section analyzes the test performance

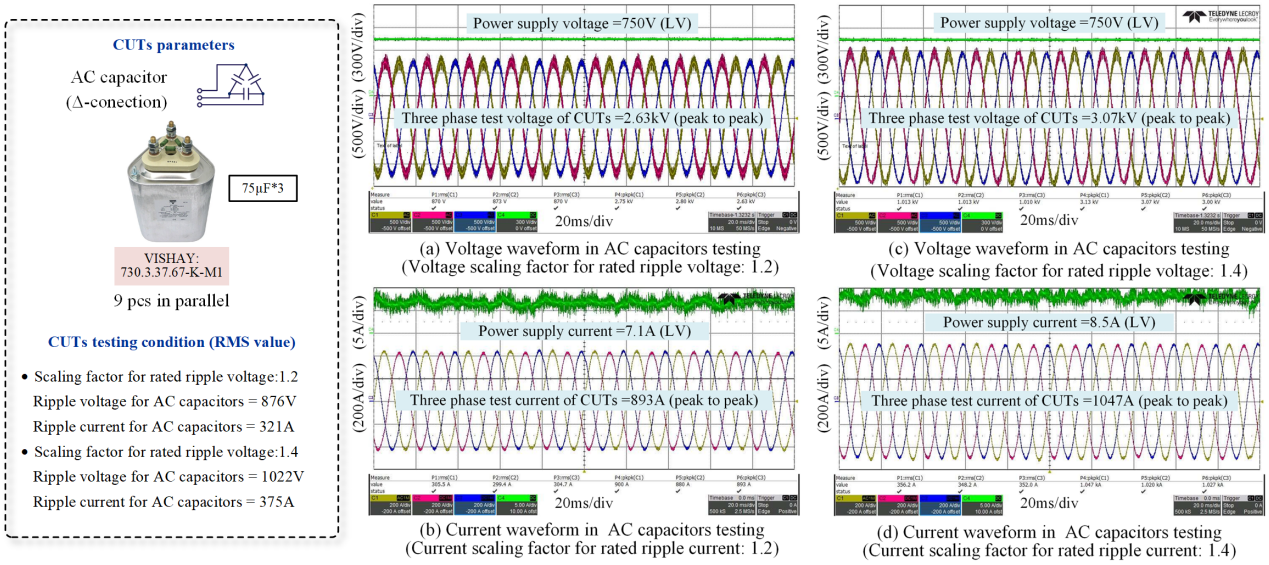


Fig. 4. Experiment results for AC capacitors testing with different ripple voltage scaling factors.

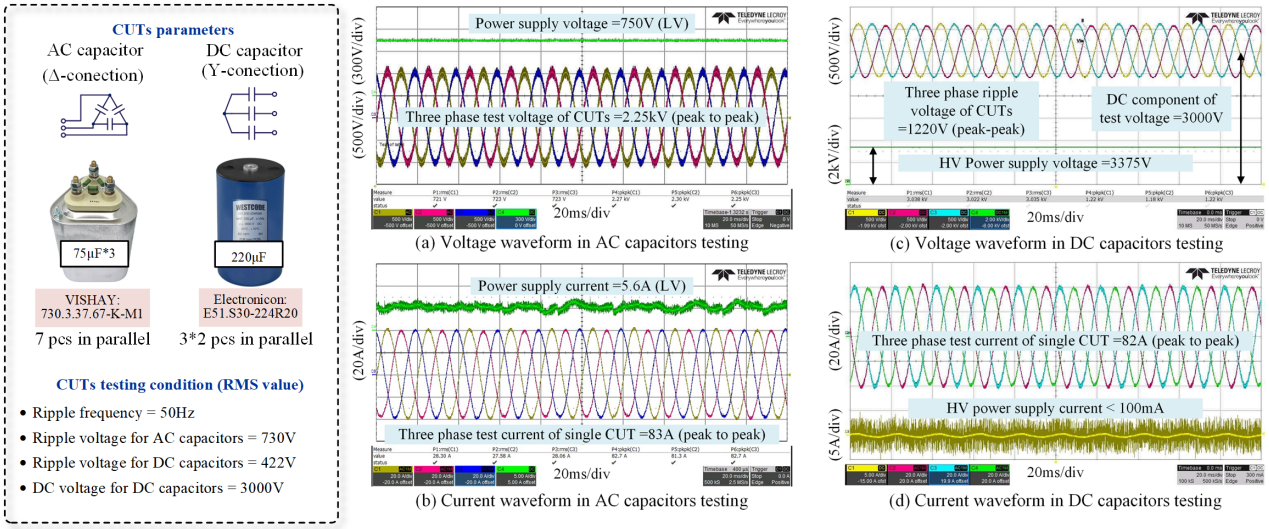


Fig. 5. Experiment results for DC capacitors and AC capacitors concurrently testing.

through a full scale experimental platform. The experimental platform is shown in Fig. 3. The control system is carried out through the RTbox controller, and the power stack uses the Semikron slimLine platform [16]. In addition, the output power of the LV power supply is set to 750V. The output power of the HV power supply is set to 3350V, so that the DC voltage of the DC capacitor is 3000V. The main parameters of the experimental platform and the CUTs are given in Table II, where CUTs include AC capacitors (VISHAY: 730.3.37.67-K-M1) and DC capacitors (Electronicon: E51,S30-224R20).

### *B. AC capacitor banks testing with with different ripple voltage scaling factor*

The test results of AC capacitor are shown in Fig. 4. It shows the ripple voltage and ripple current of the three-phase CUTs as well as the output voltage and current of the LV power supply. In this testing, the CUTs are 9 Δ-connection AC capacitors in parallel. The 1.2 and 1.4 scaling factor for rated ripple voltage are emulated for CUTs, as shown in Fig.4 (a)-(b) and Fig.4 (c)-(d), respectively. It can be seen from the results that by setting different ripple voltages and ripple currents, different stress testing requirements can be met. When keeping the constant LV voltage (750V), the LV current that needs to be provided increase accordingly. In the Fig.3 (c)-(d), the total testing power of the CUTs reaches 3.2 MVA, while the LV power supply only needs to provide 6.4 kW of power.

### *C. DC capacitor and AC capacitor banks concurrently testing*

The test results of the unified DC capacitor and AC capacitor are shown in Fig. 5. It shows the three-phase ripple voltage and ripple current of the DC capacitors and the AC capacitors, and the DC voltage component of the

DC capacitors, as well as the output voltage and current of the HV power supply. In this testing, the CUTs are 7 $\Delta$-connection AC capacitors and 6 Y-connection DC capacitors in parallel. The same ripple voltage is applied to the AC capacitors and the DC capacitors, as shown in Fig. 5 (a)-(b) and Fig. 5 (c)-(d), respectively. It can be seen from the results that the ripple voltage and current of the test capacitor are aslo stable when AC capacitors and DC capacitors are mixed testing. Meanwhile, the HV source only needs to provide the mA current.

## V. Conclusion

This paper proposes a stress emulation method for high-power capacitors, which is able to concurrently emulate realistic electrical stresses of DC and AC capacitors with high ripple voltage (kV) and high ripple current (kA). This concurrently and parallel testing method can reduce the testing time and testing cost. It is suitable for the applicaiton-oriented testing of DC and AC capacitors, including the accelerated aging testing, the fault physics analysis, and the lifetime prediction, especially for capacitors testing in high-power (MW) applications such as railway trectiong systems and wind power systems. Examples of typical testing scenarios for different power electronics applications illustrate the practicability of this method in the high power converter application cases, such as wind power converters and railway traction systems, which is convenient for laboratory and industrial implementation. The full scale experiments have verify the concept of the proposed method for DC capacitors and AC capacitors testing.

## References


[1] S. Yang, A. Bryant, P. Mawby, D. Xiang, L. Ran, and P. Tavner, "An industry-based survey of reliability in power electronic converters," *IEEE Trans. Ind. Appl.*, vol. 47, no. 3, pp. 1441–1451, May-Jun. 2011.

[2] H. Wang and F. Blaabjerg, "Reliability of capacitors for dc-link applications in power electronic converters—an overview," *IEEE Trans. Ind. Appl.*, vol. 50, no. 5, pp. 3569–3578, 2014.

[3] H. Wang, M. Liserre, and F. Blaabjerg, "Toward reliable power electronics: Challenges, design tools, and opportunities," *IEEE Ind. Electron. Mag.*, vol. 7, no. 2, pp. 17–26, 2013.

[4] S. Liu, Z. Shen, and H. Wang, "Safe operating area of dc-link film capacitors," *IEEE Trans. Power Electron.*, vol. 36, no. 10, pp. 11 014–11 018, Oct. 2021.

[5] B. Yao, X. Ge, D. Xie, S. Li, Y. Zhang, H. Wang, and H. Wang, "Electro-thermal stress analysis and lifetime evaluation of dc-link capacitor banks in the railway traction drive system," *IEEE J. of Emerg. Se. Topics in Power Electron.*, pp. 1–1, 2020.

[6] B. Yao, X. Ge, H. Wang, H. Wang, D. Zhou, and B. Gou, "Multi-timescale reliability evaluation of dc-link capacitor banks in metro traction drive system," *IEEE Trans. Transport. Electrific.*, vol. 6, no. 1, pp. 213–227, Mar. 2020.

[7] D. Zhou, Y. Song, Y. Liu, and F. Blaabjerg, "Mission profile based reliability evaluation of capacitor banks in wind power converters," *IEEE Trans. Power Electron.*, vol. 34, no. 5, pp. 4665–4677, May 2019.

[8] A. M. R. Amaral and A. J. Marques Cardoso, "Estimating aluminum electrolytic capacitors condition using a low frequency transformer together with a dc power supply," in *2010 IEEE Int. Symposium on Ind. Electron.*, Jul. 2010, pp. 815–820.

[9] K. Abdennadher, P. Venet, G. Rojat, J.-M. Rétif, and C. Rosset, "A real-time predictive-maintenance system of aluminum electrolytic capacitors used in uninterrupted power supplies," *IEEE Trans. Ind. Appl.*, vol. 46, no. 4, pp. 1644–1652, Jul.-Aug. 2010.

[10] "Ripple current tester model 11800/11801/11810." Chroma ATE Inc, http://www.chromaate.com/product/11800_11801_11810_Ripple_Current_Tester.htm, 2019.

[11] "Ripple current tester model 1820." Chroma ATE Inc, https://www.chromaate.com/tw/product/capacitor_test_system_1820_256, 2020.

[12] W. Zhou, M. Wang, Q. Wu, L. Xi, K. Xiao, K. P. Bhat, and C. Chen, "Accelerated life testing method of metallized film capacitors for inverter applications," *IEEE Trans. Transport. Electrific.*, vol. 7, no. 1, pp. 37–49, Mar. 2021.

[13] K. Hasegawa, I. Omura, and S.-i. Nishizawa, "Design and analysis of a new evaluation circuit for capacitors used in a high-power three-phase inverter," *IEEE Trans. Ind. Electron.*, vol. 63, no. 5, pp. 2679–2687, May 2016.

[14] X. Wang, M. Karami, and R. M. Tallam, "Test fixtures to apply variable dc bias and ac ripple current for reliability testing of electrolytic capacitors," *IEEE Trans. Ind. Appl.*, vol. 55, no. 4, pp. 4073–4079, Jul.-Aug. 2019.

[15] B. Yao, Q. Wang, H. Wang, K. Hasegawa, and H. Wang, "A robust testing method for dc and ac capacitors with minimum required power supply," *IEEE Trans. Power Electron.*, vol. 37, no. 5, pp. 4942–4946, May 2022.

[16] "Sks sl 150 gd 50/10 - e4 p1." Semikron Stacks SlimLine, https://www.semikron.com/zh/products/product-classes/stacks/detail/sks-sl-150-gd-5010-e4-p1-af-08801380.html, 2019.