CONDITION MONITORING OF CAPACITORS IN POWER ELECTRONIC CONVERTERS

Abstract

Marine and aerospace industries are driven towards more electric aircrafts and ships due to the demand to optimise performance using electrical systems which are more efficient than the traditional mechanical systems and to reduce gas emissions caused by fossil fuels. With the indispensable nature of the power converters in applications such as hybrid propulsion, electric vehicles, and many other safety-critical systems, condition monitoring of power converters has become essential to ensure high safety and reliability. A power converter is made up of components like capacitors, inductors, power semiconductor devices, gate drivers, sensors and a control unit. The unexpected failure of one or more of these components may lead to system downtime. In power converters, aluminium electrolytic capacitors play significant roles such as filters, snubbers, and energy storage elements. However, they are also one of the most vulnerable components due to their high failure rates compared to other components in a power converter. Therefore, with the increase in the use of capacitors in critical applications, condition monitoring of capacitors to prevent unexpected failures has become inevitable. The main factors affecting the lifetime of capacitors are environmental factors such as ambient temperature, vibration, humidity, etc., and electrical factors such as operating voltage, ripple current, and charge-discharge duty ratio.

Several research findings have been published regarding condition monitoring of capacitors. However, none or a limited number of the methods are adopted by industries because the existing condition monitoring approaches are either unreliable or highly complex and expensive to implement which make them impracticable. Hence, this research focuses on developing and implementing a novel, reliable, and cost-effective prognostic and health monitoring technology for capacitors to predict the failure during the early stages of its degradation and thereby enabling preventive maintenance. This research has been carried out in three phases. The first phase of research focuses on the study of construction, physical properties, equivalent circuit models, and failure mechanisms of an electrolytic capacitor to develop reliable methods to identify and track the dominant failure mechanisms. The most common failure mechanism in an electrolytic capacitor is the electrolyte evaporation which causes the increase in equivalent series resistance (ESR) and decrease in capacitance. Therefore, the ESR and capacitance of the capacitor are selected as the indicators to track capacitor degradation. Reliable and accurate parameter estimation methods are developed to estimate the ESR and capacitance. The developed methods have been tested experimentally in a three-phase inverter test rig and found that the error in estimation is less than 3% for ESR and 1% for capacitance. The degradation indicators are sensitive to both operating temperature and frequency. Therefore, the indicators must be normalized before decisions can be taken.

The second phase of research focuses on accelerated aging tests to study the degradation behavior and physical properties of degradation indicator. For this purpose, 30 samples of electrolytic capacitors are divided into five groups of six samples each and subjected to five different voltage levels at accelerated thermal stress of 10°C above the rated value. Based on the analysis of physical properties of electrolytic capacitors before and after ageing, normalization methods are developed to account for frequency and temperature variations. The study of impact of ageing process on physical properties is one of the important contributions by this thesis as it increases failure detection accuracy by a margin as high as 80% in some cases. The final phase of research aims to develop methods to estimate the remaining useful life (RUL) of capacitors. The results from accelerated aging tests are used to develop exponential degradation model to estimate remaining useful life based on the known failure threshold for degradation indicators. Two different methods are developed to estimate remaining useful life using nonlinear regression and extended Kalman filter. The comparison of both methods in terms of performance and complexity is done to highlight the suitability of methods for different applications.

Publications

Journals:

- **P. Sundararajan**, M. H. M. Sathik, F. Sasongko, C. S. Tan, M. Tariq, and R. Simanjorang, "Online condition monitoring system for DC-link capacitor in industrial power converters," *IEEE Trans. Ind. Appl.*, vol. 54, no. 5, pp. 4775-4785, Sept.-Oct. 2018.
- **P. Sundararajan**, M. H. M. Sathik, F. Sasongko, C. S. Tan, J. Pou, F. Blaabjerg and A. Gupta, "Condition Monitoring of DC-Link Capacitors using Goertzel Algorithm for Failure Precursor Parameter and Temperature Estimation," *IEEE Trans. Power Electron.* **(SUBMITTED/REVISION)**
- M. Sathik, **S. Prasanth**, F. Sasongko, and J.Pou, "Lifetime estimation of off-the-shelf aerospace power converters," *IEEE Aerospace Electron. Mag*., vol. 33, no. 12, pp. 26-38, Dec. 2018.
- M. Sathik, **S. Prasanth**, F. Sasongko, and J.Pou, "Online condition monitoring of IGBT modules using current-change rate identification," *Microelectron. Reliab.*, vol. 92, pp. 55-62, Jan. 2019.

Conferences:

- **S. Prasanth**, M. H. M. Sathik, F. Sasongko, C. S. Tan, P. Yaxin, and R. Simanjorang, "Condition Monitoring of Electrolytic Capacitor based on ESR Estimation and Thermal Impedance model using Improved Power Loss Computation," in IEEE Proceeding, IPEC/ECCE-ASIA 2018, Niigata, Japan.
- **S. Prasanth**, M. H. M. Sathik, F. Sasongko, T. C. Seng, M. Tariq, and R. Simanjorang, "Online Equivalent Series Resistance Estimation Method for Condition Monitoring of DC-Link Capacitors," in IEEE Proceeding, ECCE 2017, pp. 1773–1780.