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Meaurement of Electrical Parameters of Electrolytic Capacitors Using Real-World Drive Waveforms for State-of-Health Determination

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Abstract—Electrolytic capacitors form an important part of most drive systems. Consequently a method of determining the state-of-health of these capacitors without having to remove them from the system would be of value. In this paper a method of achieving this is proposed. This is achieved by measuring the current through and the voltage across the dc link capacitor within a brushless dc motor drive; from these values the impedance spectrum is calculated. From these measurements the capacitance and resistance values of the capacitor are calculated. This technique forms a useful prognostic tool for power electronic drive systems where changes to these electrical parameters are a good indicator of the state-of-health of the capacitor. Real-world results taken from an experimental system demonstrate that increases in capacitor resistance can be clearly observed.

Keywords—capacitors; Drives; Brushless machines; Prognostics and health

I. INTRODUCTION

Electrolytic capacitors form an important part of most power electronic drive circuits. As a consequence, the reliability of electrolytic capacitors will have a considerable influence on the overall system reliability [1]. Therefore, it is beneficial to be able to determine the state-of-health of electrolytic capacitors during operation and prior to failure. Over the life of an electrolytic capacitor, changes are observable in both the equivalent series resistance (ESR) and capacitance. By monitoring these properties, it is possible to determine the state-of-health of the capacitor.

In this paper, the criteria for a capacitor failure are defined by (1) and (2).

$$C < 0.8 \cdot C_n \text{ or } C > 1.2 \cdot C_n \tag{1}$$

$$R > 2 \cdot R_n \tag{2}$$

where C is the present capacitance; C_n was the value of capacitance when the capacitor was new; R is the present equivalent series resistance of the capacitor and R_n is the ESR of the capacitor when new.

II. ELECTROLYTIC CAPACITOR AGEING

The changes in electrical parameters can be attributed to two key mechanisms:

1. The evaporation of electrolyte. [2, 3, 4]
2. The electrolyte reacting with the insulation material within the capacitor. [5]

Both of these mechanisms contribute to changes within the internal structure of the capacitor, manifesting as a change in the electrical parameters.

III. DETERMINING CAPACITOR PARAMETERS FROM PERIODIC WAVEFORMS

If a capacitor is excited by a periodic waveform, and the resulting voltages and currents are recorded it is possible to calculate the impedance of the capacitor from this data. In a drive system the naturally occurring waveforms are suitable for this purpose. Using these waveforms reduces the amount of additional hardware required considerably when compared to other methods such as the dedicated PRBS testing system detailed in [6]. However great care must be exercised when selecting the excitation waveform and/or measurement frequency to ensure the capacitor's impedances can be accurately measured. For this paper only frequencies with a high power content were considered. Example frequencies with high power content include the harmonics of the switching frequency of the motor drive or the rotation frequency of the machine. Of particular use in this context is the switching frequency, as this will always be present within the drive waveforms regardless of motor speed.

IV. MEAUREMENT METHOD

To capture the data necessary for the calculation of the impedance of the dc link capacitor, two measurements are required: the voltage across and the current through the capacitor. To convert the current into an easily measurable voltage, a LEM LTS15-NP hall-effect current sensor is used. Current and voltage waveforms were recorded using a datalogging oscilloscope and exported to allow processing to be performed offline.

To obtain suitable test data, the drive under test was connected to a brushless dc motor; this motor was further connected to a generator to provide loading torque.

A. Emulation of capacitor ageing

As previously stated, one of the key markers of a failing capacitor is a change to its ESR. It is possible to emulate a change in ESR by adding additional resistance in series with the capacitor and measuring the voltage across the new network, rather than just the capacitor alone. Through the use of non-inductive resistors, the resistors should not influence the measured capacitance, but only the resistance.

V. EXPERIMENTAL RESULTS

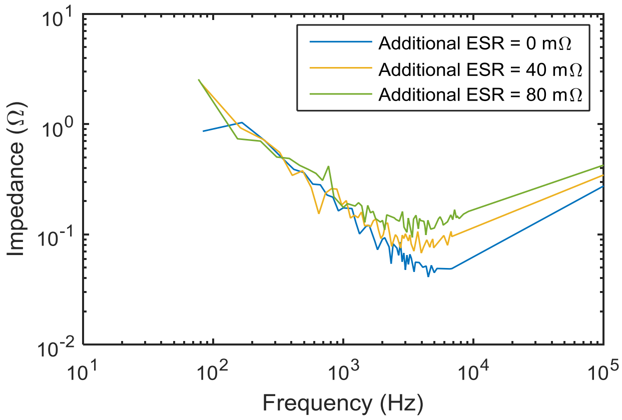

Fig. 1. Impedance of capacitor with additional ESR added (amount labelled)

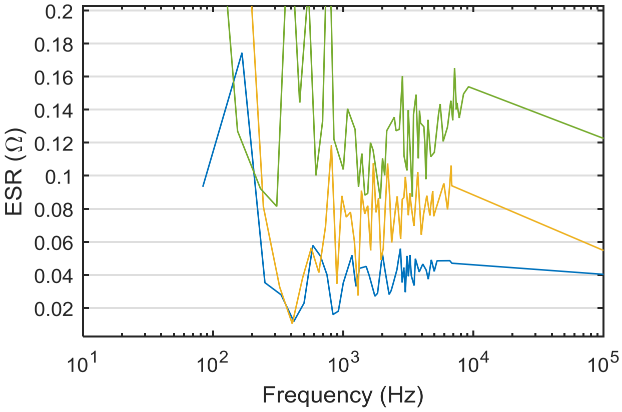

Fig. 2. ESR extracted from impedance values for capacitor with additional ESR added

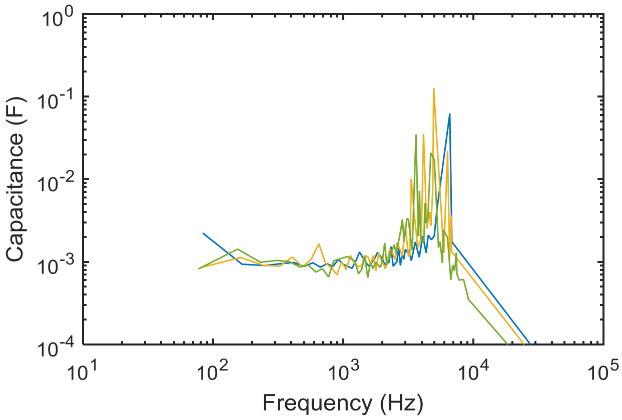

Fig. 3. Capacitance extracted from impedance values for capacitor with additional ESR added

Experimental results are presented here for three configurations: the dc link capacitor (1000µF) and 0 Ω; 40 mΩ and 80 mΩ of additional series resistance. The impedance was calculated as follows: i) the discrete Fourier transform (FFT) of both waveforms is taken to obtain their spectra; ii) the impedance is then obtained by finding the quotient of the spectra. As the impedance spectrum is a complex function, the real and imaginary parts are extracted to find the ESR (real part), and the reactance (imaginary part) from which the capacitance is determined. The results of these calculations for the three test cases can be observed in Fig. 1 to Fig. 3. These results were produced by averaging multiple periods of the drive signal prior to the calculation of the FFTs.

Firstly, in Fig. 1, the impedance of the capacitor is shown. It can be seen here that the impedance of the capacitor at lower frequencies is relatively consistent between the different test cases, but at higher frequencies clear differences can be seen. This is as expected as at low frequencies the impedance is influenced primarily by the capacitance, but at higher frequencies the ESR is the dominant contributor. In Fig. 2, the ESR is shown. In this figure the gridlines are spaced at 20 mΩ intervals, from this it can be observed that the differences in ESR correspond well to the values of the additional resistors being used. Finally, in Fig. 3, the capacitance is shown, as expected this value remains reasonably consistent between the tests as nothing has been done to change the value of the capacitance.

VI. CONCLUSIONS

A method of extracting the electrical parameters which can be used to determine the state-of-health of a capacitor within a drive system has been presented here. From the results it can be seen that this is a viable technique for the determination of these parameters. Validation of this technique has been performed by emulating a failure within the capacitor by increasing its ESR using additional series resistors. It can be seen from the results that these additional resistances are easily observable within the calculated impedances.

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