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Investigation on the Remaining Usefull Life of DC Electrolytic Capacitor

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ABSTRACT

Remaining Useful Life (RUL) prognosis of electrolytic capacitor **(ElCap)** in power converters system focus on investigating the consequence of various working circumstances. However, this is the result of the inverter design parameters on the **ElCap** RUL which is more important for power converter topology designers. This paper parametric investigation on the impact of design parameters of DC electrolytic capacitor. To carry out this inspection the condition of the ElCapis monitored with no stopping its function, moreover, its RUL is calculated for changing the value of network inductance and shoot through duty ratio. The technique proposed in this paper employs information from the simulation model supported on non-linear equations. A dataset of RUL forecasts equivalent to several permutations of operating conditions is achieved through simulations, as well as the identical dataset is utilized to develop an MLR model for RUL prediction.

KEYWORDS: Remaining Useful Life, Multiple Linear Regressions, Capacitor, Power converter.

1. INTRODUCTION

DC-LINK (DCL) capacitors are a significant element in the common of power converters (PCs), and give to repressing DCL **Voltage (V_t)** ripple, engrossing harmonics, with equilibrium the immediate power dissimilarity of PCs [1]. In several functions, they are provided with enough power for transient with unusual actions [2]. Still, capacitors are susceptible to thermal and electrical strains also have the major drawback of a restricted lifespan as well as high degradation breakdown speed [3].

As informed in [3], 30% of the faults in PCs are originated by the dreadful conditions of capacitors, which create them to be well-thought-out as the frailest link in PCs schemes. In this regard, monitoring the poor condition of the capacitor, including system repairs before serious deterioration, or using the consistent action taken by DCL to prevent potentially catastrophic failures, otherwise has a major impact. With reference to this, supervising the poverty condition of capacitors with forecasting repairs prior to severe degradation or failure happens have enormous impact for making sure the consistent action of DCL uses with preventing probable disastrous failures [3].

Over the past two decades, many attempts to understand condition monitoring (CM) for electrolytic capacitors have been completed [4]. Many of them are for capacitors in addition to PCs known as offline systems [1]. Additional are realized on-site in an actual scheme, i.e., real-online and quasi-online schemes.

Here, different types of DCL applications are considered. Moreover, there are different techniques in the methods of implementation. Most systems monitor the DCL capacitor's **Current (C_t)**-V_t, which can be obtained directly from the controller. Supplementary hardware with other sensors is based on signals coming from the circuit. In general, the research objectives of the CM as well as the implementation techniques are different. There is a great need to evaluate this CM system for the following reasons.

- Review the present CM methods also present a reference for the investigators in this field.
- Point of reference various CM systems as well as recognize the compensation and boundaries of them, to offer ideas for engineering application.
- Investigate the accessible disputes as well as investigate upcoming research chances.

In recent times, various outline papers have been issued to analyze the CM methods for DCL capacitors.

In [5], evaluated the consistency of DCL capacitors. On the other hand, their effort mostly centers on the dependability-oriented plan. Simply a to the point conversation on the CM of DCL capacitors is provided. On this basis, presents an evaluation of the CM of capacitors in PCs. Their effort mostly centers on the categorization of the CM methods.

2. DESIGN PROCEDURE FOR CONDITION MONITORING OF DC-LINK CAPACITORS

Quasi-Z-source inverter (QZSI) simulation model is used for data acquisition of ElCaplike C_t and V_t for prognosis using **Remaining Useful Life (RUL).** The QZSI simulation model is very precise; moreover its recital very much looks likes that of the real model of QZSI. As a result, using the QZSI model, the CM of the ElCapcan is generated online, as well as no sensor data is required to calculate the ElCapRUL. Removing the sensor can eliminate errors in the RUL prediction caused by incorrect sensing measurements, and the cost of additional hardware can be set aside.

MATLAB simulation of QZSI model is shown in Fig. 1. The selection of the appropriate V_t or C_t signal based on the shoot through (ShTh) or non-shoot through (nShTh) state of action is prepared by the PC signal produced. For the ShTh function, the pointer is -1 also that pro the n ShTh function, the pointer is one. Capacitor's tire out methods can effect in variations of its inner equivalent series resistance (ESR). So as to practically calculate approximately the ***Equivalent Series Resistance (ESR)*** of the ElCapa suitable form is requireed. Numerous authors have suggested various ElCapforms [1, 2]. The complex impedance is given by Z_{cp} and real part of Z_{CAP} matches with to the ESR which is given by Equation (1) and shown in Fig. 1. Equation (2) proposes that the ESR and frequency are equally dependent. Additionally, it has been essentially accounted that the ESR also based on operating temperature [1, 5, 7, 8, 9, 10, 11].

$$Z_{Cap} = \frac{1}{(\frac{1}{R_d}+j2\pi f\, c_2)} + R_e + R_r - \frac{1}{(2\pi f\, c_2)} \quad (1)$$

$$ESR = \frac{R_d}{(1+(2\pi f)^2\, C_2^2\, R_d^2)} + R_e(T^0) + R_f \quad (2)$$

2.1. FREQUENCY DEPENDENCY OF ESR

The ESR of ElCapis inversely reliant upon the square of the frequency as shown in Fig.2. Additional investigation can be done as ESR at top frequency such as f_t > 2 kHz is almost stable as well as is the same to addition of R_e and R_d, the major cause for this is that C_2 bypasses R_{d2} at higher frequencies. ESR at short down frequency is equal to sum of Dielectric Loss Resistance, Resistance Electrolyte and Resistance of Foil, Tabs and Terminal. ESR at high frequencies i. e. f_t is greater than 2 kHz, which is significantly 20% than ESR at frequency close to 120Hz. In this manner the ElCapcan carry on higher current ripple at higher frequency.

2.2. TEMPERATURE DEPENDENCY OF ESR

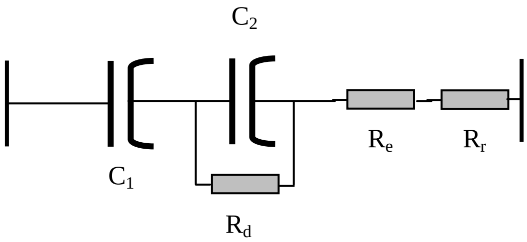
High temperature sources reduce in the ESR as a result of the raise of the electrolyte conductivity. The temperature reliance character is represented in the course of R_d by a base resistance R_{db} as well as an exponential factor, which based on temperature difference as well as a temperature Sensitivity Coefficient and written as Equation (3) and shown in Fig. 3.

$$ESR = \frac{R_d}{(1+(2\pi f)^2\, C_2^2\, R_{db}^2)} + R_e e^{\frac{T_{base}+T_{core}}{E}} + R_f \quad (3)$$

Technical data provided by manufacturer of ElCap, details an additional ample form for the ElCap proven in Fig. 4. **C**$_{Act}$ reduces with rising frequency. Frequent values series from 1uF to 1F. Resistance **ESR** reduces by rising frequency along with temperature. It enhances by rated voltage. Classic values series from 10mΩ to 1 Ω. ESR is inversely proportional to **C**$_{Act}$ for a provided rated voltage. Inductance **Ls** is comparatively free of both frequency as well as temperature. Frequent values series from 10nH to 200nH. It enhances with terminal spacing. Resistance **Rp** reports for seepage current of DCL. It reduces among increasing C, temperature and V_t, and it increases with time. Typical values range from 10/C MΩ with C in μF. The Zener diode **D** models overvoltage and reverse voltage behavior.

3. PROPOSED METHDOLOGY

The block diagram of the Machine Learning based Parametric Investigation on the Remaining Useful Life of DCL is shown in Fig. 5 and specifications are given in Table I. A Buck-Boost converter with a capacitor inductor filter is assembled which has a variable V_0, adjustable switch f and variable I_0.



C_1: Terminal Capacitance
C_2: Dielectric Loss Capacitance
R_d: Dielectric Loss Resistance
R_e: Resistance Electrolyte
R_r: Resistance of Foil, Tabs, Terminal

Fig. 1. Equivalent Circuit diagram of Capacitor [12]

Data Acquisition System (DAS) is used to acquire operating parameters of working the electrolytic capacitor under load. T_C, V_O, I_R of the ELCap is obtained with (DAS). The collected $\mathbf{V_t}$ and $\mathbf{C_t}$ in the form of analog signals are collected and converted into digital form. The collected values of $\mathbf{V_t}$ and $\mathbf{C_t}$ are used to find out remaining usefull life of DCL. Particular factors from the datasheet are furthermore used in RUL form. The RUL calculation of the DCL is computed with life time model. Finally forecasted RUL of the DCL is presented.

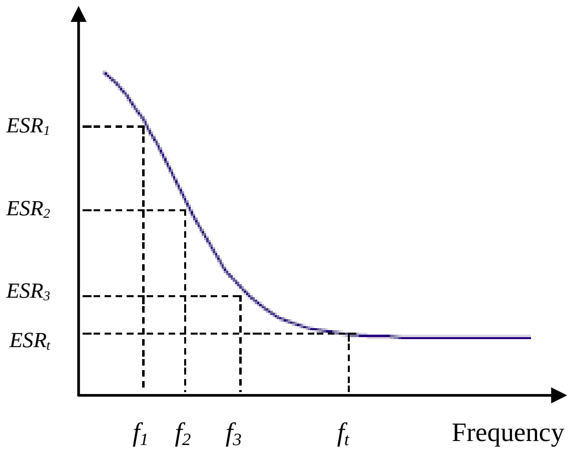


Fig.2. Frequency Dependency of ESR

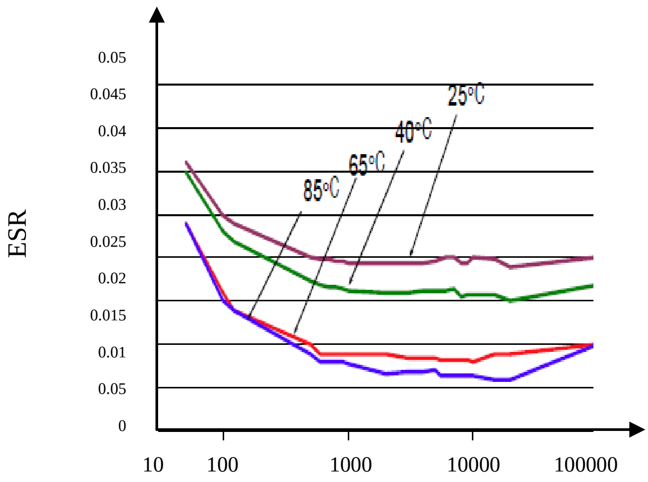


Fig.3. Temperature dependency of ESR

Table I. Parameters from the datasheet of aluminum electrolytic capacitor

Parameters from the datasheets	Symbol	Values for the 330 µf Capacitor
Lifetime at nominal ripple and upper category temperature	L_o	2155 h
Upper category temperature	T_o	79°C
Nominal ripple current at upper category temperature	I_o	0.474A
Rated voltage	U_r	41 V

Technical data provided by manufacturer of ElCap, details an additional ample form for the ElCap proven in Fig. 4. $\mathbf{C}_{Act}$ reduces with rising frequency. Frequent values series from 1uF to 1F. Resistance **ESR** reduces by rising frequency along with temperature. It enhances by rated voltage. Classic values series from 10mΩ to 1 Ω. ESR is inversely proportional to $\mathbf{C}_{Act}$ for a provided rated voltage. Inductance **Ls** is comparatively free of both frequency as well as temperature. Frequent values series from 10nH to 200nH. It enhances with terminal spacing. Resistance **Rp** reports for seepage current of DCL. It reduces among increasing C, temperature and V_t, and it increases with time. Typical values range from 10/C MΩ with C in µF. The Zener diode **D** models overvoltage and reverse voltage behavior.

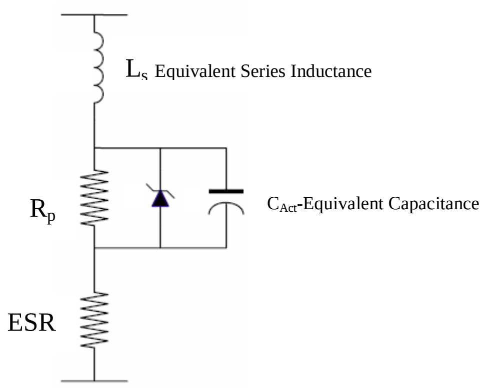


Fig. 4. Manufacturer Capacitor Model

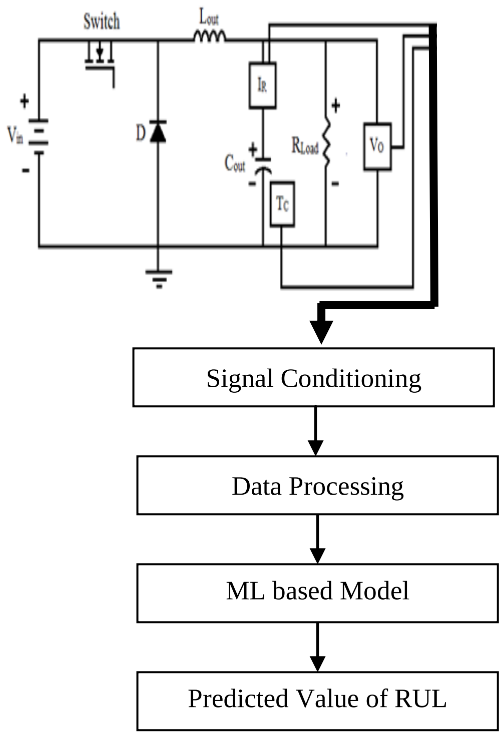


Fig. 5. Proposed Methodology

4. RESULTS AND DISCUSSION

The whole experimental setup to test the performance of the proposed method is shown in Fig. 6. Results obtained from the experiment are listed in Table V. Simulation results are listed with the experimental results. The difference between simulation result and experimental result are small and thus validates the proposed method. The dataset which is used to train the RUL model based on Machine learning is shown in Table II, Table III and Table IV for various operating conditions.

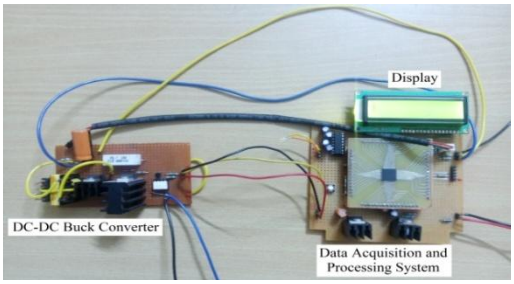


Fig. 6. Experimental setup for data collection

Table II. Lifetime of Electrolytic capacitor at $V_{O\ at}$ Temperature 42 °C

Operating Voltage (V_O) (Voltage)	**Ripple Current (I_R) (Amperes)**	**Lifetime (L_t) (Hours)**
17	0.629	415873.844
19	0.629	353604.936
21	0.629	303172.032
22	0.629	261891.400
24	0.629	227777.635
26	0.629	175446.778
27	0.629	155224.080
28	0.629	137993.642
33	0.629	144852.241
35	0.629	103778.345
36	0.629	088545.260
39	0.629	075918.131

Table III. Lifetime of Electrolytic capacitor at voltage 40 V

Ripple Current (I_R) (Amperes)	**Operating Temperature (T_O) (°C)**	**Lifetime (L_t) (Hours)**
0.629	5	640000.000
0.629	10	452548.339
0.629	15	320000.000
0.629	20	226274.169
0.629	25	160000.000
0.629	30	113137.084
0.629	35	080000.000
0.629	40	056568.542
0.629	50	028284.271
0.629	55	020000.000
0.629	60	014142.135
0.629	75	005000.000

Table IV. Lifetime of Electrolytic capacitor at $V_{O\ at}$ Temperature 40 °C

Operating Voltage (V_O) (Voltage)	**Ripple Current (I_R) (Amperes)**	**Lifetime (L_t) (Hours)**
40	0.385	79436.162
40	0.475	66041.734
40	0.565	52824.170
40	0.655	40650.032
40	0.835	21436.768
40	0.925	14690.261
40	1.015	9685.314
40	1.105	6143.444
40	1.195	3749.075
40	1.285	2201.153
40	1.375	1243.342
40	1.465	675.686

5. CONCLUSION

Remaining Useful Life prognosis in power converters system focuses on investigating the consequence of various working circumstances. However, this is the result of the inverter design parameters on the RUL which is more important for power converter topology designers. The proposed method of Multiple Linear Regressions for a parametric investigation on the impact of design parameters of DC electrolytic capacitor is proved. The technique proposed in this paper employs information from the simulation model supported on non-linear equations. The difference between simulation result and experimental result are small and thus validates the proposed method.

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