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Estimation of Residual Lifetime of Electrolytic Capacitor using Analytical Techniques

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Abstract**:** ***In the fast-evolving era of digital electronics, reliability has become a critical issue. Due to failure and faults, the component manufacturers face market reputation degradation as well as financial set back. The condition monitoring for power electronics are based on basic principles; however, by analyzing failure modes of semiconductor devices and exploring appropriate techniques, situation has been improved a lot. From toy to satellite, an electrolytic capacitor is mostly used as an important component. This paper enlightens the estimation of residual lifetime of electrolytic capacitor using analytical techniques, so that these components can be reused and problem of WEEE (Waste of Electrical and Electronic Equipment) can be reduced to a large extent. The residual life of electrolytic capacitor is calculated using various analytical and mathematical technique. Accuracy of empirical standard prediction methods such as military handbook MILHDBK and RIAC217 is compared for the residual life prediction of electrolytic capacitor. RIAC217 plus technique proves to be more accurate than MILHDBK or other standard techniques. By predicting the residual life, the capability of re-use the component increases and problem of e-waste is decreased to a great extent. Thus, the residual lifetime prediction is a critical parameter for successful operation of device as well as safe healthy environment.***

Index Terms**:** ***Electrolytic capacitor, Health monitoring, Military handbook, Mathematical modelling, Reliability, RIAC 217 plus, WEEE.***

I. INTRODUCTION

To continue working without failure reliability of a component is defined as the capacity. Reliability for safety critical applications, which determines the quality of the electronic equipment, is one of the essential characteristics, both manufacturers and customers of electronic components and a common way to define the need to predict reliability. Reliability prediction during his life without failure to perform its required function component is the ability to predict the process [1].

Traditionally, the electronic components reliability and condition monitoring can be estimated by one of the three methods: using standard handbook e.g. MIL-HDBK-217, TELECORDIA etc. which are based on the simulated data, computational analysis of operating & maintenance data sheet and by performing life testing experiments [2].

The books or literature on failure modes and its effect analysis generally deal with the functional failure of components and electronic devices. But the failures and faults are majorly depending on the device behavior under various environmental and electrical conditions and manufacturing defects. For example, V-I characteristics of PN junction diode are helpful for condition monitoring and health prognostics. Similarly, the IC fabrication techniques can affect the afterwards reliability of component a lot.

II. RELIABILITY AND FAILURE PREDICTION

To qualify a single component, a manufacturer or designer can do ample number of tests, but when these components act as in group, the scenario is different. The change in one component's parameters can affect the whole device. As the whole world is after high speed and small devices, it is responsibility of designer to do integration in such a way that there will be no cross effects of each and every component[3]

Failure prediction is the evaluation of life span of a component or device, at which that device performs as it intends to do. The electronic components often confront two types of failure i.e. intrinsic failure and extrinsic failure.

- The failure which occur, once the product is in market, related to manufacturing phase is called intrinsic failure.
- The failure which occurs during life span of components due to overload conditions such as thermal, environmental etc. are called extrinsic failures.

Lifetime evaluation is an important paragon for accessing and evaluating the faults and failures. The relation between failure and time is mentioned using bath tub curve which identifies and explores three stages of failure evolution [4]:

- The initial phase, where failure rate has been decreased,
- The constant phase, having constant failure rate,
- The wear-out phase, having extensive increasing rate of failure.

There are many factors which causes failure of an electronic device such as thermal effect, environmental effect, mechanical or electrical overloading etc. The failure can be done at packing level due to solder joints [5].

The electronic components have a vital role in army related vehicles. Where the operating conditions are different. The harsh and dynamic environment makes failure of device more frequently. Physics of failure while combined with FEA can be employed to examine the reliability performance of army vehicles[6].

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III. FAILURE MODES AND EFFECT ANALYSIS

The failure of capacitor can fail the entire system. Apart from capacitance, the electrolytic capacitor has inductance. The series and parallel resistance make it possible for capacitor to conduct[7].

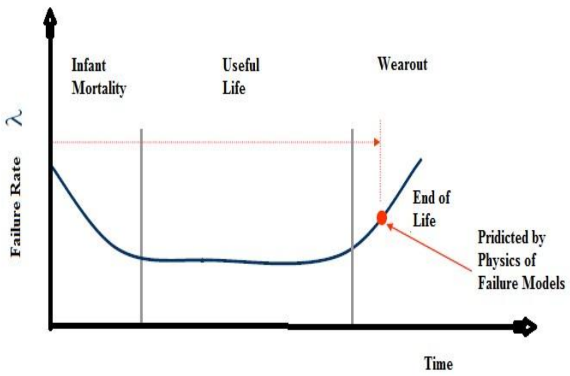

Figure 1: Bath tub curve

The end of life test can be conducted on the different capacitors, which will give the threshold value of that component. After choosing the critical component, neural networks can be applied for learning process and the system performance can be shown using linguistic variables[8].

A. Failure modes of an electrolytic capacitor

The electrolytic capacitor is the critical component that is widely used in small machines to satellite. The failure of capacitor is very dangerous for mankind. The cheap and small size of capacitor justify its enormous application era. In Taiwan, the capacitor plague deteriorates the market reputation and decreases the GDP rate due to failure of capacitor. It further increases the replacement and repair cost of device, as the failure occurs during warranty period[9]. Analysis of the deterioration explores that case rapturing or corrosion has put a lot of Taiwanese manufacturers under loss, during year 1999 to 2007 [10].

The life of an electrolytic capacitor is focused on its application area. Various over-rated electrical parameters and environmental stress factors degrade the performance of an electrolytic capacitor to a great extent. The electrical parameters are mostly voltage and current, whereas the environmental stress factors are temperature, shock and drop, humidity or pressure[11].

When the electronic device or system is exposed to different environmental conditions, there is risk of faults and failures in individual components which can further degrade the entire system[12]. The reasons for failure of electrolytic capacitors are wide, some are enlisted as following[13]:

1. Leakage of electrolyte
2. Evaporation of electrolyte
3. Over heating or over voltage
4. Corrosion
5. Voltage surge
6. Heat and Aging effect
7. Mechanical damage such as shock and vibration
8. Harsh environment conditions such as temperature

The Figure 2. is also known as fishbone diagram, as it describes the causes of failure as well as its effect on the performance as well as life of the components in use[14]. There are so many consequences related with the degradation of electrolytic capacitor. Loss or evaporation of electrolyte further reduces the weight of the capacitor[15]. As the weight is decreased, it further decreases the capacitance, subsequently the ESR value rises. A threshold value of capacitance is calculated and as the capacitance decreases below its threshold value, the capacitor stops charge storage or filtering process. So, the root cause is blend of over-rated electrical parameters, stress factors or manufacturing defects[16].

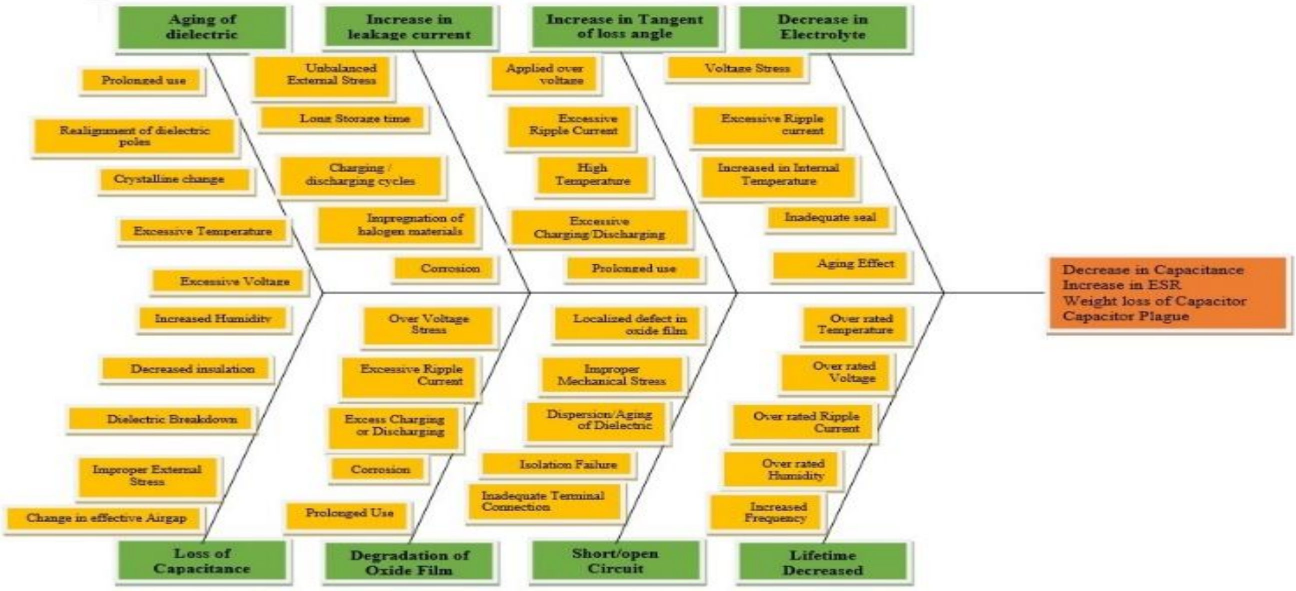

Figure 2: Cause and Effect diagram of electrolytic capacitor

B. Failure criterion of an electrolytic capacitor

An electrolytic capacitor is under fault and failure, if it satisfies any of the following mentioned failure criterions.

The values of ESR, weight and capacitance are measured at start and end of experiment[17].

Figure 3: Failure criterion of electrolytic capacitor

The failure conditions of an electrolytic capacitor are:

1. If the capacitance isreduced by 20% of its original value.
2. If the weight of capacitor is decreased by half of its original weight.
3. If the equivalent series resistance ESR is doubled of its original value.

These above mentioned conditions are key parameters to estimate the real time condition of the capacitor[18]. The user can judge the evaporation of electrolyte by the reduction in weight of the capacitor in use.

C. Effect of failure on an electrolytic capacitor

In power electronics applications, the role of an electrolytic capacitors is recommendable[19]. The failure of the electrolytic capacitor can degrade or destruct the entire system which cause permanent failure or breakdown[20]. Failure is due to reduce the electrolyte. So, life prediction is necessary, for the cases where aluminum electrolytic capacitors have been used since long.

IV. RESIDUAL LIFETIME ESTIMATION TECHINQUES

The various types of failures and faults related to electrolytic capacitor is discussed in previous section. If the failure or fault is predicted well before it actually occurs, then lot of replacement cost and efforts can be saved[21]. The residual lifetime can be calculated using analytical techniques. It consists of empirical methods as well as mathematical technique[22].

The empirical technique is the standard technique that is used by various industries. This is based on the historical data of component failure and the experience recorded by the user[23].

A. Military Handbook 217F technique

MILHDBK-217F is very well known as a reliability prediction model in military applications. The failure rate using military handbook can be calculated as:

$$\lambda = \sum_{i=1}^{n} (\lambda ref, i * \ \pi S * \ \pi T * \pi E * \pi Q * \pi A) \qquad (1)$$

Where:

$\lambda b \ and \ \lambda re$= Failure rate at Base and Reference conditions

S,T,E and Q are failure factors of stress, temperature, environment and quality respectively.

πA=Adjustment factor

The residual lifetime of electrolytic capacitor can be calculated by inserting the different values of temperature, humidity, current and voltage in equation (1).

B. RIAC-217 plus technique

In year 2006, The defense department of United States launched a reliability handbook RIAC217+ with the association of Reliability Information Analysis Center (RIAC). This is the advanced version of military handbook MILHDBK-217 and PRISM technique. Various types of base failure rates at different operating conditions are considered in this version of reliability handbook[24]. The lifetime of a capacitor using RIAC217+ is calculated using following formula:

$$\lambda = \Pi g \Pi c(\lambda ob.\Pi dc.\Pi to.\Pi s + \lambda eb.\Pi dcn.\Pi te + \lambda tc.\Pi cr.\Pi dt) + \lambda sjb.\Pi sjdt + \lambda eos \qquad (2)$$

Where:

λ =base failure rate

ob for operating; eb for environmental; tcb for Temperature Cycling; sjb for solder joint; eos for electrical overstress

Π=failure rate factor

g for growth; dc for duty cycle; t for temperature; s for stress; dt for delta temperature; sjdt for solder joint delta temperature.

By inserting various combination of temperature, voltage, humidity and current in equation (2), residual lifetime can be calculated.

C. Mathematical Modelling of electrolytic capacitor

The mathematical modelling of the electrolytic capacitor depends on the lifetime claimed by manufacturer and acceleration factors[25]. The acceleration factors for electrolytic capacitors are ripple current, voltage, temperature and relative humidity (Rh).

$$Lifetime = Datasheet\ Life \ \times A_T \times A_V \times A_I \times A_H \qquad (3)$$

$$Lifetime = Datashet\ Life \times \ 2^{\frac{(Tm-Ta)}{10}} \times \left(\frac{Va}{Vm}\right)^{-n} \times Ki^{A\frac{\Delta T}{10K}} \times \exp\{C \ \times ((RHa)^n - (RHm)^n)\} \qquad (4)$$

Where:

m is Maximum and a is applied temperature

C= Humidity Constant=0.00044

A_T, A_V, A_I and A_H are the acceleration factors for temperature, voltage, current and humidity respectively.

V.COMPARISON OF RESIDUAL LIFETIME USING VARIOUS ANALYTICAL TECHNIQUES

The residual lifetime of electrolytic capacitor is calculated using various techniques such as military handbook, RIAC 217F plus as well as mathematical technique. An electrolytic capacitor is chosen with 100µf capacity and lifetime claimed by datasheet is 2000 hours. Using DOE, Taguchi approach, 16 combination of all the factors are designed [26]and remaining useful lifetime of electrolytic capacitor is calculated as below mentioned table[27].

Table 2. Lifetime comparison of various analytical techniques

Run	Factors (Actual form)				Lifetime (hours) using Mathematical method	Lifetime (hours) using Military Handbook	Lifetime (hours) using RIAC217 plus
	Temp (^{O}C)	current (mA)	Humidity (%Rh)	Voltage (Volts)			
1	87	26	80	5.8	8220.1	8546.3	7277.2
2	87	28	82	6.0	7648.2	4802.7	5667.3
3	87	30	84	6.2	7110.1	2750.4	4228.5
4	87	32	86	6.4	6639.1	16032.3	10500.2
5	94	26	82	6.2	4079.2	2508.1	3415.4
6	94	28	80	6.4	5087.1	14619.8	12187.2
7	94	30	86	5.8	4027.8	7793.3	8012.3
8	94	32	84	6.0	5077.3	4379.5	3424.3
9	101	26	84	6.4	2102.4	1337.7	2079.2
10	101	28	86	6.2	2070.3	2295.1	3010.1
11	101	30	80	6.0	3716.1	4007.5	3887.1
12	101	32	82	5.8	3684.1	7111.3	6976.1
13	108	26	86	6.0	1185.1	3679.1	4376.4
14	108	28	84	5.8	1569.3	6546.8	7001.8
15	108	30	82	6.4	1827.6	1228.2	3004.4
16	108	32	80	6.2	2438.3	2106.9	2727.2

This table depicts the calculated lifetime using various techniques, with combination of different variables.

VI. ACCURACY OF ANALYTICAL TECHNIQUES

The accuracy of all the analytical techniques can be compared with the lifetime as claimed by manufacturer. The datasheet claims the lifetime of the electrolytic capacitor as 2000 hrs. Table 3 summarizes the variation from the claimed data sheet. The accuracy graph is plotted between mathematical technique, military handbook and RIAC217F technique with respect to lifetime claimed by datasheet.

Figure 4 shows the graphical comparison in between all the three analytical techniques, which shows that component serves at extended lifetime as compare to datasheet lifetime. On an average, RIAC217F predicts the lifetime value closest to datasheet value. The lifetime is different at different combination of stress parameters. It indicates the user to replace or reuse the capability of electrolytic capacitor.

VII. CONCLUSION

In the era of fast developing electronic industry, integration is the prime rule. But the failure of one component can degrade the whole system. Residual lifetime of electrolytic capacitor is estimated using analytical techniques i.e. mathematical, empirical method MILHDBK as well as using RIAC217F technique. An accuracy chart is plotted which shows the lifetime of electrolytic capacitor with respect to the lifetime as claimed by manufacturer. This analysis will help the consumer to use the component at various combination of input parameters. This will enable the user for reusing the component or replacement of faulty component well before the actual destruction

Table 3. Accuracy comparison of analytical techniques

Run	Mathematical	MILLHDBK	RIAC217
1	75.6694	76.59806	72.5169
2	73.85006	58.35676	64.70983
3	71.871	27.2833	52.7019
4	69.87543	87.52518	80.95274
5	50.97078	20.25836	41.44171
6	60.68487	86.31992	83.58934
7	50.3451	74.33693	75.03838
8	60.60899	54.33269	41.5939
9	4.870624	-49.5104	3.809157
10	3.395643	12.85783	33.55702
11	46.18014	50.09357	48.54776
12	45.71266	71.87575	71.33069
13	-68.7621	45.63888	54.30034
14	-27.4454	69.45072	71.43592
15	-9.43314	-62.8399	33.43097
16	17.97564	5.073805	26.66471

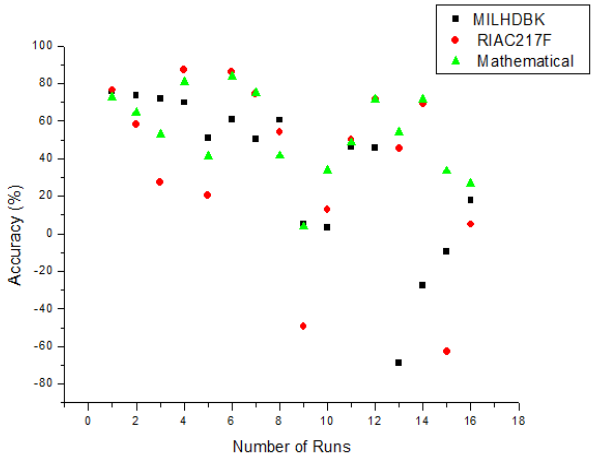

Figure 4: Accuracy comparison of analytical techniques

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