DSSCC: Decision Support System for Ceramic Capacitor using Fuzzy Logic

Cherry Bhargava, Shivani Gulati, Pardeep Kumar Sharma

Abstract*: As the technology advances, the reliability becomes the main constraint for the successful operation of the electronic product. To fully automate the system, the electronic devices become more and more complex. Reliability becomes a challenge with the regular demand of low cost and high-speed devices. Residual life estimation of passive devices such as resistor, capacitor etc. is of a great concern. Failure of one small component can lead to fully damage of whole system. In this paper, a practical approach i.e. accelerated life testing is deployed to calculate remaining useful life of the ceramic capacitor. An intelligent model is formulated using various artificial intelligence techniques. Artificial Neural Network (ANN), Fuzzy Inference System (FIS) as well as Adaptive Neuro Fuzzy Inference System (ANFIS) are deployed to predict the remaining useful lifetime of an electrolytic capacitor. An error analysis is conducted to estimate the most accurate intelligent technique. A fuzzy based decision support system is modelled, which provides an interactive GUI to users. The user can access the live health status of electrolytic capacitor at various input parameters. It will warn the user to replace or repair the upcoming fault in the component or device, before it actually degrades or shut downs the complete system. The comparative analysis of all the artificial intelligence techniques shows that Adaptive Neuro Fuzzy Inference System (ANFIS) has the highest accuracy i.e. 99.5%, as compare to Artificial Neural Network (ANN) and Fuzzy Inference System (FIS), where accuracy rate is 98.06% and 97.84% respectively. This prediction system is helpful to reduce the problem of electronic e-waste by enabling the user to reuse the component.

Index Terms*: Artificial Intelligence (AI), ANFIS, Ceramic capacitor, GUI, Residual life.

I. INTRODUCTION

A failure or fault is change of properties of system, in such a way that its functioning is seriously affected. Manufacturers often perform various experiments and tests before final release of product in the real market. By this method, a datasheet is prepared. But, when the product is launched for real time operation, it experiences variable operating conditions and environmental factors that deviate its lifetime from claimed lifetime [1]. By considering the real time operation, critical factors are decided and their effect on performance of product is computed. Residual life of the electronic product is analysed using experimental approach. An intelligent model is prepared which estimates the remaining life of ceramic capacitor. The residual life of ceramic capacitors is relied on different environmental and electrical conditions. The major conditions are temperature, humidity and vibration. The critical electrical factors are operating voltage, ripple current and dissipation factor. Except these factors such as temperature i.e. ambient temperature is also effective to the working period of ceramic capacitors [2]. In this paper the experimental observation on ceramic capacitor deterioration under various operating conditions is discussed and various experimental and intelligent techniques are deployed for health prognostics.

Ceramic capacitor

A capacitor is a device to store charge. There are various types of capacitors such as ceramic capacitor, electrolytic capacitor, paper capacitor, film capacitor etc. In a ceramic capacitor, the dielectric material is fixed ceramic. It is constructed of two or more alternating layers of ceramic and a metal layer acting as the electrodes [3]. The structure of a ceramic capacitor structure is depicted as in Figure 1.

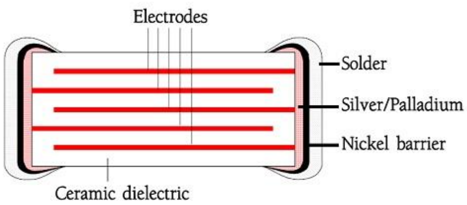

Figure.1 Structure of a ceramic capacitor

A fine mixture of paraelectric or ferroelectric granules are used to compose ceramic capacitors and desired operating conditions are formulated [2]. The operating conditions like temperature, voltage, current and frequency have a strong impact on the performance and useful life of ceramic capacitor. The typical ceramic capacitor is as shown in figure 2. By accelerating or reducing the operating conditions, the health of the capacitor may be deterioted.

Figure. 2 A pictorial view of ceramic capacitor

Due to change in temperature, ceramic capacitors experience non-linear behavior. This

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property enables the ceramic capacitor to be used as bypass capacitor or decoupling capacitor.

A major cause for mortification in ceramic capacitors is due to destruction of capacitor ability as the ions exchange during the charging and discharging of capacitor that leads to a deviate in the two main electrical parameters first, is the equivalent series resistance (ESR) and second is the capacitance. The frequent approaches of failure for ceramic capacitors are shown in figure 3 and the analogy between main causes and failure approaches of capacitor is identified [4]. Due to vary in temperature, voltage, humidity and other mechanical defects, the life of ceramic capacitor degrades and performance is deteriorated [5]. As per specification under normal working mode, capacitor is not able to work properly in the circuit when its efficiency is 40% consumed then its initial value [6]..

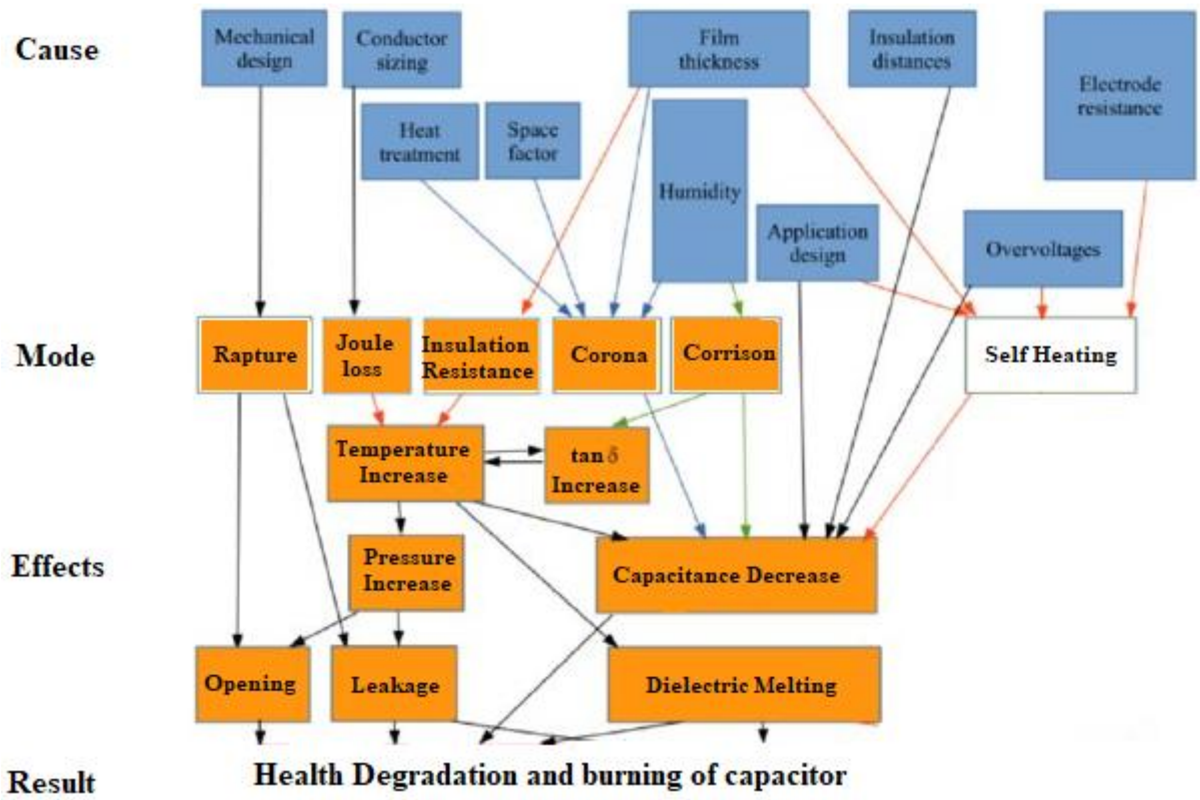

Figure.3 Cause and effect diagram for ceramic capacitor failure

II. METHODS AND MATERIALS

In this paper, the residual life of ceramic capacitor is predicted using experimental as well as artificial intelligence techniques [7]. The experimental techniques include acceleration life testing technique and the artificial intelligence techniques include ANFIS, FL and ANN are employed to formulate the design of an intelligent model [8, 9]. The flowchart of complete process is depicted in figure.4

A. Critical parameters affecting life of capacitor

The useful life of an ceramic capacitors is mostly relying on various environmental factors and operating conditions where environmental factors are temperature, humidity, vibration and shock etc.[10]. Out of these factors, ambient temperature is the most critical and important parameter for the life of multilayer ceramic capacitors [11] whereas; the various other conditions such as excessive voltage, humidity or vibration have little impact on the actual life of the capacitor [12].

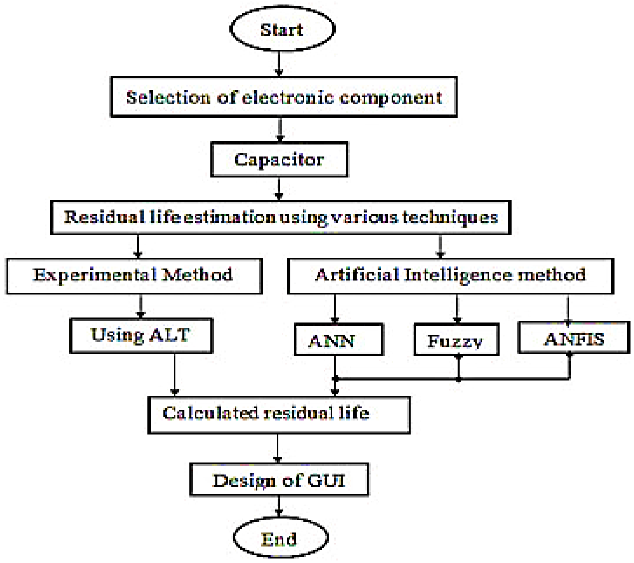

Figure.4 Flowchart for life estimation techniques

B. Temperature

A capacitor is basically an electro-chemical gadget in which increased temperature maximize the chemical reaction rates inside the capacitor (normally with a 10°C rise in temperature, the chemical reaction rate become twice). The higher temperature cause maximum changes in value of capacitance and dissipation factor because of continuous dissipation of the electrolyte through the capacitor seal and the equivalent series resistance that is a measure of electrolyte loss also changes with change in temperature [13]. So, the higher temperature changes affect the lifetime of a capacitor [14].

III. LIFE ESTIMATION USING EXPERIMENTAL METHOD (ALT)

The experimental approach is adopted by the research unit or manufacturing assemblies where huge quantity of sample is supposed to be tested under various electrical and environmental conditions. ALT i.e. Accelerated Life Testing is one of the approaches, where the selected sample is tested over exceeding conditions as suggested in datasheet. The ceramic capacitor of 0.01 microfarads of part no. CC103 of Murata Company was used for testing. Initially, the parameters of ceramic capacitor were measured by regular inspection of the capacitance with the help of LCR meter. This kind of test is imposed on approximately twenty similar ceramic capacitances[15].

The steps involved in ALT is summarised as:

1. Measure the initial parameters i.e. temperature, voltage, humidity of given ceramic capacitor.
2. Cover all the samples of ceramic capacitor with sand and put on hot plate.
3. Increase the temperature beyond the temperature i.e. 125^{o}C as suggested by datasheet. Wait till the temperature rises to desired temperature.
4. Keep the process run for 240 hours.
5. Measure the capacitance and associated parameters of all the capacitors by LCR and analyse how many are de-functioning.
6. Calculate the residual life using Arrhenius equation as described below:

$$Life = \frac{1}{Devices \times Operational\ time} \times e^{\frac{Ea}{K}\left[\frac{1}{T1} - \frac{1}{T2}\right]}$$

Where, E_a is activation energy of capacitor and K is Boltzmann's constant, T_1 is applied temperature, T2 is maximum temperature

Figure.5 Experimental setup for residual life calculation

IV. LIFE ESTIMATION USING INTELLIGENT MODELLING

Intelligent modelling is used to design an expert system which estimates the residual life of ceramic capacitor using various artificial intelligence techniques.

A. Remaining useful life prediction of ceramic capacitor Artificial Neural Network

Based on the structure and functions of biologic neural networks, a model is designed using artificial neural networks[16]. The system gets trained and tested using MATLAB software [17]. Temperature and time are the input parameters whereas residual life is output parameter. The 2-10-1 model is deployed in artificial neural network, which signifies that there are two input layers, 10 hidden layers and 1 output layer[18].

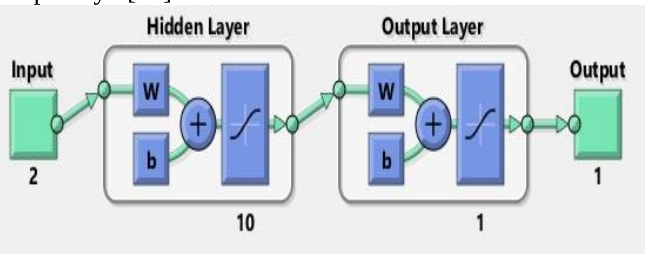

Figure 5 ANN structure of ceramic capacitor

B. Remaining useful life prediction of ceramic capacitor using Fuzzy inference model

To handle the data ambiguity and uncertainty, fuzzy inference system is incorporated [19]. With the increase in system complexity, it is difficult to access the behavior of system. The traditional methods of digital system fail in such complicated cases. For this purpose, linguistic variables are used in fuzzy logic which are user friendly [20]. Entire input set is known as crisp Set which after fuzzification converts into fuzzy sets [21]. In Fuzzy Inference System, certain rules are defined for fuzzification that defines crisp relation into fuzzy relation in IF, THEN, ELSE format, such as:

IF (F is x_1, x_2.....a_n) THEN (G is y_1, y_2….y_n)

These rules are used to obtain the residual life of the ceramic capacitor.

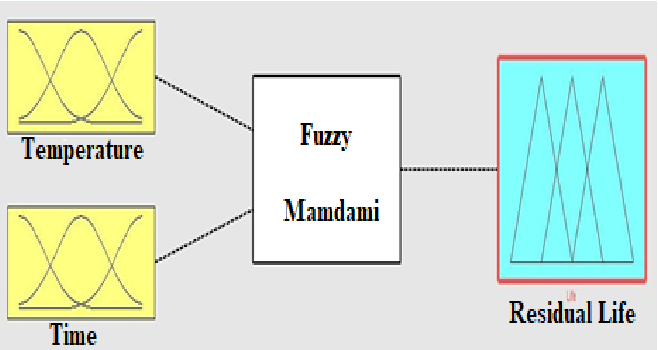

Figure 7. Ceramic capacitor fuzzy response

C. Remaining useful life prediction of ceramic capacitor using Adaptive Neuro-Fuzzy Inference System (ANFIS)

Adaptive Neuro Fuzzy Inference System is a hybrid technique comprises both ANN as well as fuzzy tool [22]. It has advantage of both the technique as ANN has this self-learning mechanism but it has the disadvantage that is the output is not that user understandable. It cannot handle ambiguity. On the other hand, the advantage with fuzzy logic is that it can handle uncertain data and also linguistic variable can be used to have better understanding but no self-learning is there [23].

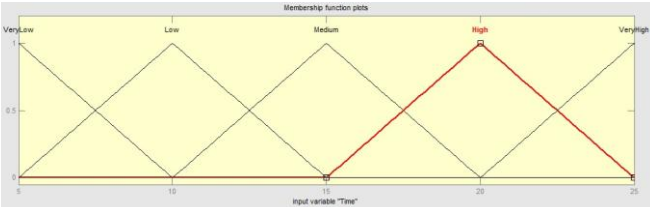

Figure 8 Membership function for input variable 'time'

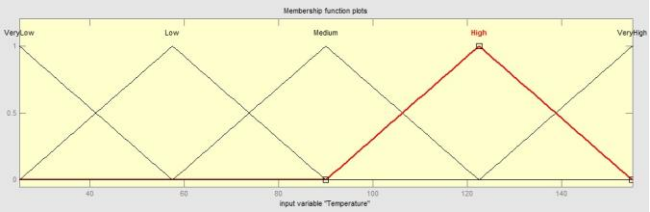

Figure 9 Membership function for input variable 'temperature'

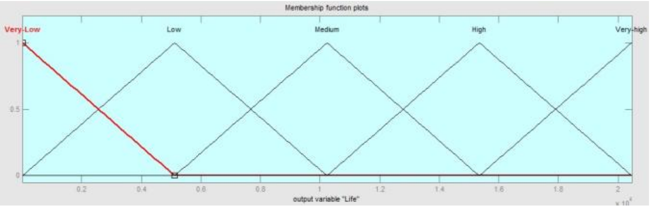

Figure 10 Membership function for output variable 'residual life'

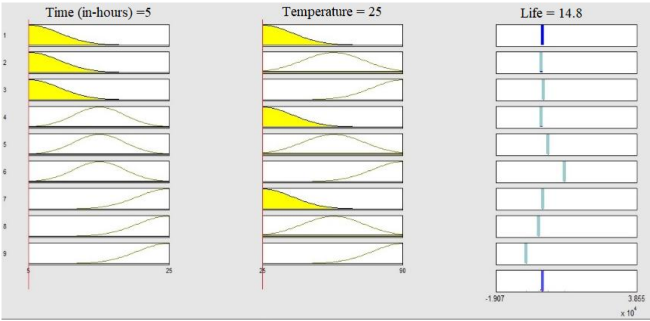

Figure 11 Rule viewer

Hence to combine each other advantages, these two techniques have been combined to formed third technique that is ANFIS. The rules needed by fuzzy get self-updated through the self-learning mechanism possessed by ANN. That's why less number of errors is shown by the predicted data of ANFIS [24].

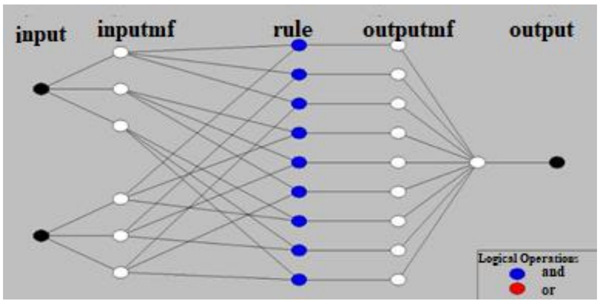

Figure 12 Ceramic capacitor ANFIS structure

D. Design of graphical user interface (GUI)

Graphical User Interface is an interactive platform to access by the user, by which the user can monitor the real time health condition of the ceramic capacitor. This decision support system is designed using fuzzy logic. With the help of this useful interface, a user can interact with the intelligent system to check the performance ratio as well as remaining useful life of the ceramic capacitor [25]. The input parameters to this GUI are temperature and time, whereas the residual life of ceramic capacitor acts as output parameter for this decision support system[26]. This system helps the user to change the component or reuse the component by looking into the real time health condition of ceramic capacitor.

V. RESULT AND DISCUSSION

This paper is mainly focused on the calculation and analyze the life estimation of ceramic capacitor. Various experimental as well as analytical techniques are explored to estimate the remaining useful life of a ceramic capacitor. The capacitor's lifetime was calculated using the methods and the residual life time calculated by each method is noted. The average lifetime obtained using different techniques and the accuracy obtained is summarized as in table 1. After analysis of various techniques, it is found that the ANFIS method provides the least error to predict the useful life of ceramic capacitor i.e. 0.05% as compare to ANN which has error 1.94% and Fuzzy generates error 2.16%.

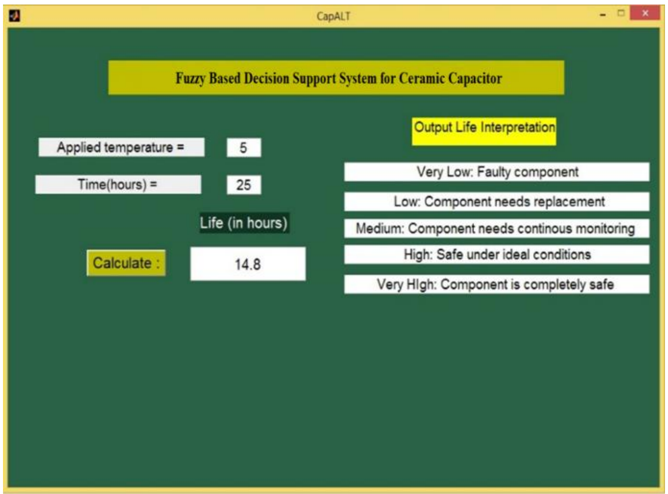

Figure 12 Results obtained in designed GUI

Table 1. Residual life estimation of ceramic capacitor

Techniques	Remaining Useful Life using experimental technique (hours)	Remaining Useful Life using ANN (hours)	Remaining Useful Life using Fuzzy (hours)	Remaining Useful Life using ANFIS (hours)
Residual Lifetime of ceramic capacitor (hours)	1185.28	1162.23	1210.889	1192.11
Average error %	-	1.94%	2.16%	0.5%

Accuracy %	-	98.06%	97.84	99.5%

VI. CONCLUSION

The ceramic capacitor is explored at various electrical and environmental conditions to estimate its remaining useful lifetime. Accelerated life testing is deployed as experimental technique and Arrhenius method is used as analytical technique for detailed insight. An intelligent modelling is done and expert system is modelled using artificial intelligence techniques. A comparison is made between the result of various artificial intelligence techniques such as ANN, FL as well as ANFIS. It is concluded that ANFIS is the most reliable and accurate technique with the accuracy 99.5%. A fuzzy based GUI is designed for the consumers to understand the real time health monitoring of the ceramic capacitors.

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