Reliability Prediction of Thyristor using Artificial Intelligence Techniques

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Abstract

Objective: To use temperature and duty cycle as a health assessment tool for implementing prognostics and health management in thyristor and which can be further implemented to various other electronics components. Methods: To predict the reliability of thyristor, statistical approach has been identified and analysed for its life prediction. The military handbook MIL-HDBK-217F N2 and Reliability Information Analysis centre RIAC 217Plus™ failure models are explored. Further in order to verify and validate the effectiveness and reliability of these systems, both MIL-HDBK-217F N2 and RIAC 217Plus™ reliability results have been compared. Findings: The operational parameters and modelling of thyristor have been selected and life prediction analysis is carried out. The analysis has been identified by using statistical methods. The various conditions such as temperature, stress and design parameters have been explored and screening has been done to improve reliability. It has been analysed that input current and temperature are the decisive parameters that affects the health and failure mechanism of thyristor. The study of model parameter with respect to variation in stress parameters have been carried out. Novelty: To validate the effectiveness of developed system, both MIL-HDBK-217F N2 and RIAC 217Plus™ assessment prediction equations are compared.

Keywords: Duty Cycle, Failure Rate, Heuristic Technique, Junction Temperature, MIL-HDBK-217F N2, RIAC 217Plus™

1. Introduction

Sensor technology can very well inform the operator, about the current working of a device but in case of failure of an electronics circuit, it is not possible for sensor conditioning monitoring system to indicate or check which electronic component in the whole circuit has been stop working or failed or misfired. Before that failure prediction of component is must before installing them in the circuit. When failure of component is must before installing them in the circuit. When failure of component occur due to any of the following reasons: Shock, drop, vibrations, radiations, failure of over current/over voltage protection system etc., perfect health prognostics can't be done as these are environmental or mishandling effects. While the initial work has helped validate the that the physics of failure are correct and that the technique is applicable to develop a PHM for electronics system, a number of underlying issues must be addressed before fielding more advanced prototypes. The testing methods used to stress the electrical components to failure was a repeatable laboratory test. Real stress histories are not repeatable and incremental. Therefore the damage per drop cannot be used to determine the remaining useful life accurately¹.

2. Failure Rate Prediction System

Health of a component or circuit can be determined by either condition monitoring or by life consumption monitoring. While condition monitoring can be done before installation or after installation of the component. Present methodology is designed to provide the pre-installation process to check the failure rate of a thyristor.

Among most sensitive electronic components, thyristor was identified as one of them and as a result

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became the focus point of the lifetime prediction investigations. Several documented lifetime prediction methodologies have been discussed in the previous work.

As a result, it was concluded that the life prediction must be done prior to installation of device in the circuit, which not only help the manufacturer in estimating the device working capacity, but also to the consumer that when this part needs to be replaced. This work also fulfils the need of an algorithm which can be applied for different types of thyristors. Failure of an electronic component can be broadly classified in to three categories: Due to manufacturing defects, mechanical issues and electrical factors.

In the recent past much research has been outlined failure prediction models due to failure modes of thermal cycling, manufacturing defects may include fatigue-creep, uneven doping, wear out happens due to mechanical issues are distortion, fracture, wear, corrosion, severe vibratory environments, mechanical loading etc. The applicability to determine mechanical failure of individual electrical components has been demonstrated in by using resistance based techniques. The paper is divided into following part: In part two, problem formulation has been discussed. In part three, failure rate prediction system are presented using MIL-HDBK-217F N2 and RIAC 217Plus™ failure rate models. For generating a refined pool of population, heuristic technique was implemented and for simulation, MATLAB was utilized. Part four consist of results and was followed by conclusion.

3. Problem Formulation

The junction temperature plays a vital role while predicting life of power thyristor. The consistent performance of a thyristor can very well judged by rise or fall in junction temperature ($T_J$). If the Operating temperature is below 50°C, it will not damage the thyristor but modifications will be formulated by consumer to inhibit slow turn on, enhance latching current and increase holding current. If junction temperature exceeds 125°C, it will degrade the voltage rating, as increase in junction temperature will increase blocking current, which will effect on voltage rating. Whereas while working in between room temperature and 125°C gives optimized operational life and voltage rating. With variation in temperature, duty cycle, RMS value of rated forward current, rated blocking voltage, environmental factor been, operating base failure rate etc. varies at large extend. These variations and hence the failure rate prediction of thyristor have studied and compared. The failure rate models applied were MIL-HDBK-217F N2 and RIAC 217Plus™. For generating a refined pool of population, heuristic technique was implemented and for simulation, MATLAB was utilized.

4. Simulation

4.1 MIL-HDBK-217F N2 System

The military handbook data has been analysed sample has been generated using genetic algorithm and simulated by using MATLAB.

4.1.1 Population Generation

Heuristic approach has been utilized in the purposed work merely to generate refined population from a big pool of data. Rise in junction temperature has been considered in the range of 50°C to 125°C, with each small increment of 0.1°C, which will give us 751 samples. Similarly, in case of RMS value of rated forward current, which has been considered in the range of 1 A to 175 A, with each small increment of 5 A, will give us 36 samples. The rated blocking voltage has been taken from 0.3 V to 1 V with 0.1 V increment which gives us seven options. The fourth gene, environmental factor, has been considered from 0.5 to 43 with each small increment of 0.5 unit, where all the three (except space) bases viz., ground, naval and airborne were considered as the environmental condition. Fourth gene provides 87 options. These four variable quantities were considered as four genes and together form a chromosome population, whose sample chromosome has been shown in Figure 1.

<table>
<thead>
<tr>
<th>Chromosome-1</th>
<th>Temperature (°C)</th>
<th>Rated Forward Current (Ampere)</th>
<th>Rated Blocking Voltage (Volts)</th>
<th>Environmental Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>55.7</td>
<td>10</td>
<td>0.7</td>
<td>20</td>
</tr>
</tbody>
</table>

Figure 1. Sample data of MIL-HDBK-217 F N2.

Feasible solutions have been generated by using genetic algorithm. These variable combinations generates 1,64,6924 chromosomes. Two new offspring have been formulated by using the method crossover. The number of genes is decisive to ensure perfect information assortment. The mutation rate is below 1.5%. Finally after ten consecutive runs, we got a reduced population of 19152 chromosomes. This polished population will then fed to MATLAB for simulating results.
4.1.2 Simulation

The failure rate equation of the microcircuits in the MIL specification is as follows:

\[ \lambda_P = \lambda_B \pi_T \pi_R \pi_S \pi_E \pi_Q \] (1)

Temperature factor, \( \pi_T \), is given by:

\[ \pi_T = e^{\left( \frac{-3082}{T_e + 273} - \frac{1}{298} \right)} \] (2)

Current rating factor, \( \pi_R \), depends mainly on RMS value of rated forward current, is given by:

\[ \pi_R = (I_{rms})^{0.4} \] (3)

Voltage stress factor, depends mainly on value of rated blocking voltage, is given by:

\[ \pi_S = (V_s)^{1.9} \] (4)

Nomenclature:

- \( \lambda_P \) Predicted failure rate.
- \( \lambda_B \) Base failure rate.
- \( \pi_T \) Temperature factor.
- \( \pi_R \) Current ratting factor.
- \( \pi_S \) Voltage stress factor.
- \( \pi_E \) Environmental factor.
- \( \pi_Q \) Quality factor depends upon class of device.

The simulation results obtained from MATLAB were shown in Figures 2-4.

Figure 2. Temperature vs. FR with constant rated blocking voltage and forward current.

Figure 3. Rated forward current vs. current rated factor.

Figure 4. Rated blocking voltage vs. voltage stress factor.

4.2 RIAC 217Plus™ System

For RIAC 217Plus™ System, rise in junction temperature has been considered in the range of 50°C to 125°C, with each small increment of 0.1°C, which will give us 751 samples. Similarly in case of duty cycle, which has been considered in the range of 10% to 80%, with each small increment of 1%, will give us 71 samples. The operating base failure rate has been taken from \( 3.22 \times 10^{-4} \) to \( 3.27 \times 10^{-4} \) with \( 0.01 \times 10^{-4} \) increment which gives us seven options. These three variable quantities were considered as three genes and together form a chromosome population, whose sample chromosome has been shown in Figure 5.
Figure 5. Sample date of RIAC-217 Plus.

These variable combinations generate 3,19,926 chromosomes. A crossover operator is applied to the parents to produce two new solutions, the offspring. The mutation rate is kept low, usually below 1.5% as in previous case. After ten consecutive runs, we got a reduced population of 2265 chromosomes. This polished population will then fed to MATLAB for simulating results.

4.2.1 Simulation

The failure rate equation for thyristor is:

$$\lambda_P = [\lambda_{OB} \pi_{DCO} T_O + \lambda_{EB} \pi_{DCN} E_{AO} + \lambda_{TCB} \pi_{CR} \pi_{DT}] + \lambda_{SJ} \pi_{SJDT} + \lambda_{IND}$$  \[5\]

Where various terms used in the above expression are expressed as below:

Reliability growth failure rate multiplier ($\pi_G$) is expressed as:

$$\pi_G = e^{[\frac{1}{\beta} (Y - 1993)]}$$  \[6\]

Operating duty cycle failure rate multiplier for duty cycle is given by:

$$\pi_{DCO} = \frac{DC}{DC_{non}}$$  \[7\]

Temperature operating failure rate multiplier for temperature will be:

$$\pi_{TO} = e^{[\frac{1}{0.0008617} \left( \frac{1}{T_{AO} + T_R + 273} \right) \left( \frac{1}{298} \right)]}$$  \[8\]

Duty cycle (non-operating) failure rate multiplier will be:

$$\pi_{DCN} = \frac{1 - DC}{DC_{non}}$$  \[9\]

Cycling rate failure rate multiplier is:

$$\pi_{CR} = \frac{CR}{CR_i}$$  \[10\]

Delta temperature failure rate multiplier:  \[11\]

$$\pi_{DT} = \left( \frac{T_{AO} + T_R - T_{AE}}{DT_i} \right)^2$$

Solder joint delta temperature failure rate multiplier:

$$\pi_{SJDT} = \left( \frac{T_{AO} + T_R - T_{AE}}{44} \right)^{2.26}$$  \[12\]

The simulation results obtained from MATLAB were shown in Figures 6-9.

Nomenclature:

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda_P$</td>
<td>Predicted failure rate.</td>
</tr>
<tr>
<td>$\pi_G$</td>
<td>Reliability growth failure rate multiplier.</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Growth constant.</td>
</tr>
<tr>
<td>$\lambda_{OB}$</td>
<td>Operating base failure rate.</td>
</tr>
<tr>
<td>$\pi_{DCO}$</td>
<td>Duty cycle operating failure rate multiplier.</td>
</tr>
<tr>
<td>$\pi_{TO}$</td>
<td>Temperature operating failure rate multiplier.</td>
</tr>
<tr>
<td>$E_{ao}$</td>
<td>Operating activation energy.</td>
</tr>
<tr>
<td>$T_{AO}$</td>
<td>Ambient operating temperature.</td>
</tr>
<tr>
<td>$T_R$</td>
<td>Rise in junction temperature above the ambient operating temperature.</td>
</tr>
<tr>
<td>$T_J$</td>
<td>Junction temperature.</td>
</tr>
<tr>
<td>$\lambda_{EB}$</td>
<td>Environmental base failure rate.</td>
</tr>
<tr>
<td>$\pi_{DCN}$</td>
<td>Duty cycle (non-operating) failure rate multiplier.</td>
</tr>
<tr>
<td>$\pi_{TE}$</td>
<td>Temperature (environment) failure rate multiplier.</td>
</tr>
<tr>
<td>$E_{anop}$</td>
<td>Non-operating activation energy.</td>
</tr>
<tr>
<td>$\lambda_{TCB}$</td>
<td>Temperature cycling base failure rate.</td>
</tr>
<tr>
<td>$\pi_{CR}$</td>
<td>Cycling rate failure rate multiplier.</td>
</tr>
<tr>
<td>$\pi_{DT}$</td>
<td>Delta temperature failure rate multiplier.</td>
</tr>
<tr>
<td>$\lambda_{SB}$</td>
<td>Solder joint base failure rate.</td>
</tr>
<tr>
<td>$DC$</td>
<td>Duty cycle.</td>
</tr>
<tr>
<td>$T_{AO}$</td>
<td>Operating ambient temperature, (°C).</td>
</tr>
<tr>
<td>$T_{AE}$</td>
<td>Non-operating ambient temperature, (°C).</td>
</tr>
<tr>
<td>$CR$</td>
<td>Cycling rate.</td>
</tr>
</tbody>
</table>

4. Results

This paper concentrates particularly on operation, modelling and life prediction of thyristor. Statistical Analysis methods have been explored to design critical parameters such as input current, stress and...
temperature. To validate the effectiveness of developed system, both MIL-HDBK-217F N2 and RIAC 217Plus assessment prediction equations are compared.

Figure 6. Temperature vs. failure rate.

Figure 7. Duty cycle vs. failure rate.

Figure 8. Temperature vs. FR with varying DC.

Figure 9. Operating failure rate versus predicted failure rate.

5. Conclusion

Thyristor, a most life limiting component in the world of power electronics. The standard military handbook
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database and Reliability Information Analysis centre instructions have been explored to predict the operational life of a thyristor. Using MATLAB and heuristic technique, a new application regarding life prediction of thyristor has been proposed, where change in duty cycle with increase in junction temperature is considered. By assessing accurate life of a component, customer confidence and component's market value can be accelerated.

This paper explores a simple health prognostic method for thyristor life, so that it will not breakdown accidentally. This model uses the computation of few variables of thyristor. The main consideration is capacitor's voltage and current measurements. Although it is verified and validate for a single type of thyristor, yet condition monitoring of different topologies of power converters can also be done by this proposed method.

Appendix

The data for various constants used in the failure rate prediction by RIAC 217Plus™ System and MIL System are mentioned in Table 1.

Table 1. Standard values of various constants

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Constant</th>
<th>Value</th>
<th>Sl. No.</th>
<th>Constant</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>$\lambda_{EB}$</td>
<td>0.001011</td>
<td>9.</td>
<td>$TR_{default}$</td>
<td>60</td>
</tr>
<tr>
<td>2.</td>
<td>$\lambda_{TCB}$</td>
<td>0.002030</td>
<td>10.</td>
<td>$VS_{default}$</td>
<td>0.37</td>
</tr>
<tr>
<td>3.</td>
<td>$\lambda_{SB}$</td>
<td>0.000870</td>
<td>11.</td>
<td>$E_{op}$</td>
<td>0.4</td>
</tr>
<tr>
<td>4.</td>
<td>$\lambda_{IND}$</td>
<td>0.020010</td>
<td>12.</td>
<td>$E_{nonop}$</td>
<td>0.4</td>
</tr>
<tr>
<td>5.</td>
<td>$\beta$</td>
<td>0.2</td>
<td>13.</td>
<td>$DT_{1}$</td>
<td>73</td>
</tr>
<tr>
<td>6.</td>
<td>$CR_{1}$</td>
<td>508.77</td>
<td>14.</td>
<td>$\lambda_{b}$</td>
<td>0.0022</td>
</tr>
<tr>
<td>7.</td>
<td>$DC_{op}$</td>
<td>0.26</td>
<td>15.</td>
<td>$\lambda_{Q}$</td>
<td>0.5 (for S-class)</td>
</tr>
<tr>
<td>8.</td>
<td>$DC_{nonop}$</td>
<td>0.74</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. References

1. Ramakrishanan A, Pecht M. Life consumption monitor-