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DSSBD: An intelligent Decision Support System for Residual Life Estimation of PN Junction Diode

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ABSTRACT

High reliability, high speed and low cost are the prime factors account for the complexity of electronic systems. Reliability and failure prediction are the major constraints to estimate the residual life of the component to anticipate the costly failures or system unavailability. Reliability prediction of passive components, especially PN junction diode, is of great concern as it is a critical element of bipolar junction transistors and other semiconductor devices, so the chances of failure as well as damage are increased as every component has its own characteristics and operating conditions. In this paper, artificial Intelligence techniques are employed on PN junction diode which embrace knowledge of failure mechanism of a component and predict the residual life of the component and a preventive action to be taken before serious breakdown occurs. The residual life calculated from experimental method is compared with artificial intelligence techniques, namely. ANN, fuzzy logic and ANFIS. The ANFIS has been proved as the most accurate system to predict remaining useful lifetime with an accuracy of 99.03%. A Graphical user interface is also designed based on fuzzy inference system, which indicates the remaining useful lifetime of PN junction diode.

Keywords: Accelerated life testing, ANFIS, artificial intelligence (AI), GUI, residual life

INTRODUCTION

The residual life prediction depends on the average life of the electronic components and on the operating conditions of a component. As many components are integrated on a chip, the chances of failure are increased, as each component has its own characteristics and operating conditions (Coldren, Corzine, & Mashanovitch, 2012). So, Intelligence techniques are implemented which increase

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the performance of an individual component or complete system and conserve the working condition of a component such that if it drifts from actual output, a suitable action to be taken before any failure occurs in each electronic component such as diode (Al-Zubaidi, Ghani, & Haron, 2013). One of the major concerns for electronic engineers regarding diode is to predict its remaining useful life to protect it from costly failures and system unavailability. The remaining useful life of diode is determined by various environmental and electrical circumstances, such as temperature, humidity, atmospheric pressure and vibration. Electrical factors are operating voltage and current. Ambient temperature is also effective to ensure the longevity of diode. On the contrary, factors such as vibration, shock and humidity have little effect on the life of the diode(Kang, Kim, Choi, Kim, & Kwon, 2009). In this paper, diode deterioration under various operating conditions is discussed.

PN JUNCTION DIODE

Figure 1 shows an image of a PN junction diode. Temperature rise in PN junction diode due to internal current decreases the performance of diode.

Figure 1. PN junction diode

Operating conditions, such as temperature, voltage and current have a strong impact on the performance and utility of PN junction diode (Diehl, 2003). It is also well known the application of stress can change the energy gap of a semiconductor, the resulting change depending on the magnitude of the stress, as well as the direction with respect to the crystal orientation (Qin, Chung, Lin, & Hui, 2008). The expert system is designed using MATLAB GUI in which the fuzzy expert model is designed first and used to implement the final expert system user interface. This system can be designed using neuro-fuzzy technique to obtain more accurate results (Zhao, Chen, Guo, & Li, 2009).

METHODS AND MATERIALS

The residual life of pn junction diode was predicted using different techniques and methods as shown in Figure 2.

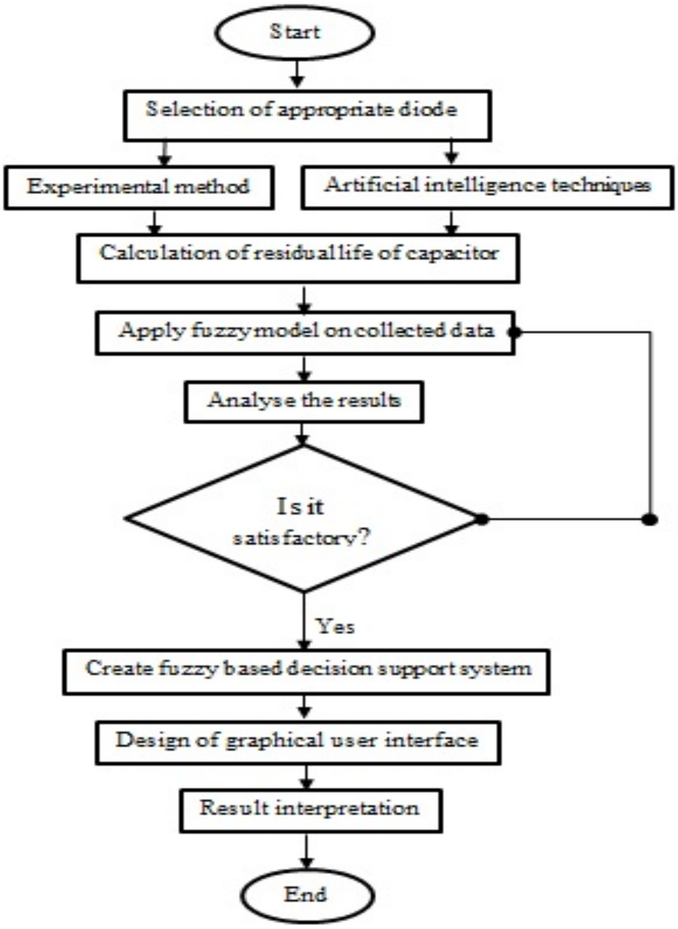


Figure 2. Flowchart of designing fuzzy-based decision support system

Figure. 2 shows the step wise procedure for calculating residual lifetime as well as designing of graphical user interface. The failure time was calculated using experimental method as well as artificial intelligence methods and then fuzzy logic was applied on the collected data. The ANN, fuzzy and ANFIS methods were employed as artificial intelligence techniques. The most accurate method was calculated based on experimental data.

Critical Parameters

The lifespan of diode is dependent on environmental and electrical factors; the environmental factors are temperature, humidity, atmospheric pressure and vibration and electrical factors are operating voltage and current (Silberberg et al., 1984). Temperature (ambient temperature) is the most important to increase the lifespan of diode while vibration, shock and humidity have little impact.

Temperature factor. As the ambient temperature of a diode increases its performance, the degradation begins and after a specified temperature, the diode fails and may harm the complete circuit. So, the higher temperature changes affect the lifetime of a diode (Dwyer, Franklin, & Campbell, 1990).

Voltage factor. The life of diode is affected less by applied voltage. When voltages above the rated one is applied, the internal current of diodes starts rising and more heat dissipation takes place through the diode and if the current rises, it will degrade the performance of diode completely and sometimes leads to failure of diode (Renge & Suryawanshi, 2008).

Life estimation of diode using experimental method

This method is mainly used by big manufacturing units where large number of samples or electrical units are subjected under tests (Fard & Li, 2009). These tests can be environmental, electrical or thermal. One example of such testing is Accelerated Life Testing (ALT) (Ahmad, Islam, & Salam, 2006). In accelerated life testing technique, a component is subjected to high temperature for limited hours, which ensures its remaining lifetime (Naikan & Rathore, 2016). The quality of a component during the life test is observed by regular checking of the value of the component using digital multimetre. Here, the testing was performed on diode based on the following steps (Huang et al., 2017):

a) In the first step, 20 diodes were placed on the hotplate, the value of each diode was measured and the desired temperature level from 25°C to 160°C was set in the hot plate. Waited till the temperature achieves the maximum rate.

b) The trial went on for 420 hours. This time length was chosen according to various temperature ranges. Time interval was shorter at higher temperature as chances of failure of components were greater compared with lower temperature limit.

c) The value of every diode was measured and noted after two hours of using the multimetre. The number of diodes failed was checked after few hours and calculation of the output life was done.

Figure 3. Experimental setup

Life estimation of diode using artificial intelligence techniques

The remaining useful life of diode was also estimated using artificial intelligence techniques such as ANN, Fuzzy and ANFIS. Artificial intelligence techniques are the modern way of estimation as they show better results and estimation is done in an intelligent way like a human brain (Bhargava, Banga, & Singh, 2017).

Life estimation using ANN. Artificial Neural Network is an analogous system of human neural network which tries to mimic the functioning of actual brain. Input data along with target data has been fed to the network. The system will train itself and reduces the error after every epoch and hence, after specific number of epoch the best result is shown (Dylis & Priore, 2001). The number of neurons in the input layer consists of input parameters, such as temperature and time which are used to obtain the output life of electronic component (Yan, Koc, & Lee, 2004).

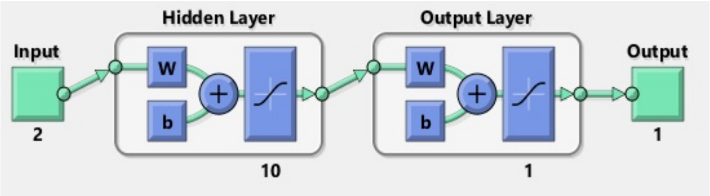


Figure 4. ANN structure

Life estimation of PN junction diode using Fuzzy Logic. Fuzzy Inference System is a soft-computing technique to design intelligent model with an advantage that it is user-friendly as it involves linguistic variable. For example, previously "True" or "False" or "Yes" or "No" or "0" or "1" were used. That showed only extreme value but in practical world we can have many other values like water problems. Water can't be just "Hot" or "Cold", it can be "Slightly cold", "Slightly Hot", "Slightly Moderate" among others. Hence this kind of Interpretation makes it easy for user to understand the response of the system (Kirby & Chen, 2007). That's Fuzzy and is known for handling ambiguity and uncertainty. Figure 5 shows the relation of membership function with the input parameters (Brevern, El-Tayeb, & Vengkatesh, 2009).

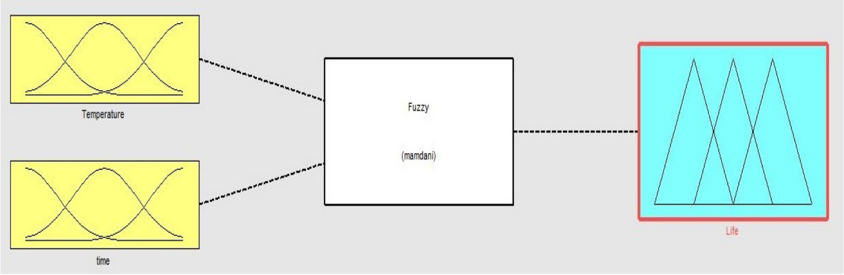


Figure 5. Fuzzy model for diode

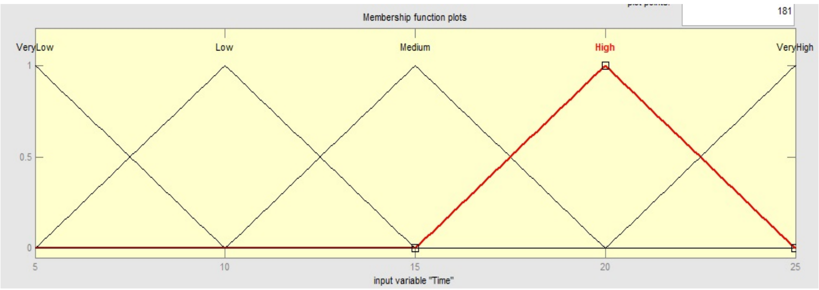


Figure 6. Triangular membership function for time

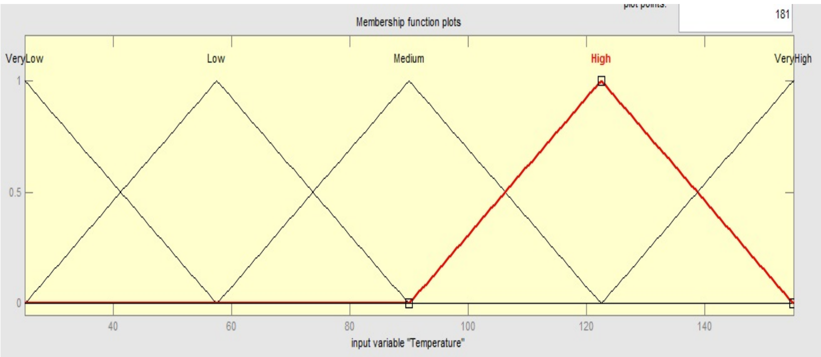


Figure 7. Triangular membership function for temperature

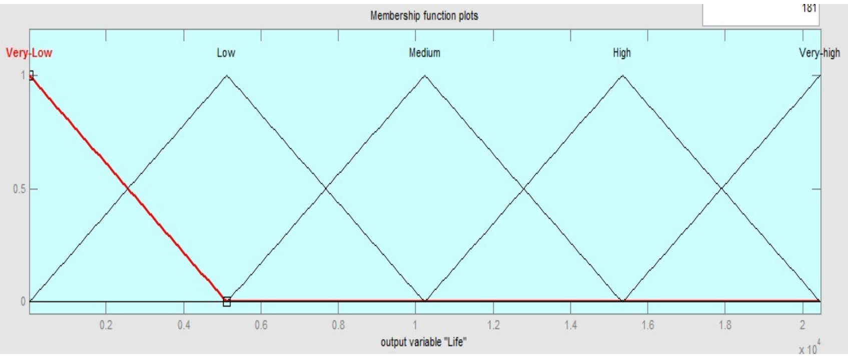


Figure 8. Triangular membership function for life

Life estimation of diode using ANFIS (Artificial neural fuzzy inference system). The ANFIS is Adaptive neuro fuzzy inference system and its architecture is shown in Figure 9. It is a Sugeno fuzzy model where the final fuzzy values are optimised using the artificial neural network training. The main difference between Mamdani and Sugeno system is that the Sugeno output membership functions are either linear or constant (Dragomir, Gouriveau, & Zerhouni, 2008). Therefore, the Sugeno method is computationally more efficient and thus, more likely to have a faster response. In this work, the Sugeno fuzzy inference system is selected. Here, the applied temperature and maximum temperature are used as input parameters and life is used as the output parameter (Dragomir et al., 2008). The linguistic variables Very low (VL), low (L), medium (M) and high (H), very high (VH) were used for the inputs as well as for the output. Twenty rules were formed and the failure factor such as temperature of diode was kept into this system and rules were designed. The rules are shown in Figure 10. The triangular membership function was chosen for input variable which gave the least error when compared with the other membership functions (Chen, Zhang, & Vachtsevanos, 2012).

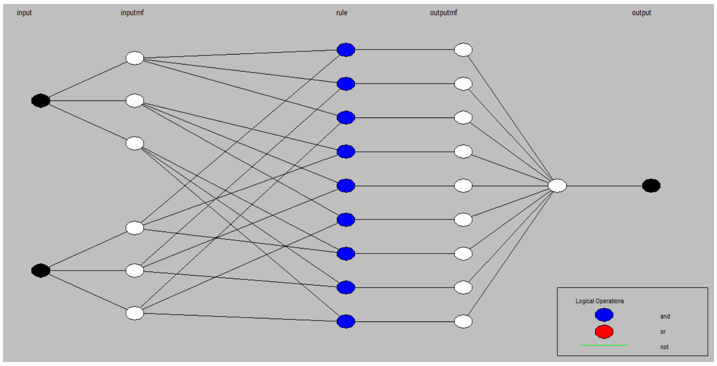


Figure 9. ANFIS structure

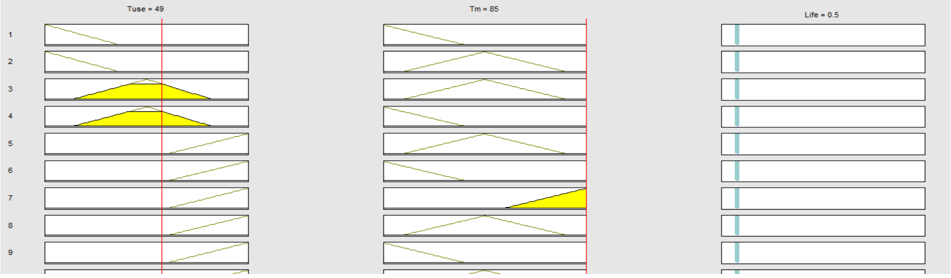


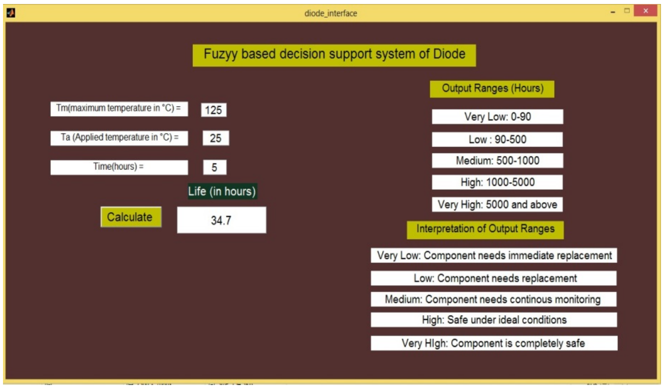
Figure 10. ANFIS Rule viewer (Yu, Zhou, Zhu, & Xu, 2012)(Yu, Zhou, Zhu, & Xu, 2012) (Yu, Zhou, Zhu, & Xu, 2012)

Design of GUI for Diode

Designing of graphical user interface (GUI) is the last phase of this method (Lefkowitz, 2000). The GUI user can interact with the expert system to check the operating condition of diode. The failure parameters of diode are given to this expert system as an input and the expert system gives the output as the remaining useful life. The GUI was created using the MATLAB-R2013a (Simulink & Natick, 1993). The entire database including rules was designed using the fuzzy logic. The following steps explain how a designed fuzzy fuzzy based decision support system works:

- In first step, data is collected using various techniques such as using experimental method, artificial intelligence modelling and analytical method.

- After data collection, numeric data consisting of input variables and output variable in the form of linguistic variables such as high, low or very low are formulated.
- Then, create a new fuzzy model using MATLAB and choose the number of input variables according to actual number of inputs and output variable in the same way.
- Now, choose a membership function such as triangular as per the range of data and fit the complete data in each variable using that membership function.
- Once all the input variables are set in membership functions in linguistic variables, design a rule base to check the output and if the output life is same as actual measured life then save and export the fuzzy file.
- In the next step, click on open new graphical user interface in MATLAB and save that file and after the file is saved, t two files are created one is .fig file and other is .m file. all the editing process is done in .fig file. Choose the static text boxes, edit text boxes and push buttons according to the number inputs and outputs.
- Name all the static boxes as the input variables and output variables and edit boxes are used to enter the input by the user and name the push button as calculate button.
- After designing the complete structure of expert system, right click on calculate and then click callback and view callback.
- In the callback, program is written using various commands in order to set and get all the input and output values and attach the saved fuzzy file in the program to evaluate and get the desired output. The file is saved after that.
- Verify the output by running the .m file from workspace window in MATLAB.



Fuzyy based decision support system of Diode

Tm(maximum temperature in °C) = 125

Ta (Applied temperature in °C) = 25

Time(hours) = 5

Life (in hours) 34.7

Output Ranges (Hours)
Very Low: 0-90
Low : 90-500
Medium: 500-1000
High: 1000-5000
Very High: 5000 and above

Interpretation of Output Ranges
Very Low: Component needs immediate replacement
Low: Component needs replacement
Medium: Component needs continous monitoring
High: Safe under ideal conditions
Very HIgh: Component is completely safe

Figure 11. Decision support system for life estimation of PN junction diode

RESULTS AND DISCUSSION

This paper focuses on life estimation of pn junction diode. Various methods have been explored to design critical parameters. The diode residual lifetime is calculated using experimental technique and an intelligent system is created which predicts residual life of pn junction diode. The mean life is obtained using various methods as shown in Table 1 which shows the residual meantime using accelerated life testing (experimental method) and artificial intelligence techniques. The accuracy of AI techniques has been decided by considering experimental data as reference. The ANFIS is proved as the most accurate method compared with ANN and Fuzzy logic.

Table 1
Comparison of residual life obtained using various methods

Techniques Used	Experimental Method	Artificial Intelligence Techniques		
	Accelerated Life Testing (ALT)	Artificial Neural Networks (ANN)	Fuzzy logic (FL)	Adaptive neuro-fuzzy inference system (ANFIS)
FIT (Failure In Time)	541917.3	573000.2	556096.2	547291.5
MTBF (Mean Time Between Failure) (hours)	1845.3	1745.2	1798.25	1827.18
Accuracy of AI techniques (%)	-	94.57%	97.45%	99.03%

It is found that an Artificial Intelligence technique i.e. adaptive neuro fuzzy inference system ANFIS provides highest accuracy to predict the useful life of diode i.e. 99.03%.

CONCLUSION

The residual life of diode is determined by experimental and artificial intelligence models to determine the relative effectiveness of each of the developed model. The diode is used in many of the electronic devices. The failure parameters of diode must be identified, and these parameters are necessary to ensure the reliable design of diode with an estimated lifetime. The residual lifetime of diode is estimated using experimental and artificial intelligence methods. The accuracy of life estimated using artificial intelligence techniques such as using ANN is 94.57%, while fuzzy shows an accuracy of 97.45%. It has been observed that the adaptive neuro fuzzy (ANFIS) method provides the highest rate of accuracy at 99.03%.

REFERENCES

Ahmad, N., Islam, A., & Salam, A. (2006). Analysis of optimal accelerated life test plans for periodic inspection: The case of exponentiated Weibull failure model. *International Journal of Quality and Reliability Management, 23*(8), 1019-1046.

Al-Zubaidi, S., Ghani, J. A., & Haron, C. H. C. (2013). Prediction of tool life in end milling of Ti-6Al-4V alloy using artificial neural network and multiple regression models. *Sains Malaysiana, 42*(12), 1735-1741.

Bhargava, C., Banga, V. K., & Singh, Y. (2017). Reliability comparison of a fabricated humidity sensor using various artificial intelligence techniques. *International Journal of Performability Engineering, 13*(5), 577.

Brevern, P., El-Tayeb, N., & Vengkatesh, V. (2009). Mamdani fuzzy inference system modeling to predict surface roughness in laser machining. *International Journal of Intelligent Information Technology Application, 2*(1), 12-18.

Chen, C., Zhang, B., & Vachtsevanos, G. (2012). Prediction of machine health condition using neuro-fuzzy and Bayesian algorithms. *IEEE Transactions on Instrumentation and Measurement, 61*(2), 297-306.

Coldren, L. A., Corzine, S. W., & Mashanovitch, M. L. (2012). *Diode lasers and photonic integrated circuits* (Vol. 218). New Jersey: John Wiley & Sons.

Diehl, R. (2003). *High-power diode lasers: fundamentals, technology, applications* (Vol. 78). Germany: Springer Science and Business Media.

Dragomir, O., Gouriveau, R., & Zerhouni, N. (2008). *Adaptive Neuro-Fuzzy inference system for mid term prognostic error stabilization.* Paper presented at the International Conference on Computers, Communications and Control, ICCCC'08.

Dwyer, V., Franklin, A., & Campbell, D. (1990). Thermal failure in semiconductor devices. *Solid-State Electronics, 33*(5), 553-560.

Dylis, D. D., & Priore, M. G. (2001, January 22-25). *A comprehensive reliability assessment tool for electronic systems.* Paper presented at the Reliability and Maintainability Symposium (pp. 308-313). Philadelphia, USA.

Fard, N., & Li, C. (2009). Optimal simple step stress accelerated life test design for reliability prediction. *Journal of Statistical Planning and Inference, 139*(5), 1799-1808.

Huang, X., Denprasert, P. M., Zhou, L., Vest, A. N., Kohan, S., & Loeb, G. E. (2017). Accelerated life-test methods and results for implantable electronic devices with adhesive encapsulation. *Biomedical Microdevices, 19*(3), 46-57.

Kang, J. M., Kim, J. W., Choi, J. H., Kim, D. H., & Kwon, H. K. (2009). Life-time estimation of high-power blue light-emitting diode chips. *Microelectronics Reliability, 49*(9), 1231-1235.

Kirby, E. D., & Chen, J. C. (2007). Development of a fuzzy-nets-based surface roughness prediction system in turning operations. *Computers and Industrial Engineering, 53*(1), 30-42.

Lefkowitz, H. M. (2000). Graphical user interface. U.S. Patent No. 6,091,417. Washington, DC: U.S. Patent and Trademark Office.

Naikan, V., & Rathore, A. (2016). Accelerated temperature and voltage life tests on aluminium electrolytic capacitors: A DOE approach. *International Journal of Quality and Reliability Management, 33*(1), 120-139.

Qin, Y., Chung, H. S., Lin, D., & Hui, S. (2008). *Current source ballast for high power lighting emitting diodes without electrolytic capacitor.* Paper presented at the Industrial Electronics, 2008. IECON 2008. 34th Annual Conference of IEEE.

Renge, M. M., & Suryawanshi, H. M. (2008). Five-Level Diode Clamped Inverter to EliminateCommon Mode Voltage and Reduce $ dv/dt $ inMedium Voltage Rating Induction Motor Drives. *IEEE Transactions on Power Electronics, 23*(4), 1598-1607.

Silberberg, Y., Miller, D., Gossard, A., Wiegmann, W., Smith, P., & Eilenberger, D. (1984). Passive mode locking of a semiconductor diode laser. *Optics Letters, 9*(11), 507-509.

Simulink, M., & Natick, M. (1993). *The mathworks*. In: Inc, USA.

Yan, J., Koc, M., & Lee, J. (2004). A prognostic algorithm for machine performance assessment and its application. *Production Planning and Control, 15*(8), 796-801.

Yu, Y., Zhou, T., Zhu, M., & Xu, D. (2012). *Fault diagnosis and life prediction of dc-link aluminum electrolytic capacitors used in three-phase ac/dc/ac converters.* Paper presented at the Second International Conference on Instrumentation, Measurement, Computer, Communication and Control (IMCCC) (pp. 825-830). Harbin, China.

Zhao, F., Chen, J., Guo, L., & Li, X. (2009). Neuro-fuzzy based condition prediction of bearing health. *Journal of Vibration and Control, 15*(7), 1079-1091.