Research Article

Diagnosis of Faulty IGBT Switches in Multi-Level Inverter Using ANFIS Technique

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Article History: Received: 10 November 2020; Revised 12 January 2021 Accepted: 27 January 2021; Published online: 5 April 2021

Abstract: Consistent performance of multilevel inverters is frequently downgraded by the fault in power electronic components such as IGBT switches, which is a major obstacle in operation of motor and drive. Identification of open & short circuit problems of IGBT switches in multilevel inverters is constantly a broadly explored area. Several procedures have been suggested to recognise the faulty IGBT switches of inverters based on current measurement and analysis. Bearing in mind the downsides of load current centred fault detection techniques, in this paper, inverter output voltage is considered for fault estimation purpose, because it is independent of load variations. Adaptive neuro-fuzzy inference system (ANFIS) is a dominant technology in the grouping of difficult patterns. In the present work, classification of faulty IGBT switches is carried out through ANFIS technique. Results show that ANFIS reduces number of inputs and size of the network and hence avoids the usage of any in-between numerical processes to decrease the size of the network and in turn lessens the processing time. The values of root mean square error lies in the range of acceptable limit and it shows the effectiveness of the ANFIS based approach in the identification of both open & short circuit problems of IGBT switches of multilevel inverters.

Keywords: open circuit fault, multi level inverter, short circuit fault, ANFIS, induction motor, controller drive

1. Introduction

In recent times, long term performance of multilevel inverters is primarily influenced by the power electronic switching components such as IGBT or MOSFET (Banaei M.R & Salary E 2013, Javad Gholinezhad & Reza Noroozian 2013). As soon as a failure of IGBT switch occurs, it is important to attend the fault as earlier as possible so that motor and drive system operation is unaffected and further failure of system components is avoided (Kim SM et al., 2016, Mohsen A et al., 2016, Mohsen A et al., 2017, Ouni S et al., 2017). Fault diagnosis of MLID is constantly a broadly explored area and has produced quite a few attention among several researchers in the improvement of superior fault analytical techniques and security system (Behrooz Mirafzal 2014, Bayram D et al., 2017, Jianghan Zhang et al., 2014,Talha M et al., 2016). Open & short circuit problems are the maximum shared failures in IGBT switches and leads to disaster of battery and/or the impedance load connected to the MLID (Estima J & A. Marques Cardoso 2013, Hu K, et al., 2016, Jorge O. Estima & António J. Marques Cardoso 2013, Marjan Alavi, et al., 2014). Several procedures have been suggested to recognize the faulty IGBT switches of MLID based on load current analysis (Wu F et al., 2017). In recent times, artificial intelligence based control algorithms has shown much enhanced performance, and it is also easy to apply in real time condition monitoring systems, which in turn enhances the reliability of the entire system. In particular, in the case of multi level inverter (MLID) system, there are different signals which could be used in a better way along with artificial intelligence techniques for identification of fault condition of motor or drive. MLID faulty IGBT switch diagnosis is mostly accompanied with the analysis of current signal or voltage signal. Considering these facts, in this paper, inverter voltage signal is measured for open & short circuit fault identification purpose, because it is autonomous of load deviations. Fault detection is a part of a security pattern and can also be treated as pattern recognition problem. ANFIS technique can be adopted to execute the fault identification (Muniraj C & Chandrasekar S 2011). These procedures allow the mapping of both input and output using a nonlinear connection and it provides the skill to distinguish abnormal circumstances because of their fundamental capability to categorize and generalize. The data or signals can be used to train the networks, so that it will classify the discrepancy among standard and irregular condition of the system. ANFIS is controlled with fuzzy interpretation systems realized in the background of adaptive networks. Hence, in the present study, faulty IGBT switch detection process is computerized through ANFIS technique. Fast Fourier Transform (FFT) technique is mainly used in the present work to collect the key features for easy classification of faulty switches. When the features extracted from FFT are given as an input to

ANFIS network, it will reduce the number of inputs and size of the network which results in reduction in computational time.

2. Cascaded H-Bridge MLID

Basic arrangement of cascaded MLID consists of several H-Bridge inverter units in series. Mostly distinct DC power supply will be used for each unit. Output of the MLID will be near sine wave with harmonics and output voltage consists of different number of levels (based on the number of individual units). In this work, 5 level MLID is used as shown in Figure 1 with 2 individual unit and 8 switches. In the output of the MLID, both V & I measuring scopes are provided across the load. Pulse width modulation generator is applied to collect the necessary gate input pulses for the 8 IGBT switches.

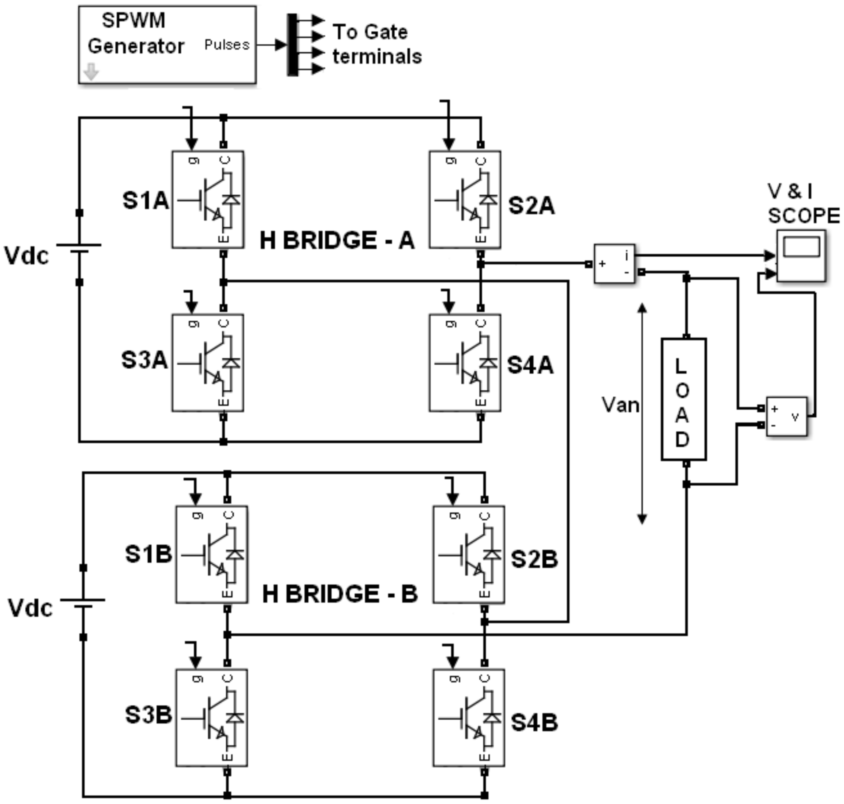


Figure.1. Configuration of 1Φ 5-level MLID with load.

3.Voltage Patterns of Multi Level Inverter with Faulty Switches

In this work, Fast Fourier Transform technique is adopted to collect salient characteristics from the inverter voltage signals of MLID for the detection of faulty switches. FFT technique is a most powerful algorithm to understand the frequency components of any given signal and it is also easy to practically implement in any advanced processors. It is possible to get the key information such as Total Harmonic Distortion %, ratio of 3rd harmonic/fundamental (%) and ratio of 5th harmonic/fundamental (%) using the FFT technique. Root mean square value of inverter output voltage waveform is also computed in this work which is an additional feature used for detection of faulty switches. Evaluated features are fed into the adaptive neuro fuzzy network. Output of the trained network indicates the fault condition of the multilevel inverter. Since there are 8 switches present in the example system, initially O.C (open circuit) fault is created and then S.C (short circuit) fault is created in IGBTs. Inverter voltage signal is collected and stored in PC. Inverter voltage signals obtained at open fault of IGBT switches are shown in Figure 2. Output voltage signals obtained at short fault of IGBT switches are shown in Figure 3. All these signals are measured at modulation index value of 0.85. 'A' and 'B' represents the corresponding cell of the H-Bridge unit. From the graphical assessment of the open circuit and short circuit faulty voltage signals, it is detected that there is a substantial alteration in all voltage signals when matched with standard output voltage signal without any fault.

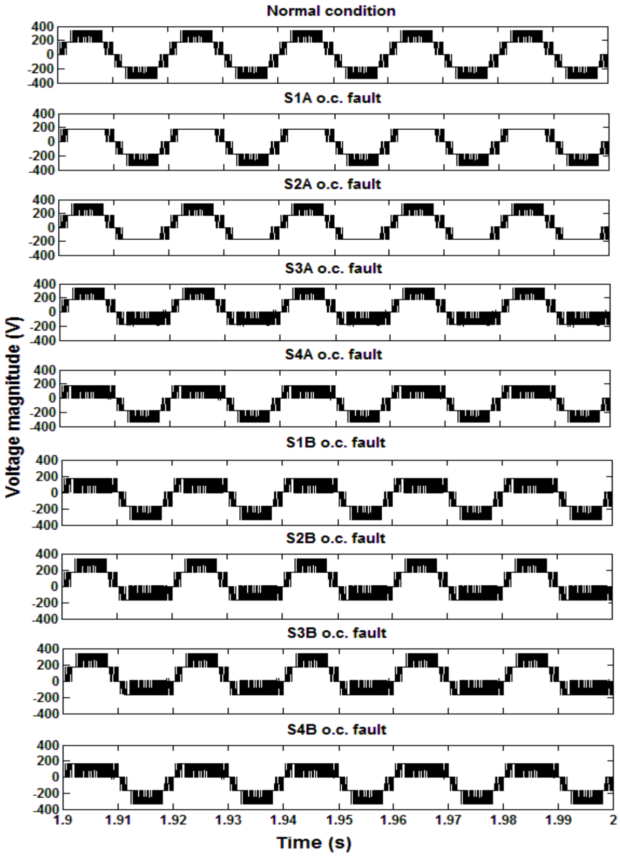


Figure.2. Voltage signals obtained at open fault of IGBTs of Cell A and B.

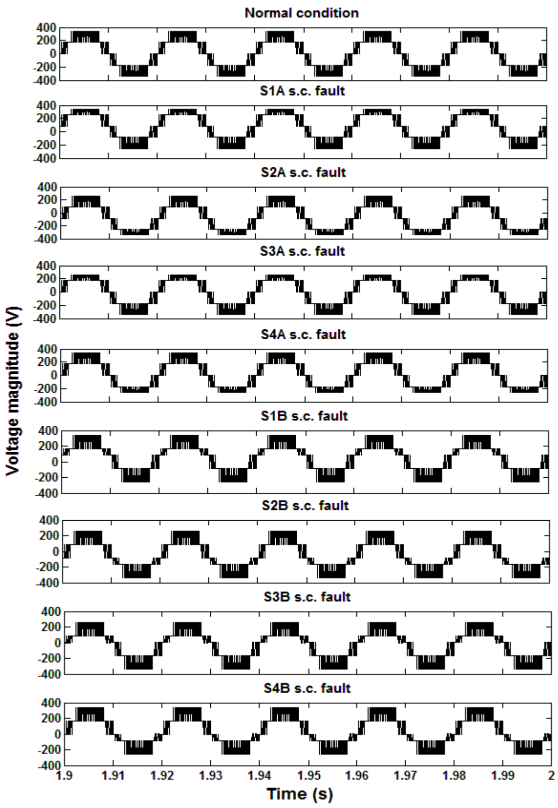


Figure.3. Voltage signals obtained at short fault of IGBTs of Cell A and B.

3.Extraction of Salient Features

Fast Fourier Transform technique is a powerful technique to extract frequency characteristics of any signal and MATLAB toolbox available for evaluation of FFT components is most useful for many researchers. Frequency spectrum of the normal output voltage signal obtained upto 2 kHz is shown in Figure 4, in which magnified view is also shown inside as a separate plot. Various harmonic peaks (3^{rd}, 5^{th}, 7^{th}, 9^{th}, etc.) obtained in the frequency spectrum are clearly distinguishable in the inside magnified plot. From the frequency spectrum results, it is possible to easily estimate the THD, 3rd harmonic/fundamental and 5th harmonic/fundamental using the functional tool boxes available in MATLAB. Mining of prominent features of the voltage signal plays a vibrant role in the MLID fault detection system.

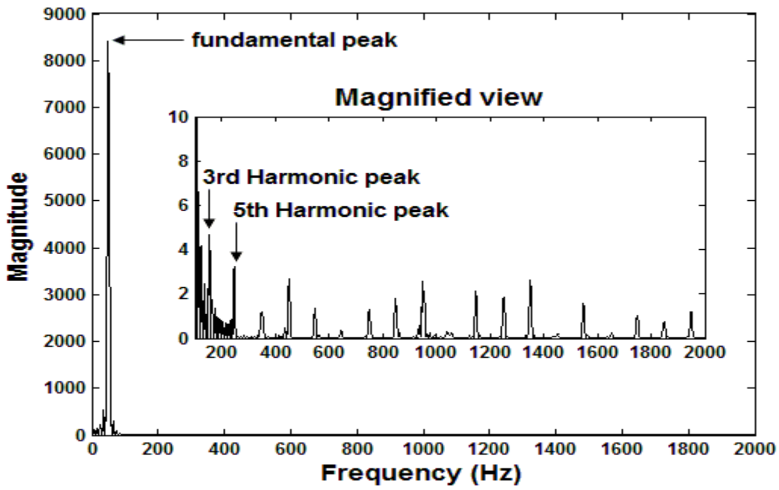


Figure.4. FFT result of output voltage at normal condition

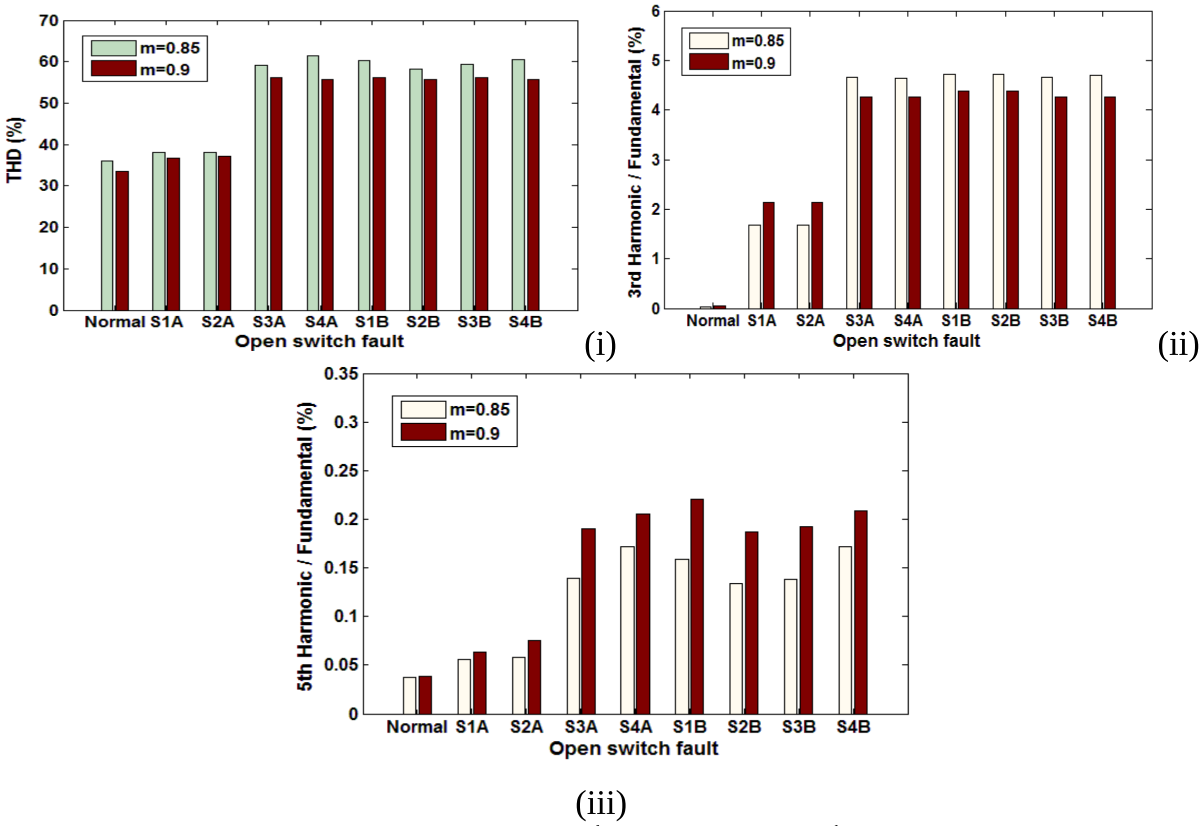


Figure.5. FFT features of voltage signal (i) THD (ii) 3^{rd} harmonic ratio (iii) 5^{th} harmonic ratio at different IGBT open circuit fault cases

Figure 5 (i,ii,iii) displays the differences in the THD, 3rd harmonic and 5th harmonic ratio of output voltage signal at different open circuit IGBT fault cases of MLID. Entire simulation is carried out with 0.85 and 0.9 modulation index values. With increasing modulation index value, reduction in THD and 3rd harmonic ratio is noticed, whereas in the case of 5th harmonic ration, it is increasing with increase in modulation index. Results obtained clearly demonstrate the variations in mined features under normal and fault condition. One more additional feature such as RMS value of inverter voltage signal is computed and Figure 6 indicates the RMS value of inverter voltage at different IGBT open circuit fault cases. With increase in modulation index value, corresponding increase in voltage RMS is also noticed.

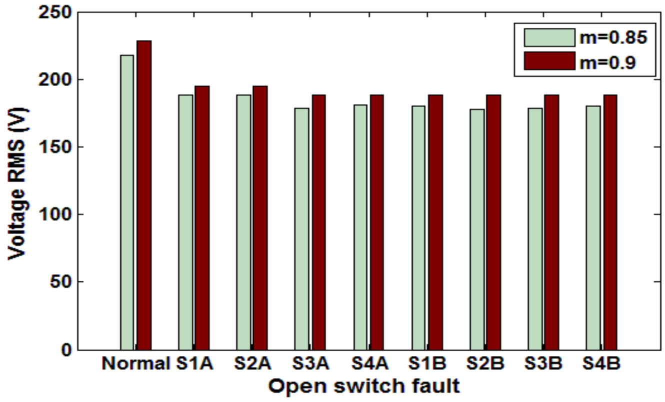


Figure. 6. RMS value of voltage at open fault of IGBTs of cell A&B at *m*=0.85.

4. Identification Of Faulty IGBT Switches Using ANFIS Technology

In this approach, the salient features such as output voltage THD value, output voltage RMS value, 3rd harmonic ratio and 5th harmonic ratio which are extracted using FFT methodology at different IGBT open and short circuit fault are fed into the ANFIS network and the configuration of ANFIS model adopted in this work is shown in Table 1.

Table 1. Configuration of ANFIS network

No. of Inputs	4
No. of membership functions	3
Fuzzy rules	81
Iterations	500
Training Sets	204
Test Sets	150
Convergence Criteria	0.01
Initial step size	0.01
Membership function	gbell

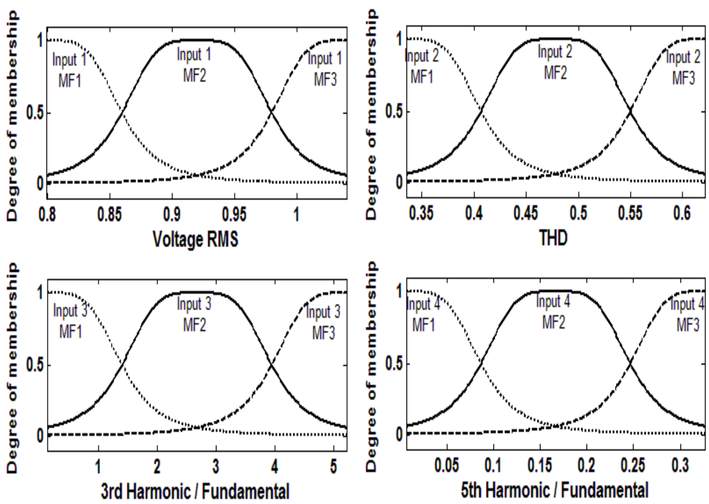


Figure.7. Range of FFT features with respect to Fuzzy membership function "gbell"

Matlab tool box was used for the implementation of adaptive neuro fuzzy system in this work, in particular the popular fuzzy logic tool is adopted in this work. 'gbell' function is adopted in the fuzzy tool box as a membership function and the defuzzified output is obtained using the weighted average calculation process. Figure 7 shows the respective 'gbell' graph of 4 FFT inputs given to adaptive neuro fuzzy network such as THD, RMS value, 3rd Harmonic ratio and 5th Harmonic ratio. The range of value of gbell membership function lies from 0 to 1.

Table 2. ANFIS network output pattern for switch fault

Nature of Fault	ANFIS output
No fault	1
S1A fault	2
S2A fault	3
S3A fault	4
S4A fault	5
S1B fault	6
S2B fault	7
S3B fault	8
S4B fault	9

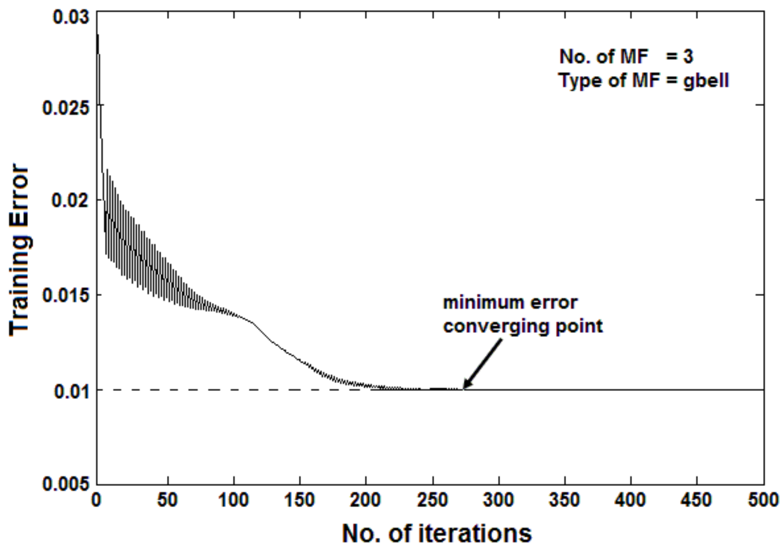
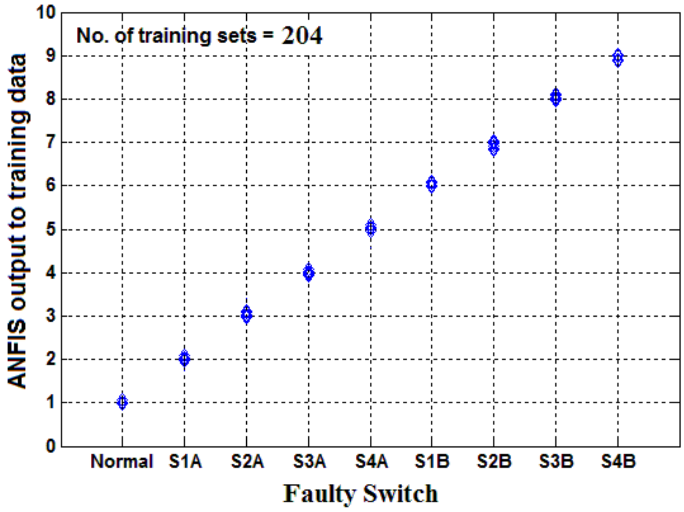


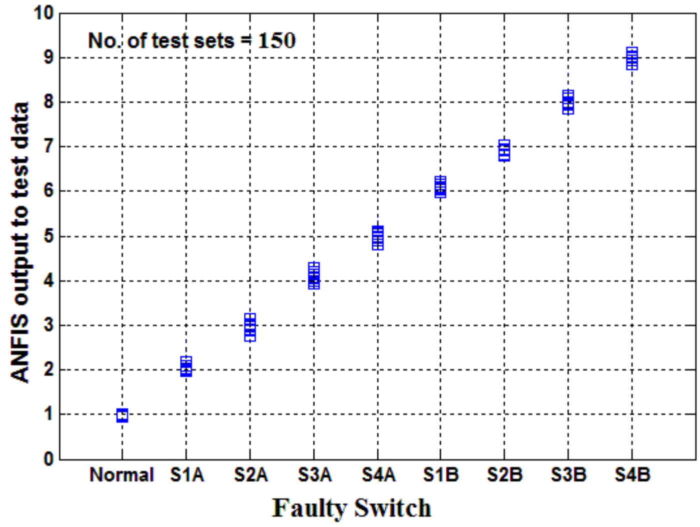
Figure.8. Minimum error converging point of training error of ANFIS with gbell MF.

Table 2 clearly indicates the output of the adaptive neuro fuzzy network at different IGBT faults of MLID used in the present work. Figure 8 illustrates the minimum error converging point of the ANFIS network with corresponding reduction in the training erro at different number of iterations. It is observed that proposed network reaches the minimum error converging point before reaching 300 iterations. However, in the starting phase of the training process until 100 iterations, more variations in RMSE value is detected. But once the iterations goes above 150, then naturally the variations in RMSE value is very much reduced and becomes smooth and gradually touches the target convergence criteria of 0.01. Performance of the network clearly shows less number of iterations i.e. 300 is enough for the optimized training of the network. This approach touches the convergence point rapidly and takes little iteration. The ANFIS identification rates have been studied with 204 training sets consisting of each fault conditions at modulation index value which lies in the range of 0.8 to 0.95.

Figure 9 (i) & (ii) indicates the output of the proposed network for both training and testing data respectively. As per Fig.9 (i), it clearly indicates that proposed network output is very much closer to the relevant trained pattern (please refer the pattern in Table 2). It confirms that the network is able to train properly the given inputs and also has differentiated the different IGBT fault cases accurately for the given set of training data. Figure 9 (ii) indicates the output of the proposed network with 150 additional test data simulated with different IGBT fault cases. The modulation index value of the test data varies from 0.8 to 0.95. Results obtained with test data also indicate that the proposed network topology easily distinguishes the faulty IGBT switch cases consistently.



(i)



(ii)

Figure.9. Range of variations in ANFIS output for (i) training (ii) testing data with open switch fault case.

Table 3. Fault detection results of ANFIS topology in %

Nature of Fault	**Detection rate (%) with different membership function**	
	trimf	**gbellmf**
No fault	100	100
S1A fault	97	99
S2A fault	97	100
S3A fault	95	97
S4A fault	96	98
S1B fault	96	97
S2B fault	98	98
S3B fault	95	99
S4B fault	96	100

In this work, in order to judge the efficacy of the projected network, both triangular and ‘gbell’ membership functions are tested with same set of data and the results are tabulated in Table 3. Results obtained clearly shows the effectiveness of 'gbell' function in identifying the faulty IGBT switches (i.e. 98.8% accuracy obtained in this case) when compared with triangular function. Variations in min, max and mean values of RMSE values are plotted against the IGBT faulty switches for the entire data set in Figure 10. Most of the cases the root mean square error value of IGBT faulty switches falls less than 0.04 and in very few faulty cases only falls above 0.05 and it clearly demonstrates that it is in satisfactory limit.

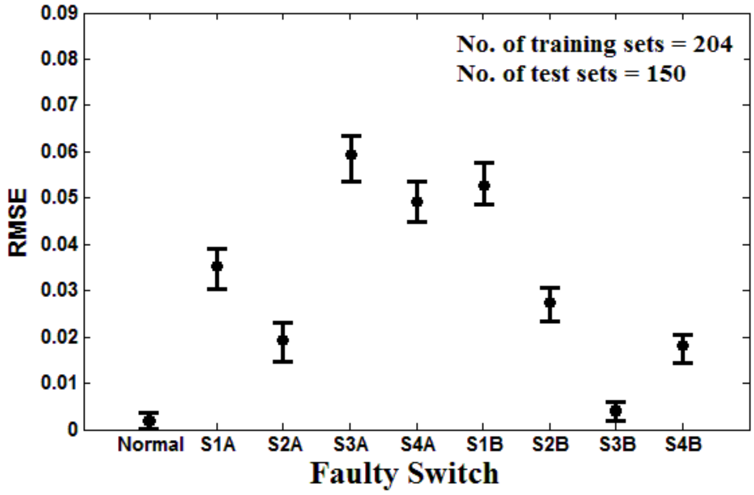


Figure.10. Variations in RMSE value of ANFIS network at different open circuit IGBT fault

8.Conclusion

This paper has investigated the output voltage characteristics of 5 level cascaded MLID under open and short IGBT switch fault condition for the detection of faulty switches. Prominent features of voltage signal such as THD, 3rd Harmonic/Fundamental and 5th Harmonic/Fundamental are mined adopting FFT technique. Then mined features are set as an input to the powerful soft computing technique such as ANFIS. Proposed methodology took less than 300 number of iterations for successful training the network and it is faster. Results obtained in this work clearly indicates that the proposed ANFIS network takes less number of input data and hence the entire size of the network reduces which in turn leads to the reduction in computation time. The values of root mean square error lies in the range of satisfactory boundary and it demonstrates the efficacy of the ANFIS methodology in the classification of both open & short faults of IGBTs of MLID. Proposed network structure can be straightforwardly realized in the current innovative embedded systems without any need for additional hardware.

Acknowledgement

Author (Sivakumar Muthusamy) would like to thank **The Research Council (TRC), Oman** and **University of Technology and Applied Sciences – Nizwa (UTAS-N)** for providing financial support for accomplishing this research work.

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