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Fuzzy Logic Based Power Quality Disturbance Detection

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Abstract - *From last decades year, occurrence power quality disturbance was a serious issue in any power system. Power quality of distribution system and load side consumer is very much important consideration. But day by day this issue is very much occurs in power system and different methods for identification and removal of power quality disturbance are present by authors. Therefore we need to determine and classify the power quality disturbance for analysis and design power quality improvement device. In many of study and author was presented the methods for analysis of power quality disturbances and removal of power quality disturbances from power system. This paper is present the technique for power quality disturbance detection of IEEE 14 bus system using fuzzy logic controller. In this method, the three phase voltage of common bus bar are measured continuously and send to root mean square (RMS) calibration subsystem. That calibrated value of different power quality disturbance is utilized for design rules base for (FLC) fuzzy logic controller. The system is design in MATLAB Simulink modelling.*

In this work, different power quality disturbances like voltage sag, swell, momentary interruption, harmonics condition classify using fuzzy logic controller based on per unit values of input bus bar three phase voltages. Also this fuzzy logic controller system is compared with Back propagation based Artificial Neural Network power quality classifier technique.

Key Words: *Power Quality Disturbance, Fuzzy logic, Neural Network*

1. INTRODUCTION

Day by day power consumptions increases due to the continuous increase of change of business set ups which have increases the use of PLC programmable logic controllers, sensitive electronics components, computer and laptops etc. And every consumer side load requires green supply which taken from wind energy system, fuel cell bases system, smart grid and power system with good power quality of supply. Any country may be in loss due to nonlinear behavior of three phase voltage and current of power supply system or grid system Electrical or electronics equipments may be malfunctioning if any fluctuation or deviation occurs in power system voltage, current or frequency. If disturbance occurs in power quality of grid then it will increases the chance of power blackouts. Also chance of disconnection occurs in national grids of any countery. For improve that power quality disturbance, the consumer side may use the uninterrupted power supply system (UPS) and voltage stabilizer but cost of this equipment also very high. Hence the power quality is important issue for any power grid system.

Integration of nonconventional energy sources like wind, fuel cell, tidal energy and solar pv array system are increases day by day. Also nonlinear loads and switching devices required for integration of such energy sources. But integration of such system may cause harmonics, voltage sag, voltage swell, momentary interruptions, frequency variations etc in power grid or load side of power system. From last two year some of the solid state switched based power electronics devices has been developed for improve the power quality of supply side. But that devices increases the costing and complexity of any control system of power quality improvement system. When power electronics based controlled capacitor connected with power system are cause transient oscillations in bus bar or node of grid. Due to the sudden change of load conditions, power system network grid contingencies and variable output of renewable energy sources causes the harmonics distortion and low frequency problems in power system grid power quality. This types of low frequency and harmonics problems may impose the penalties on consumer end side like reactive power cost, cost of re-dispatched, cost of load curtailment to removal of disturbing load from system. Hence, Power quality events must be monitored, maintained upto standard level of power supply system for economical power system operation condition achievement. But in large and complex power system network there are large amount of data make power quality analysis difficult for classification or monitoring system. There for requirement of intelligent tool for detection and classification of power quality disturbances in power system or grid network.

In this paper we have to present the power quality disturbance classification technique using fuzzy logic controller. Based on fuzzy rule base for power quality voltage and current signal, that system classify the PQ disturbance very efficiently. All system is design, analyzed and tested in MATLAB simulink software.

2. PROPOSED APPROACH

2.1. Block diagram

Figure 1 shows the Block diagram of fuzzy logic controller based PQ classification system in which IEEE 14 bus microgrid system is design in MATLAB simulink modelling. Then after different power quality disturbances was simulated using circuit breaker, variable loads, harmonics generators (source) etc. The phase voltages or each phase current are measured. That measured value of three phase voltages i.e. training data set are

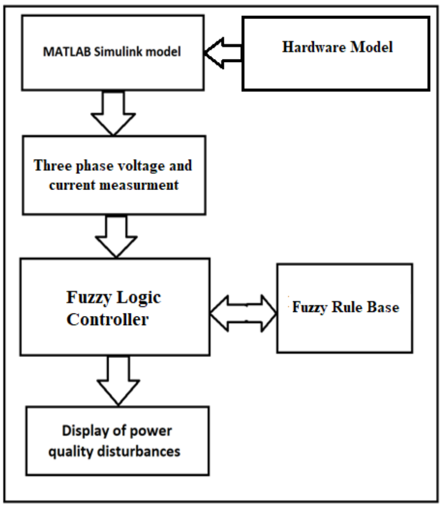

Fig-1: Block diagram of fuzzy logic controller based PQ classification system

utilized for design fuzzy rule base for power quality disturbance analysis and classification. Also same data set is used for training of Back propagation Based Artificial Neural Network (BP-ANN) for comparisons with fuzzy logic controller classifier system.

2.2 IEEE 14 Bus System

Figure 2 shows the complete IEEE 14 bus power system and their corresponding transmission line parameters are design using data set in [1]. The transmission line and generator bus data set is provided in [1] is used for design IEEE 14 bus system.

After designing of IEEE 14 bus power system, different conditions of power quality disturbances are simulated in matlab simulink model by utilizing the three phase load parameter adjustment. Also some time three phase circuit breaker is utilized for connect and disconnect the load and generator of IEEE 14 bus system by adjustment of simulation ON and OFF time of breaker.

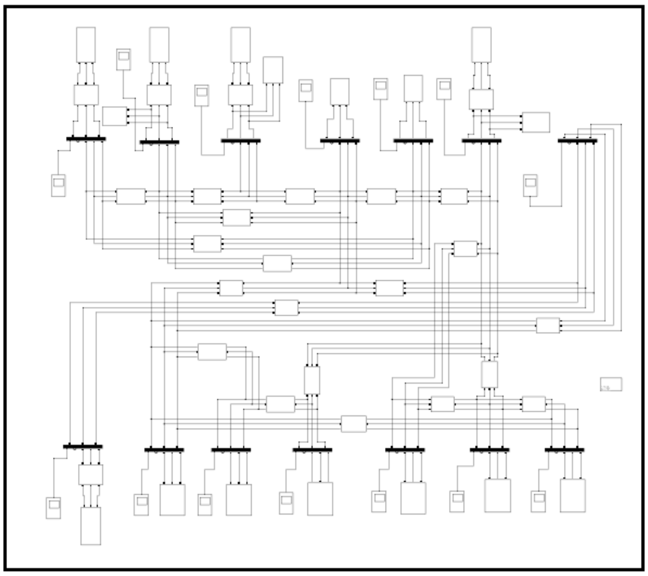

Fig-2: MATLAB simulink model of IEEE 14 bus system

2.3 Complete simultion model

Figure 3 shows the complete matlab simulation model of IEEE 14 bus system with fuzzy logic controller classifier and BP-ANN classifier. In which three phase per unit voltage is send to RMS calibration subsystem model. In that RMS subsystem model root mean square calibration of sinusoidal AC voltage done for make the values constant AC magnitude. Then that RMS measures per unit voltages are measured for different power quality disturbances like sag, swell, momentary interruption, harmonics and also for normal conditions. Then that measured voltages at each disturbance conditions are utilized for training the BP-ANN and for designing the rule base for fuzzy logic controller. After training of BP-ANN and designing of fuzzy logic controller with rule base is connect after RMS measurement subsystem. Then in future if any power quality disturbance detected then BP-ANN and Fuzzy logic controller (FLC) are classify the power quality disturbances.

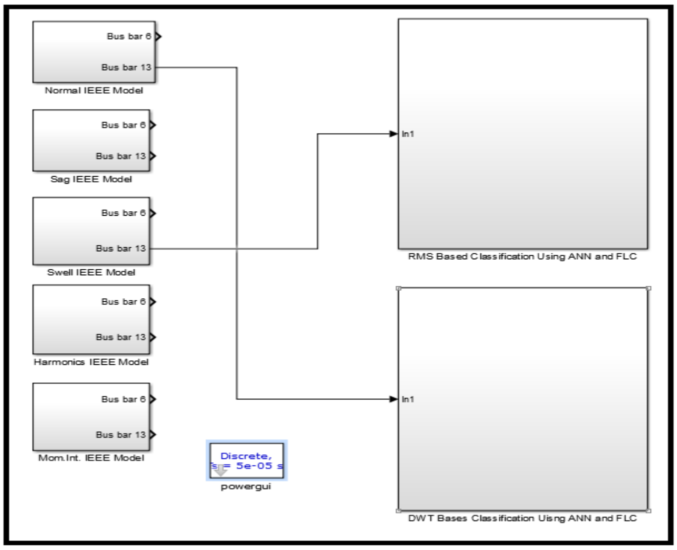

Fig-3: MATLAB simulink model using RMS calibration based system using Fuzzy logic and Neural Network

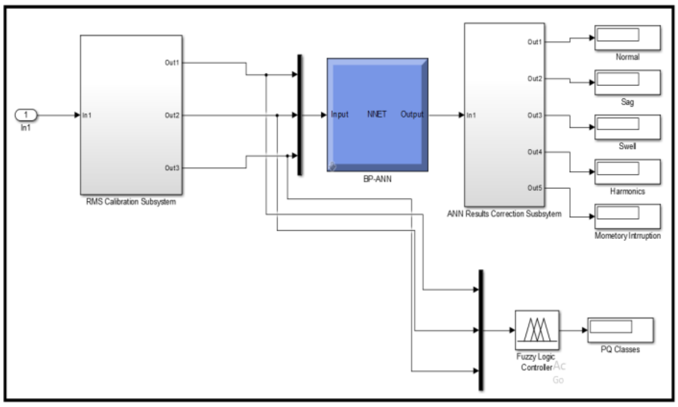

Fig-4: Root Mean Square calibration based power quality disturbance classification using fuzzy logic controller

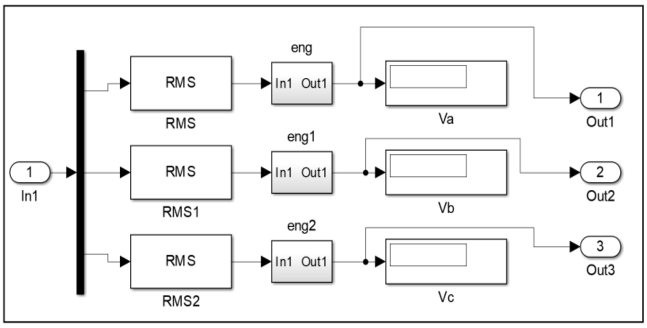

Fig-5: RMS Calibration subsystem

Figure 5 shows the RMS calibration MATLAB Sımulınk subsystem model in which input is three phase combined voltages. That three phase voltages are separated by using demux and then separated three phase per unit voltages are send to RMS calibration block. Then after RMS calibration block, that RMS values measured three phase voltages send to energy calibration model which is shown in figure 6.

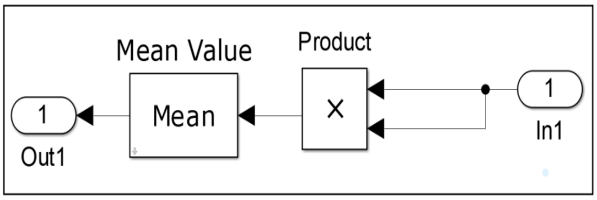

Fig-6: Energy calibration subsystem

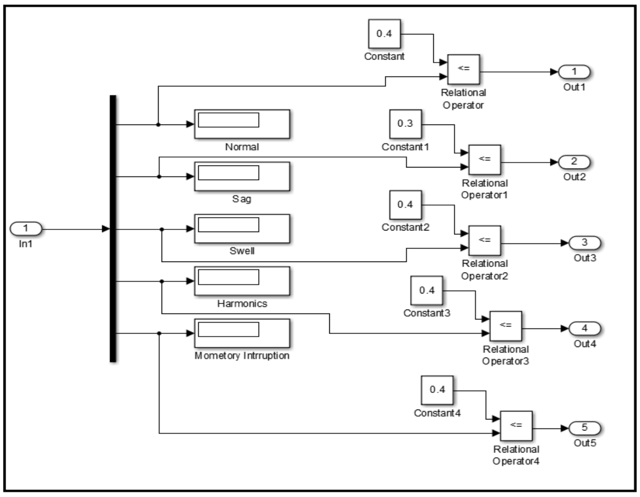

Fig-7: Neural network results corrections subsystem

Figure 7 shows the BP-ANN output correction subsystem. When BP-ANN training done then ANN gives the output are not exact as per targeted decided output. In some cases ANN provide the output nearer to target output. For that output need correction to make it as target output values. In this ANN model there are five target classes like Normal, Sag, Swell, Harmonics and Momentary Interruption for classes. For classification of such power quality disturbances, Table 2 shows the target matrix for ANN classification. While table 3 shows the actual output generated by ANN after training. Hence for making Table 3 error output same as target output in table 2 we have to design ANN correction calibration subsystem in figure 7.

3. SIMULATION RESULTS

3.1 Results from IEEE 14 Bus System

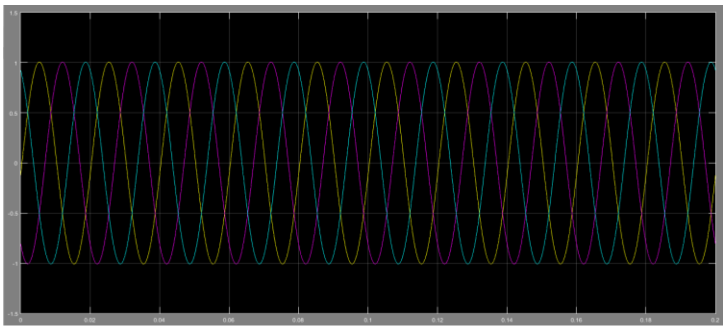

Fig-8: Normal three phase voltage of IEEE 14 bus system at bus bar 6

Note that from figure number 8 to 9, Y axis shows the per unit voltage and X axis represents the simulation time in seconds. Figure 8 shows the normal condition three phase voltage waveform which measured at bus bar 7 of IEEE 14 bus system. In which it is observed that system voltage becomes normal and per unit value of each phase voltages are 0.95 Pu for normal RL three phase loaded connected with IEEE microgrid system.

Figure 9 shows the three phase voltage measured at bus bar 2 of IEEE 14 bus system during voltage sag condition occurs in between 0.15 sec to 0.2 sec of simulation time. From zero simulation time to 0.15 sec time duration, there is voltage sag occur of 0.6 per unit voltage from 0.15 sec to 0.2 sec simultion time.

Similarly figure 10 shows the three phase voltage measured at bus bar 10. Figure 11 shows the three phase per unit voltages measured at bus bar 10 of IEEE 14 bus system while figure 12 shows the three phase per unit voltage measures at bus bar 1. All power quality disturbances occurs in between 0.15 to 0.3 second of simulation time.

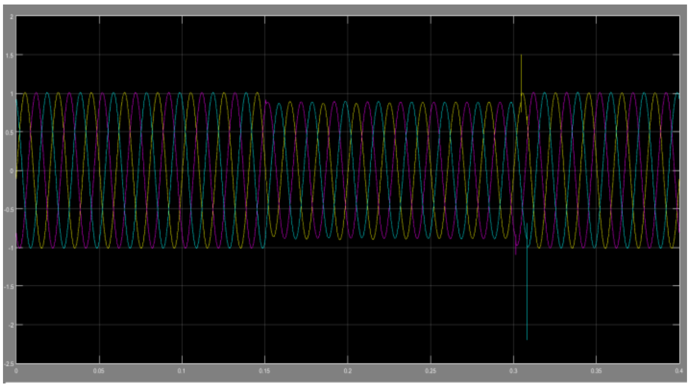

Fig-9: Voltage sag generation at bus bar 2

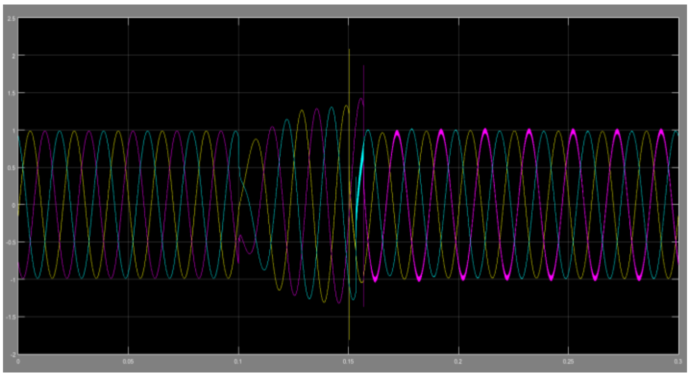

Fig-10: Voltage swell generation at bus bar 10

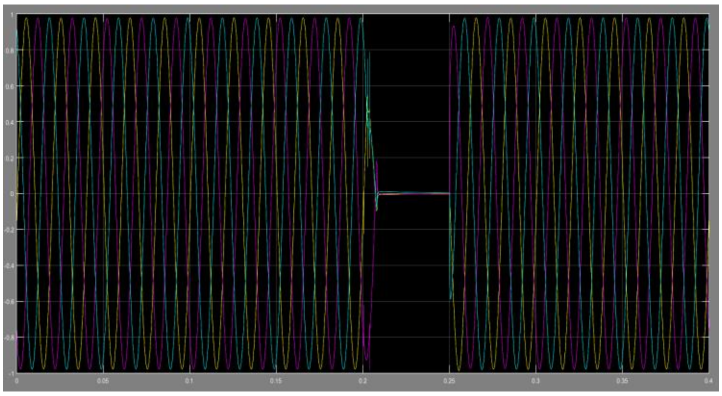

Fig-11: Momentary interruption voltage waveform measured at bus 10

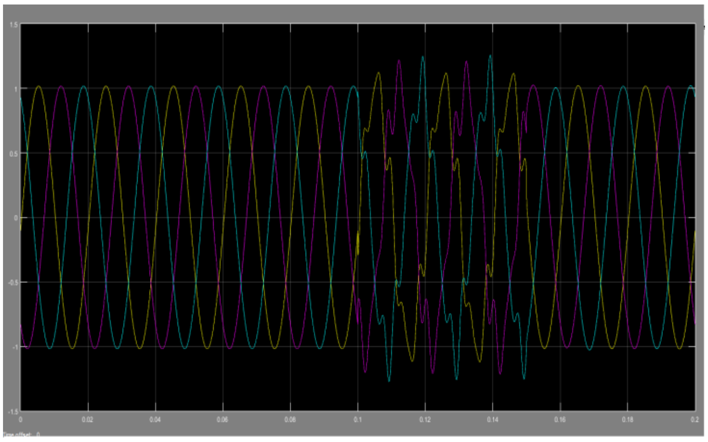

Fig-12: Harmonics voltage measured at bus bar 1

3.2 Artificial Neural Network results

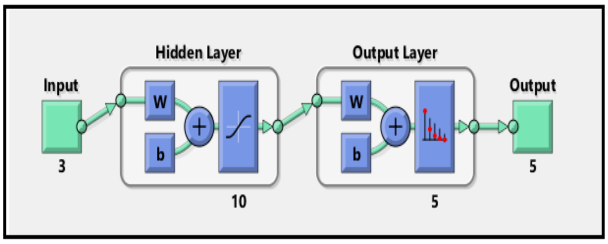

Fig-13: Generalized structure of Neural network in MATLAB Simulink model

Figure 13 shows the generalized structural diagram of BP-ANN model in which three phase per unit voltages are inputs while five types of power quality disturbance classification status are outputs. For that separate neural network structure are utilized and input for Neural network was IEEE 14 bus system three phase per unit voltage which measured at different bus bar locations bus bar 6 and bus bar 13. Similarly, three phases per unit voltages are measured at different bus bar location and can be utilized for training of neural network for considering the different bas bar voltage effect for different power quality disturbances.

Neural network train for 10 power quality disturbance cases at different bus bar location i.e. bus bar 6 and 13. Table 1 shows the input three phase per unit voltages measured at bus bar 6 and 13 for different power quality disturbance conditions. That three phase per unit voltages are input training data set for BP-ANN system. Also, table 2 shows the corresponding target output of BP-ANN system in which there are five status for power quality disturbance detection. If status is 1 means power quality disturbance is occurs while 0 means no power quality disturbance occurs in system.

Table-1: Training input data set for Artificial Neural Network

Sr. no.	Condition	Bus Bar No.	Va(PU)	Vb(PU)	Vc(PU)
1	Normal	6	0.9171	0.9171	0.9171
2	Normal	13	0.8319	0.8319	0.8319
3	Sag	6	0.3247	0.3254	0.255
4	Sag	13	0.318	0.3187	0.3189
5	Swell	6	1.539	1.561	1.5
6	Swell	13	1.321	1.337	1.285
7	Harmonics	6	0.51	0.5098	0.5099
8	Harmonics	13	0.51	0.5098	0.5099
9	Mont. Intr	6	0.3807	0.3972	0.3849
10	Mont. Intr	13	0.3636	0.3795	0.3679

In table 1 and 2, the serial number of table shows the corresponding power quality disturbance condition in IEEE 14 bus system. For example serial number 3 in table 1 shows the three phase per unit voltages measures at bus bar 6 during voltage sag condition in power system. While serial number 6 in table 2 shows the corresponding output for power quality classification for serial number 6 in table 1.

Table-2: Training target data set of Artificial Neural Network

Sr. no.	Condition	Bus Bar No.	Normal	Sag	Swell	Harmonics	Momentary Interruption
0 1	Normal	6	1	0	0	0	
0 2	Normal	13	1	0	0	0	
0 3	Sag	6	0	1	0	0	
0 4	Sag	13	0	1	0	0	
5	Swell	6	0	0	1	0	0
6	Swell	13	0	0	1	0	0
7	Harmonics	6	0	0	0	1	0
8	Harmonics	13	0	0	0	1	0
9	Mont. Intr	6	0	0	0	0	1
10	Mont. Intr	13	0	0	0	0	1

Figure 14 shows the selection of percentage of training data set, validation data set and testing data set from entire 15 numbers of samples. Training data set: These are presented to the network during training, and the network is adjusted according to its error. Validation data set: These are used to measure network generalization, and to halt training when generalization stops improving. Testing data set: These have no effect on training and so provide an independent measure of network performance during and after training.

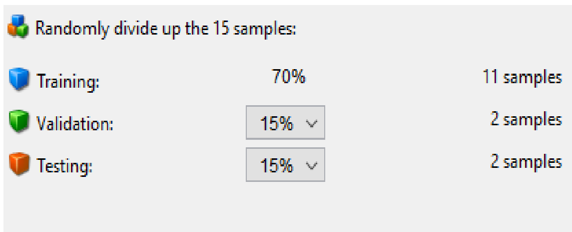

Fig-14: MATLAB NNSTART window for training data set selection for training data, validation data and testing data

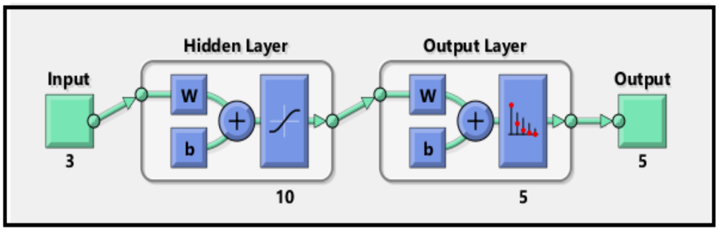

Fig-15: Generalized structure of ANN for training

Figure 15 shows the generalized structure of back propagation based Artificial Neural Network in which input are three phases per unit voltage and then corresponding targets are different power quality disturbance as shown in table 1 and 2 respectively. Hidden layer is consist of 10 neurons and having sigmoidal activation function of each neuron while output neuron is consist of 5 neurons and having soft competitive activation function.

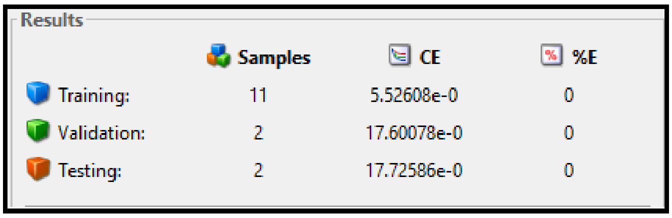

Fig-16: Training performance parameter for neural network for power quality disturbance classification

Figure 16 shows, there are total 15 power quality disturbance data set is utilized for training og BP-ANN i.e. 70% data utilized for training. For validation and testing 30% dataset was utilize i.e. 4 sample data set. Also MSE (Mean square error) for all data set was zero after successful training of ANN.

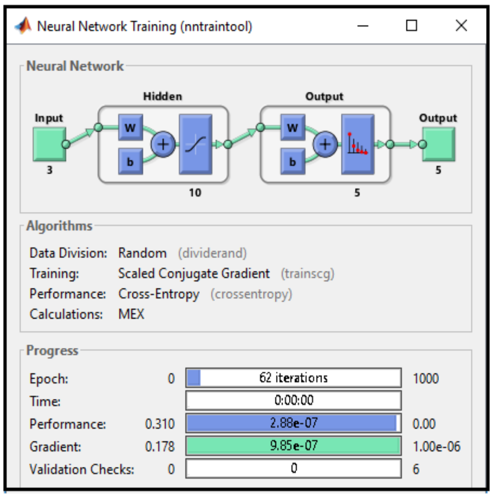

Fig-17: Training performance window for ANN

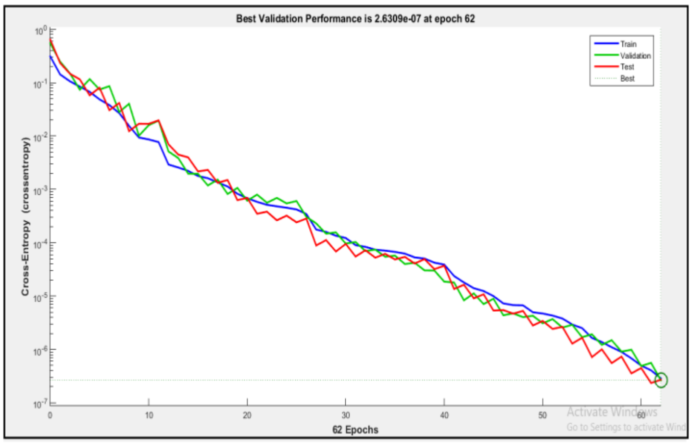

Fig-18: Training performance characteristics of ANN for power quality disturbance classification

Figure 18 shows the training performance window for training of power quality classification neural network. In this total 62 epochs are required for complete training of ANN using back propagation algorithm. Gradient for this training was measures as $9.85*10^{-7}$. During training of neural network for fault classification, neural network takes 28 epochs and mean square error becomes minimum of $2.639*10^{-7}$ shows by green line in figure 27.

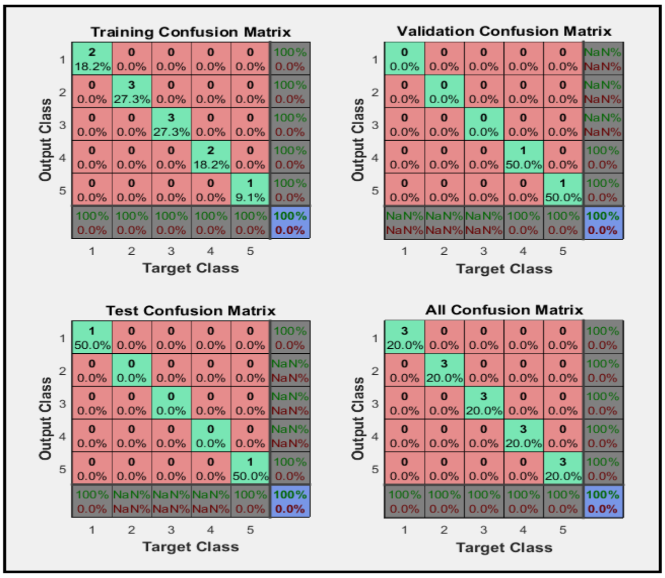

Fig-19: Confusion matrix for training of neural network for power quality disturbance classification

Figure 19 shows that 100% data are perfectly classify the power quality disturbances and not confused for any other data set classification. It means that for remaining 0% data set neural network was in confusion state for classify the fault i.e. not confused for training of data. Perfectly classify all types for power quality disturbances.

Table-3: Actual output of Artificial Neural Network without correction subsystem after training

Sr. no.	Condition	Bus Bar No.	Normal	Sag	Swell	Harmonics	Momentary Interruption
1	Normal	6	1	2718e-20	7.615e-8	1.26e-6	1.388e-7
2	Normal	13	1	1.54e-19	5.549e-8	1.533e-5	1.582e-6
3	Sag	6	4.164e-5	0.9999	9.343e-13	7.318e-12	3.024e-5
4	Sag	13	9.672e-6	1	2.293e-13	8.459e-13	7.235e-6
5	Swell	6	5.656e-7	9.254e-19	0.9998	0.0002216	3.882e-9
6	Swe	13	0.000	9.141	0.9993	0.0005	8.523e-8

	ll		1414	e-18		957	
7	Harmonics	6	6.643e-5	6.609e-19	1.545e-11	0.9997	0.0002362
8	Harmonics	13	6.643e-5	6.609e-19	1.545e-11	0.9997	0.0002362
9	Mont. Intr	6	0.492	0.0004436	1.264e-8	0.001251	0.5063
10	Mont. Intr	13	0.5296	0.06846	1.041e-8	5.516e-5	0.4019

Table 3 shows the actual output of ANN after training. İt observed that, there are small variations in target output of ANN which is shown in table 2. For make output of ANN same as target output, we design the ANN correction subsystem shown in figure 7.

3.3 Fuzzy Logic Controller Results

Figure 20 shows the fuzzy logic controller design in fuzzy toolbox of matlab Simulink modeling. There are three inputs of three phase per unit voltages and one output status which shows the power quality disturbance classification types.

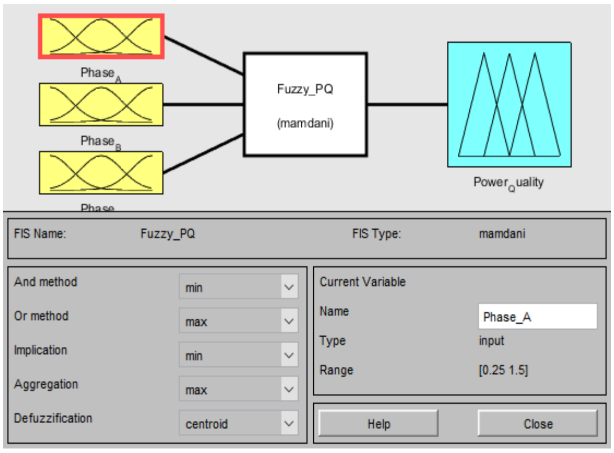

Fig-20: Fuzzy logic controller for power quality disturbance classification

Figure 21 shows the fuzzy partition of input phase A per unit voltage in which membership function divided into five partitions. Phase A divided into five membership function like Very low (VL), Low (L), Medium (M), High (H) and Very High (VH) and all membership functions are triangular membership function. The ranges of all membership function shown in table 4.

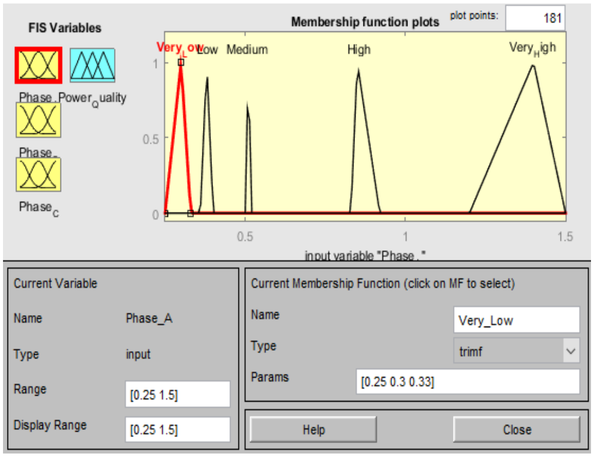

Fig-21: Input Phase A voltage membership function for fuzzy loguc controller

Figure 22 shows the membership function partition for FLC output in which membership function are Normal, Sag, Swell, Harmonics and Momentary Interruption and all membership functions are triangular types. The ranges of all membership functions are shown in table 5.

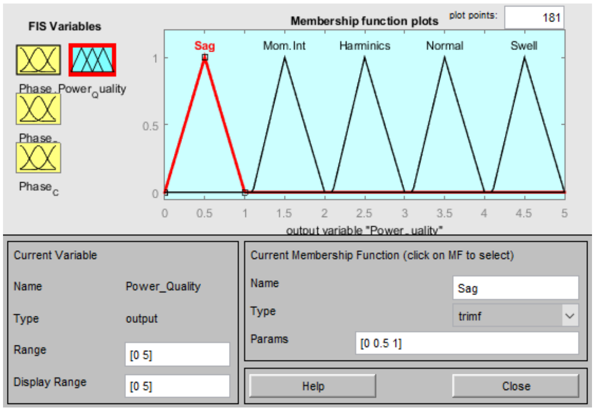

Fig-22: Output of power quality classification membership function for fuzzy loguc controller

Table-4: Input Membership function with fuzzy partition for inputs voltage of phase A, B and C

Name of membership function	Type of Membership Function	Ranges in Per Unit
Very Low (VL)	Triangular	0.2500 to 0.3000 to 0.3300
Low (L)	Triangular	0.3500 to 0.3800 to 0.4000
Medium (M)	Triangular	0.5000 to 0.5100 to 0.5200

High (H)	Triangular	0.8300 to 0.8500 to 0.9200
Very High (VH)	Triangular	1.200 to 1.400 to 1.500

Figure 23 shows the fuzzy rule bases design in MATLAB simulink modeling. This rules are If then rules with AND operator. There are total five rule base are design for FLC which shown in figure 23.

Table-5: Output Membership function with fuzzy partition for power quality disturbance classification

Name of membership function	Type of Membership Function	Ranges in Per Unit
Sag	Triangular	0 to 0.5 to 1
Momentary Interruption	Triangular	1.1 to 1.5 to 2
Harmonics	Triangular	2.1 to 2.5 to 3
Normal	Triangular	3.1 to 3.5 to 4
Swell	Triangular	4.1 to 4.5 to 5

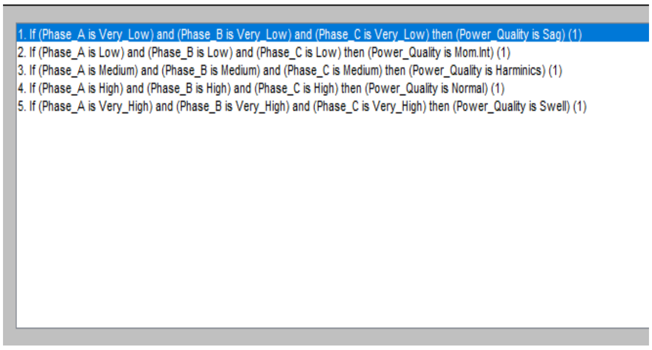

Fig-23: Fuzzy Rule base editor for fuzzy logic controller

Figure 24 shows the individual membership function of all input and output behaviors' for all five fuzzy rule bases. If input A is 0.875 , B is 0.875, C is 0.875 then output of FLC based on rule base is 3.54. Hence rule number 4 is executed because per unit voltages A, B and C in the rage of High membership function. Figure 25 shows the fuzzy output controlling surface which represent the behavious of FLC controller response for corresponding input per unit three phase voltages.

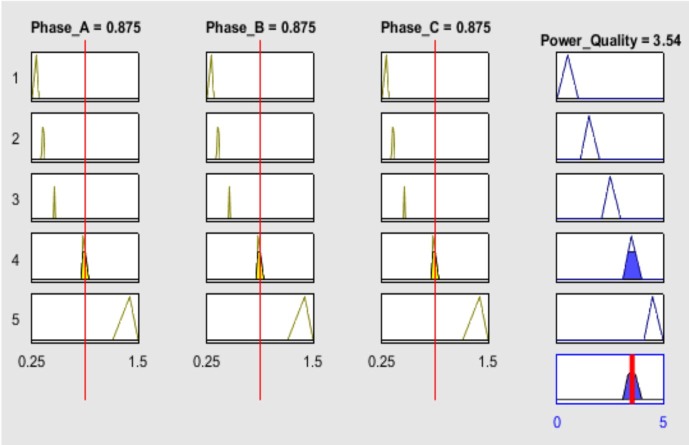

Fig-24: Fuzzy rule base with membership functions representation

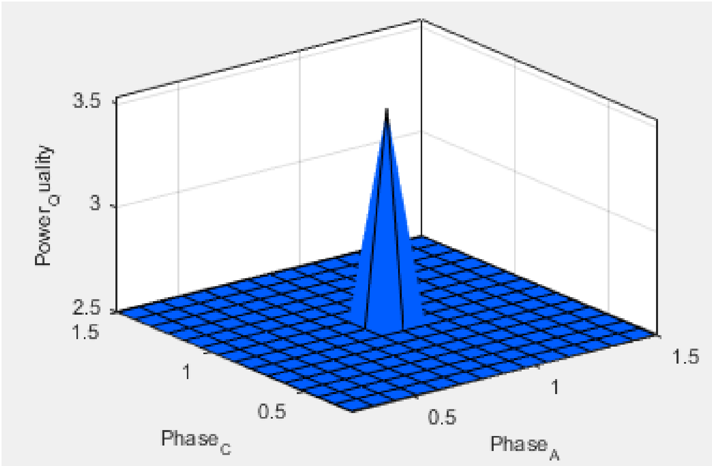

Fig-25: Fuzzy output representation controlling surface for fuzzy logic controller

Table-5: Actual output of Fuzzy logic controller

Sr.no.	Condition	Range of M.F.	Actual output of Fuzzy Logic Controller
1	Sag	0 to 0.5 to 1	0.5
2	Momentary Interruption	1.1 to 1.5 to 2	1.546
3	Harmonics	2.1 to 2.5 to 3	2.533
4	Normal	3.1 to 3.5 to 4	3.55
5	Swell	4.1 to 4.5 to 5	4.541

Table 5 shows the actual output of fuzzy logic controller in which it is observed that fuzzy logic controller gives the classification of different power quality disturbance detection with in a range of fuzzy membership for all types of power quality disturbance classes.

5. CONCLUSION

This paper present the power quality disturbance detection technique in power system microgrid. In which an FLC using RMS measurement subsystem is presented. Also, BP-ANN classifier is used for classification of power quality disturbances. The complete system is design and tested in MATLAB 2015 simulink software.

From simulation result it is clear that using BP-ANN the power quality classification efficiency is 90% while 10 % error occurs due to confusion of ANN after training. For getting answer same as target output of ANN we need to design ANN output correction subsystem model. Hence BP-ANN classifier is requires correction subsystem for exact classification of power quality disturbances.

While using FLC classifier, this provide direct results of power quality disturbance classification. FLC classifier is 100% efficient for power quality disturbance classification. Also FLC controller not required any output correction subsystem as compared with ANN. Hence ANN system is complicated for design as compared with FLC. Also, ANN system required large data set for training of ANN. Also for small change of system parameter, the new training data set is required for ANN training. But FLC controller not required new rule base while small changes occurs in system.

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