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Artificial Intelligence Controller based Grid Connected Distribution Systems for Improvement Power Quality

BONTHU YASHWANTH[1], Y.RAJASEKHAR REDDY[2]

[1]M.Tech Student, Dept of EEE, Mother Teresa Institute of Science and Technology, Kothuru Sathupally, T.S, India

[2]Associate Professor, Dept of EEE, Mother Teresa Institute of Science and Technology, Kothuru Sathupally, T.S, India

Abstract: The decay of power quality is one of the principal issues of electrical distribution systems. One of the main reasons for this is the use of non-linear devices like the switching devices and the power electronics converters. Non-linearity leads to detrimental effects on the utility of the power supply, system efficiency, reduction in power factor, etc. The reactive power is increased due to the reduction in power factor and it does not have any contribution in the transfer of energy, hence its compensation is needed. In this paper, the Artificial Neural Network (ANN) and Adaptive Neuro Fuzzy Inference System (ANFIS) based control methods for a Three-Phase Distribution Static Compensator (DSTATCOM) are proposed. This is used for compensation of the reactive power along with the current related power quality issues that include harmonics. These control methods are simulated in the MATLAB environment with the help of the SIMULINK toolbox. The simulation results suitably demonstrate the performance of these methods and it is found that source current waveforms with lesser distortion are achieved with ANFIS as compared to ANN.

I.INTRODUCTION

Power Quality remains one of the prime aspects of any power distribution system. It has to follow IEEE 1547 standards throughout the different levels of the power system, which are the Generation level, Transmission level, Distribution level, and Utilization level. Because of the extensive use of automatic and power electronic based devices in an electric distribution system, power quality problems have substantially increased. The distribution system has poor

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power quality because of the inadequate reactive power during the steady as well as the dynamic state. These problems generally arise due to the presence of reactive and unbalanced loads [3,6]. A VSC DSTATCOM gives a robust and effective methodology of providing shunt compensation in a line that can help enhance the power quality [4-5]. Various control methods are available to derive the reference currents for the DSTATCOM like the synchronous reference frame theory (SRFT) [1]. The ANN and ANFIS based methods are able to determine and model the non linear systems and can give a better source current waveform and hence better power quality. In this paper, the SRFT method is compared to ANN and ANFIS based methods. The ANN based control method is efficient and viable as it is able to identify as well as model such non-linear systems [9]. However, the ANFIS based method has more efficiency as compared to the ANN based method in giving a better source current waveform. The step size estimated using ANFIS learns faster and there is a lesser static error in the estimation of the fundamental weights a compared to the other specified methods [7-8]. The comparative results of ANN and ANFIS are analyzed and it is found that ANFIS gives a superior performance when compared to ANN.

II. SYSTEM CONFIGURATION

The circuit diagram in Fig. 1 is that of the DSTATCOM system. A reactive load has been connected to a three-phase three-wire distribution system. The DSTATCOM is attached with a DC bus through a Voltage Source Controller (VSC). The VSC is realized with the help of three insulated-gate bipolar transistors (IGBTs) having diodes which are connected antiparallel. The AC sides are connected to a point of common coupling and loads. A Pulse Width

Modulating controller has been used for providing pulses..

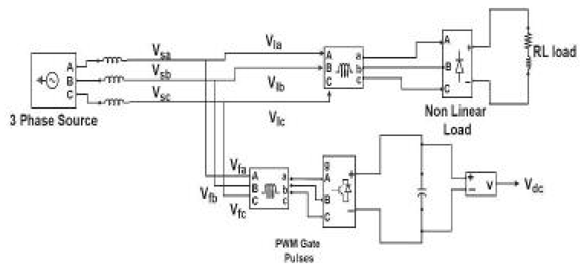

Fig. 1. Fundamental Line diagram of the DSTATCOM system

III. CONTROL ALGORITHM

For power quality compensation, compensating reactive power is provided by the DSTATCOM depending on the needs of the load. The. DSTATCOM is controlled by several algorithms. Here we make use a conventional algorithm to generate the data, and use two Artificial Intelligence based control algorithms to enhance the results.

A. SRFT Algorithm

SRFT algorithm is also called the d-q based algorithm. This algorithm is used to produce pulses for the functioning of the DSTATCOM. These pulses are provided at the ground terminal. Clarke Transformation is used for converting a-b-c to αβ0 reference frame and further αβ0 to d-q frame using Park Transformation.

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (1)$$

After getting the desired currents in d-q frame, quadrature current is terminated and then direct current is added to the error signal generated using the Proportional Integral (PI) control. This error signal is generated using 200V reference and DC link voltage. Then d-q reference frame has been transformed back to the a-b-c frame by making quadrature current zero. This method is called Reverse Park Transformation.

$$\begin{bmatrix} i_{\alpha dc} \\ i_{\beta dc} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_{ddc} \\ i_{qdc} \end{bmatrix} \quad (2)$$

Then the resulting current is compared with source current using hysteresis current controller in order to produce Pulse Width Modulation (PWM) signals. These signals are then fed to the main circuit.

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B. Artificial Neural Network (ANN) trained on data obtained by SRF Method

Artificial Neural Network is comprised of three layers:

Firstly, the input layer followed by the hidden layer and finally the output layer as shown in Fig. 2.

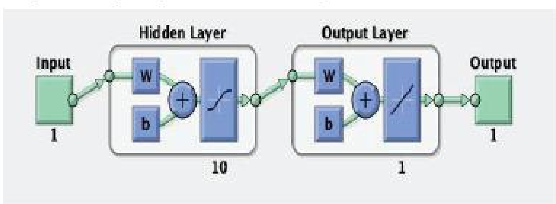

Fig. 2. Neural network structure

The Network is trained using the Feed Forward Back- Propagation Levenberg-Marquardt algorithm with threephase load current as the input for the ANN block shown in Fig. 3.

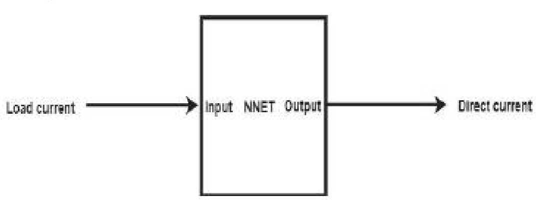

Fig. 3. Simulation model of ANN controller

To produce hidden layer output, we have used the tangent sigmoid activation function. This hidden layer has ten neurons. The output layer neurons are trained using linear activation function to produce the output. 200001 data collected from SRF control algorithm out of which 70% of this data is used for training, 15% is used for testing and 15% is used for validation. The data samples used for the process of training is shown in Table I.

TABLE I. DATA USED TO TRAIN ANN

LOAD CURRENT			Direct Current
Phase A	Phase B	Phase C	
-5.03E-08	-1.07E-02	1.07E-02	0.00E+00
6.46E-04	-2.17E+00	2.17E+00	1.12E-30
7.57E+00	-7.57E+00	-3.29E-04	1.24E-24
-1.32E+01	7.52E+00	5.69E+00	4.87E-19
3.90E+00	-1.36E+01	9.74E+00	1.98E-15
-2.55E-04	1.34E+01	-1.34E+01	7.94E-15
1.37E+01	1.32E-03	-1.37E+01	1.02E-13
-4.31E+00	1.36E+01	-9.33E+00	1.72E-13
5.28E-01	-1.37E+01	1.32E+01	4.65E-13
-1.36E+01	-5.13E-04	1.36E+01	1.29E-09

The performance of the network is analyzed by its mean square error (MSE). Its equation is as follows:

$$E_{mse} = \sum_{K=1}^{N} \frac{1}{2}\left[x_{f_i} - x_{o_i}\right]^2 \quad (3)$$

where xfi represents the calculated output and xoi denotes the desired output and N signifies the number of training samples The

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best validation performance Mean Square Error (MSE) obtained is 5.98251e-8.

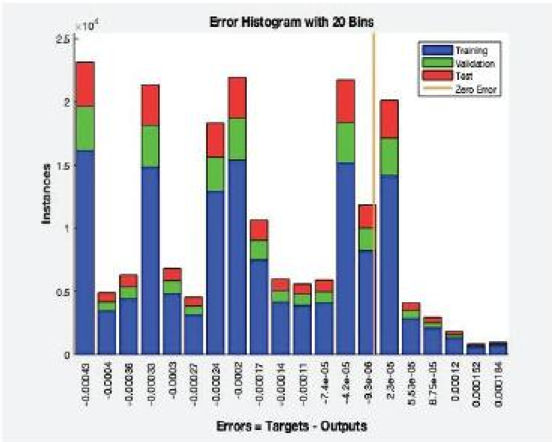

Fig. 4. Error histogram of ANN

The importance of the proposed algorithm is that it needs less time for training the data that has been obtained from the SRFT algorithm, although more memory is required. Training stops when generalization does not improve further, as shown by an increase in the MSE of the validation samples.

C. Adaptive Neuro Fuzzy Inference System (ANFIS) trained on data obtained by SRF Method

Adaptive Neuro Fuzzy Inference System (ANFIS) is basically a family of artificial neural networks which are functionally equivalent to the fuzzy inference systems and combine non-linear and adaptive, non time invariant problem solving attributes of artificial neural networks with the important notions of proximate rationale and analysis of information as given by the fuzzy set theory. Their general advantage over ANN is that ANFIS presents a significantly better ability to learn. A fuzzy inference system has four components, which are an interface for fuzzification, a base for rules, an inference mechanism, and an interface for defuzzification. It is further split into five layers as shown in Fig. 5. Layer 1 is the input layer that takes three inputs that are the three-phase load currents and sends the input to layer 2 which performs the process of fuzzification by making crisp values fuzzy. Layer 3 defines the layer which matches output to input. Layer 4 defines the normalization layer which is used to measure the firing strength of normalization for a particular given rule. Layer 5 defines the defuzzification layer which is used for converting into crisp values from fuzzy values and give the desired output direct current. Accuracy is bettered as a result. Epochs used for training the ANFIS structure is 10 and the triangular membership functions has been used. The number of nodes is 78, with 27 linear and 27 non-linear parameters. The number of training data pairs are 200001. 27 fuzzy rules have been used for the training. The training MSE obtained is 0.000041.

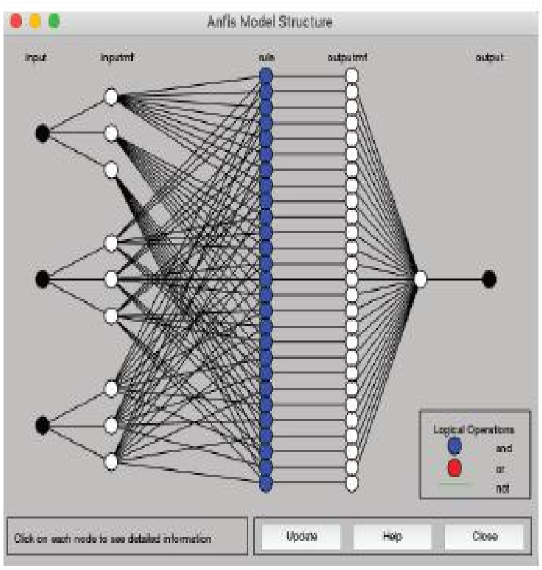

Fig. 5. Structure for ANFIS

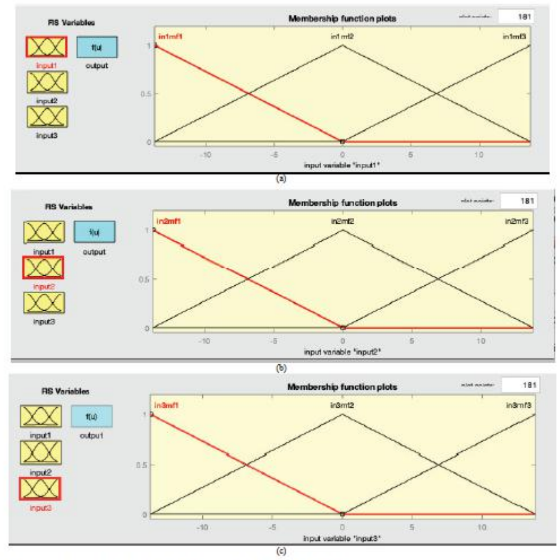

Fig. 6. Optimized membership function for input variables (a) input1, (b) input2, and (c) input3

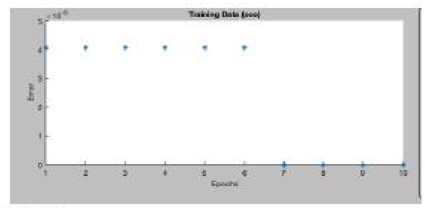

Fig. 7. Training error for 10 epochs

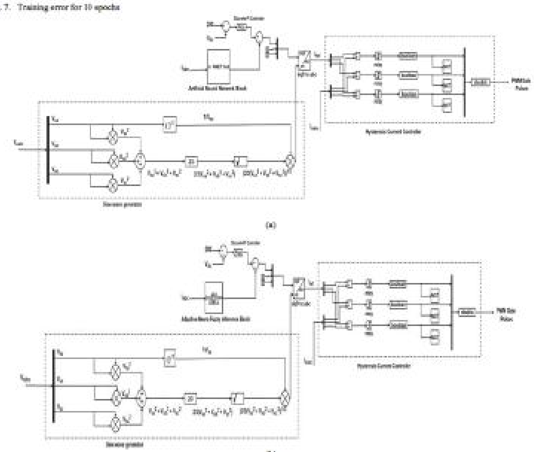

Fig. 8. Control circuit diagram of (a) ANN algorithm and (b) ANFIS algorithm

IV. MATLAB SETUP OF DSTATCOM ARRANGMENT

MATLAB Simulink model consists of a DSTATCOM system corresponding to the system arrangement presented above in Fig.

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1 comprising the source, load, DSTATCOM, and control blocks. The first part of the circuit is basically a distribution system circuit including a combination of inductance and resistance and a diode which makes the whole system a nonlinear load. The above-mentioned SRF, ANN and ANFIS based theories are used to simulate this DSTATCOM model. Fig. 8 (a) - (b) shows the control circuit diagram of the algorithms used. The following algorithms are implemented using the MATLAB SIMULINK block set. Simulation is accomplished in discrete mode at a maximum step size of 5e-06 with ode23s solver.

V. RESULT AND DISCUSSION

The behavior of the DSTATCOM using ANN and ANFIS control algorithms in enhancing the power quality of the above distribution system can be observed by studying the waveforms of the various parameters after compensation.

A. Results obtained using ANN based controller

Fig. 9 shows the simulation results when the DSTATCOM is controlled using ANN control algorithm and connected to the common coupling point. Here the source current is a sine wave approximately. In addition, the source current and the voltage are in phase with each other at the point. Hence, the source current is maintained at unity power factor. Total Harmonic Distortion (THD) is found to be 1.65% for the source current.

B. Results obtained using ANFIS based controller

Fig. 10. Shows the results obtained on controlling the DSTATCOM using ANFIS based technique. Here also the source current and voltage at the common coupling point are in phase with each other. Thus, unit power factor is obtained. Total Harmonic Distortion of the source current as

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seen is 1.51% that is lesser than what is obtained using ANN.

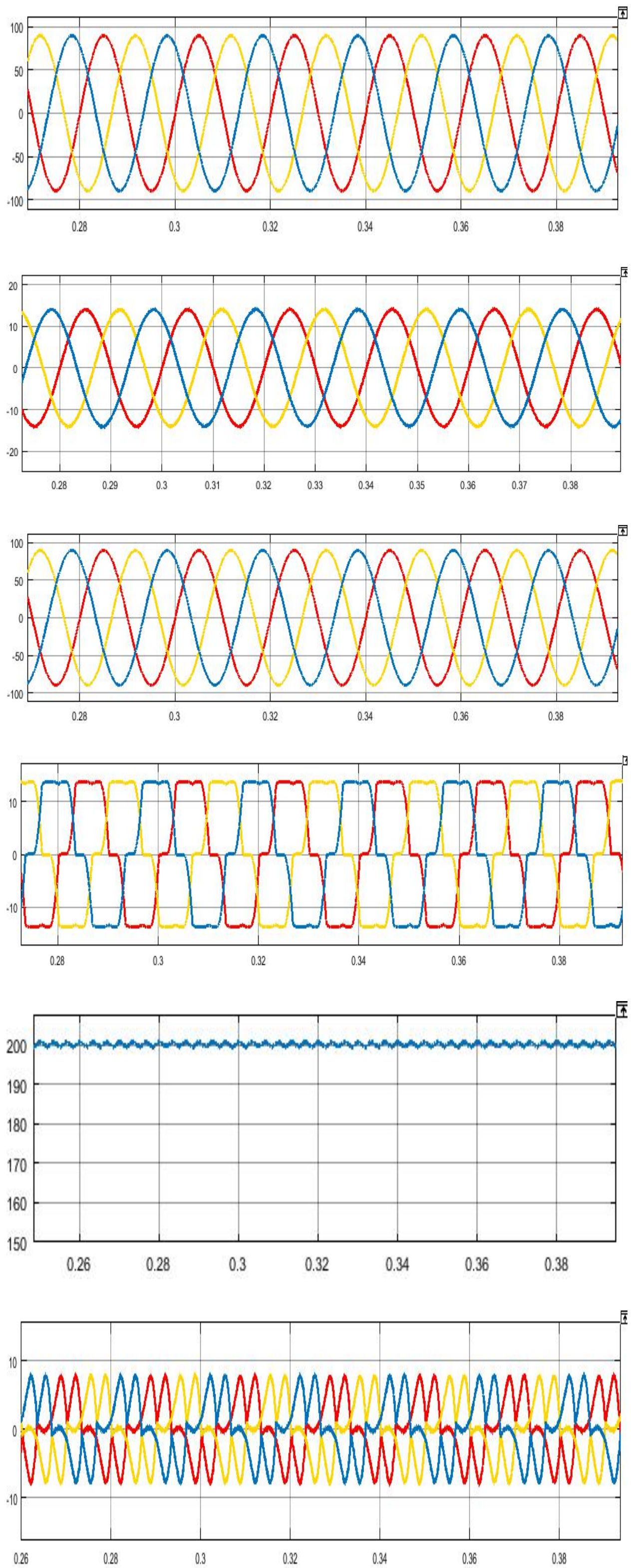

Fig. 9. Waveforms obtained using ANN control algorithm

C. Comparison between ANN and ANFIS control algorithms

Total Harmonic Distortion (THD) is a measure that is used for comparing the results obtained on applying the two control algorithms. THD can be defined as the equivalent root mean square (RMS) voltage of all the harmonic frequencies divided by the root mean square voltage of the fundamental frequency.

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} V_{n\_rms}^2}}{V_{fund\_rms}} \quad (4)$$

Vn,rms is the RMS voltage of the nth harmonic Vfund,rms is the RMS voltage of the fundamental frequency Since THD is calculated using the amplitudes of the harmonics, Fourier analysis is a method that helps determine THD. THD for source current and source voltage is calculated by using the FFT Analysis of the power GUI block. The ANFIS control algorithm as compared to ANN control algorithm

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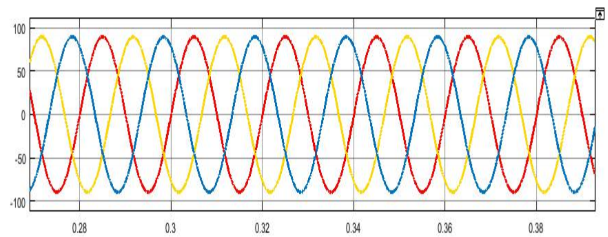
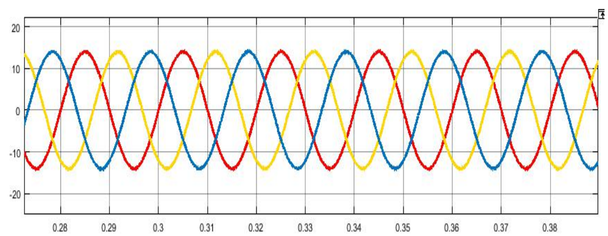
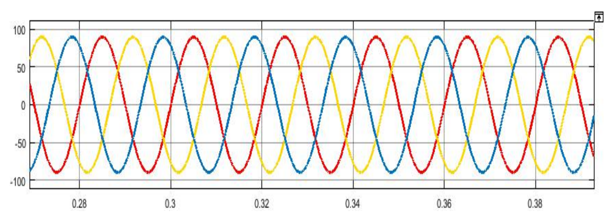
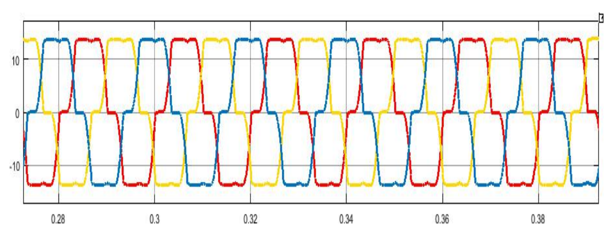
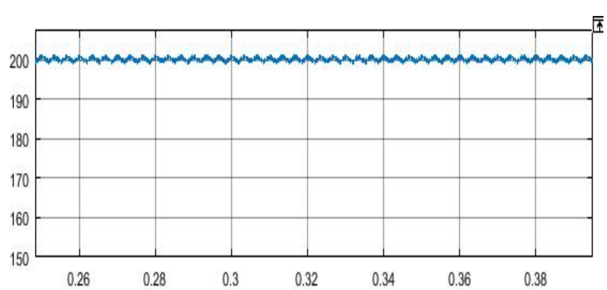
provides better waveforms and lower THD. The THD graph for ANFIS shows more distortion as compared to the one obtained using ANFIS.











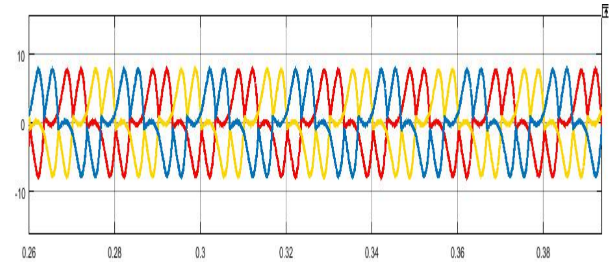


Fig. 10. Waveforms obtained using ANFIS control algorithm

The results obtained from the conventional method, that is SRFT control algorithm and from the artificial intelligence- based control algorithms, ANN and ANIFIS have been compared.

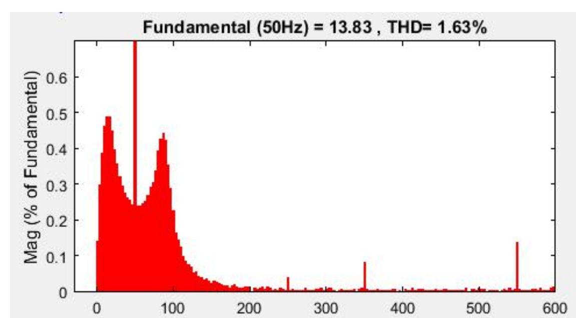


Fig. 11. THD Using ANN control algorithm

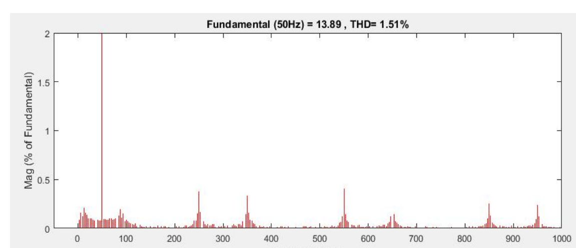


Fig. 12. THD Using ANFIS control algorithm

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TABLE II. COMPARISON RESULTS OF THD OBTAINED IN THE DISTRIBUTION SYSTEM

DSTATCOM Control Algorithm	Rise Time	Peak Overshoot	Settling Time	THD	Convergence Rate
SRFT	0.001	4.55	0.0142	1.75%	High
ANN	0.0013	4.42	0.0139	1.65%	Low
ANFIS	0.0014	4.02	0.0135	1.55%	Low

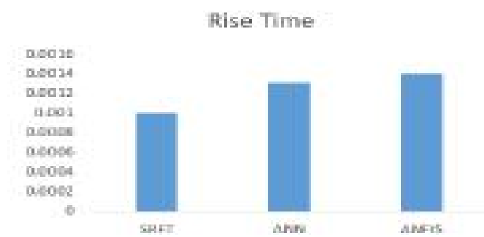

TABLE III. SIMULATION PARAMETERS

Shunt Capacitor Capacitance and Initial Voltage	1500e-06 F, 156 V
Sampling Time	5e-06 s
PI Controller (Proportional, Integral)	0.4, 50
Source Inductance	2e-06 H
Load Inductance	0.003 H
Shunt Inductance	0.002 H
Source RMS Voltage	110 V

VI. Conclusion

In this paper, we have used Artificial Neural Network (ANN) and Adaptive Neuro Fuzzy Inference System (ANFIS) control methods to improve the power quality compensation. SRF theory, ANN as well as ANFIS based techniques have shown the satisfactory operation of DSTATCOM. The ANFIS control technique has considerably improved the performance of the DSTATCOM as compared to that of the ANN technique. The ANFIS based technique utilizes both Fuzzy Logic as well as ANN algorithm and provides higher accuracy and lower THD in source current in conditions of varying load. MATLAB simulation along with test results prove the efficacy of the mentioned algorithms. Thus, ANFIS has proven to be more efficient as well as effective method in order to control the DSTATCOM for the improvement of power quality. A considerable change in the THD can be observed as ANFIS reduces the THD obtained using ANN as mentioned above, and thus reduces the effect of harmonics. This is how better results are obtained and the power quality is improved.

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