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D-STATCOM for Power Quality Improvement Trained by ANN

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Abstract: ***Power quality has become an important issue since many loads at distribution ends have become intolerant to various power quality issues. The power quality issues such as voltage sag, voltage swell and harmonics which are certainly major concerning issues in the present era. These issues can lead to failure of the many sensitive loads connected to the distribution system. To solve this problem advanced custom power devices are used. One of such device is the Distribution Static Synchronous Compensation (D-STATCOM). DSTATCOM provides to maintain the desired power factor, voltage and also suppress the harmonic content in distribution network. The event of power quality is detected by trained artificial neural network then the appropriate event will be mitigated using neural network aided D-STATCOM. The results show clearly the performance of the Artificial Neural Network based D-STATCOM in mitigating the voltage sag, harmonics, reactive power compensation and power factor improvement.***

Keywords: Distribution Static Compensator (D-STATCOM), Artificial Neural Network (ANN)

1. Introduction

The electric power system is classified in to three division viz. generation, transmission and distribution. The generation unit is required to produce adequate amount of power to meet the customer's demand for a reliable power supply system. Transmission systems must transport bulk power generated over long distances without overloading and damaging the equipment and distribution systems should deliver the electric power to each customer's premises. Distribution system is connected to the customer directly though it is located at the end of power, so the power quality mainly depends on distribution system. The reason behind this is that, the failures of electrical distribution network account for about 90% of the average customer interruptions. In the earlier days, the major focus was on generation and transmission for power system reliability. But now a day's more attention for reliability assessment is focused only for the distribution systems. Power Quality (PQ) related issues are of most concern now-a-days. The use of power electronic devices, viz. adjustable speed drives (ASD), converter and inverter, choppers, programmable logic controllers (PLC), energy-efficient lighting, etc. are lead to a complete change of electric loads and its nature. These are the major causes and the major victims of power quality problems [1]. Due to their use of this equipment, all these loads may cause disturbances to the system such as transients, short duration variations (sags, swells, and interruption), long duration variations (sustained interruptions, under voltages, over voltages), voltage imbalance, waveform distortion (dc offset, harmonics, inter harmonics, notching, and noise), voltage fluctuations and power frequency variations and these are generally referred as power quality problems.

For the reasons described above, there is a growing interest in mitigating power quality disturbances by developing newer equipment. Even though, many techniques available for mitigating various power quality problems, the use of custom power devices like, Dynamic Voltage Regulator (DVR), Unified Power Quality Controller (UPQC) and Distribution Static Compensator (D-STATCOM) is considered to be the efficient method.

A shunt compensating device having ability to improve the power quality by voltage regulation, load compensation and power factor improvement. The use of various controlling devices like PI, PID, fuzzy logic, and sliding-mode are in practice now [2]. The most common type used in industrial systems till date is Conventional PI based control. Though the structure of PI is fixed, it cannot perform in an optimized manner under variable load or nonlinear load conditions [3]. This raises a need for the development of new controllers with more improved performance. In the recent years, for the applications of power electronics Artificial-intelligence (AI) techniques, particularly the NNs, are having a significant impact on it. While maintaining the stability of the converter system over a wide operating range, Neural-network- based controllers provide fast dynamic response and are considered as a new tool to design control circuits for PQ devices [4].

The ANN can perform better than conventional PI controller and it also provides very good basics to build nonlinear controllers. A lot of research works are going on for DSTATCOM on combination with neural network. In this paper design of ANN based controller for current control and voltage control of shunt active filter instead of PI controller is used.

Neural networks are composed of numerous elements operating in parallel, which is, inspired by biological nervous systems. In general, the network function is determined mostly by the connection between elements. To obtain a particular function neural network is trained by adjusting the value of weights between elements. The neural network is trained offline using data obtained from conventional PI controller. A three leg VSI is used to inject or absorb the appropriate voltage through an LC filter and an injection transformer is used to compensate load voltage from the distorted supply voltage. The Levenberg - Marquardt Back propagation algorithm is used to implement the control scheme of the VSI [5]. Initially the data from PI controller is

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stored in workspace. These saved data are trained offline using ANN.

2. DSTATCOM Model in Synchronous Reference Frame

In distribution systems for more active power supply capability implementation of shunt type of fact devices is preferred when compared to series type devices. Main objectives of shunt compensator are [2]:

1) The source currents should be sinusoidal and contain only positive sequence components.
2) The power factor or the voltage magnitude at PCC should be controlled.

To achieve this objective, the compensator should be able to inject negative, zero sequence fundamental frequency components in addition to harmonic currents of all sequences. In DSTATCOM voltage source converter bridge is connected to a common dc bus. The DC bus voltage is held by the capacitor C_{dc}. Since there is no energy source connected to the DC bus, power exchanged by the DSTATCOM is zero if switches are ideal; the losses in the reactors and capacitor are zero. Then the losses are to be supplied by the active power drawn from the AC system. In order to stabilize the capacitor voltage in steady state, a DC bus voltage control is necessary. The power supplied to the load varies over the line period of fundamental (supply) frequency, the capacitor will charge and discharge resulting in a voltage ripple. So that RMS current supplied from the source to achieve unity factor at PCC is required to minimize. The reference for the source current vector is first computed and the desired compensator current is obtained as the difference between the load and the source (reference currents). To inject the desired currents, DSTATCOM must have a high bandwidth closed loop current control loop. The synchronous reference theory is based on the transformation of the stationary reference frame three phase variables (abc) to synchronous reference frame variables (d, q, 0) whose direct (d) and quadrature (q) axes rotate in space at the synchronous speed ωe.

The current transformation from abc to d-q-0 frame is defined as [5],

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin\theta & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (1)$$

The conversion of DQO current to ABC using Park transformation:

$$I_{abc} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\theta & -\sin\theta & \frac{\sqrt{2}}{2} \\ \cos\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{2\pi}{3}\right) & \frac{\sqrt{2}}{2} \\ \cos\left(\theta + \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) & \frac{\sqrt{2}}{2} \end{bmatrix} \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} \quad (2)$$

3. Artificial Neural Network

Neural-networks is one of the new technology that is getting fashionable in the present era. This area of neural networking is the "fuzziest" in terms of a definite set of rules to abide by. There are many types of networks - ranging from simple Boolean networks (perceptions), to complex self- organizing networks (Kohonen networks), to networks modelling thermodynamic properties (Boltzmann machines).

3.1 Layers of ANN

The network consists of several "layers" of neurons, an input layer, hidden layers, and output layers. Input layers take the input and give the data to the hidden layers (so-called hidden because the user cannot see the inputs or outputs for those layers). These hidden layers do all the necessary computation and give the results to the output layer.

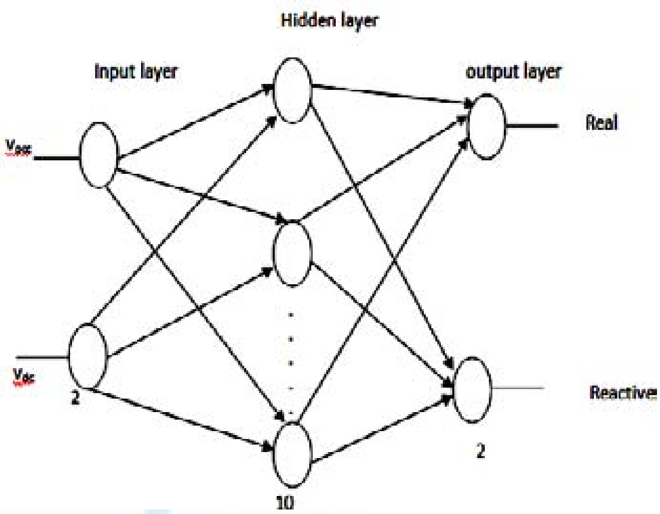

Figure 1: Architecture of ANN [5]

The figure 1 illustrates the architecture of artificial neural network (ANN). The ANN controller consists of three neuron layers, the input layer, the hidden layer and the output layer. The input layer transmits the input signal to the hidden layer. The latter begins the learning process and the output layer continues the learning process and provides outputs.

The designed ANN controller has 3 layers composed of 2 input layers, 10 hidden layers and 2 output layers. It has a 2 input layer obtained from the error voltage at the point of common coupling (pcc) and the error voltage at the dc link.
The output of ANN controller is the reference variable for the PWM generator. Therefore, the output of ANN with varying amplitude and phase passes through a comparator and is compared with a carrier signal. When the ANN output's magnitude is more than carrier signal's magnitude, the PWM circuit generates high output and when the ANN output's magnitude is less than carrier signal's magnitude, the PWM circuit produces low output.

3.2 Neural Network Training

The main aim of training of ANN is to finds the suitable weight values which may cause the desired output. For fast

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convergence, back propagation algorithm is used. Select ANN topology with number of layers, nodes and initialize with random weights. The input to the neural network is the error voltage at the point of common coupling and error voltage at the DC link. Calculate the difference with the obtained output and actual output which is nothing but an error. The error is determined and a portion of it is propagated backward through the network [6].

3.3 Levenberg-Marquardt Algorithm

The back- propagation (BP) algorithm is used to train the most commonly used multilayer perceptron (MLP) model of neural network which is too slow for practical problems. Some high performance algorithms are available to train MLP models but it is 10 to 100 times faster than BP algorithm. These algorithms are based on numerical optimization techniques like Conjugate gradient, quasi Newton and Levenberg Marquardt algorithms (LMA), etc. Out of these, in Levenberg Marquardt algorithm, training process converges quickly. LMA combines the excellent local convergence properties of Gauss-Newton method hence found to be the fastest training algorithm for moderate size neural networks.

4. Proposed Control Scheme

4.1 Block Diagram

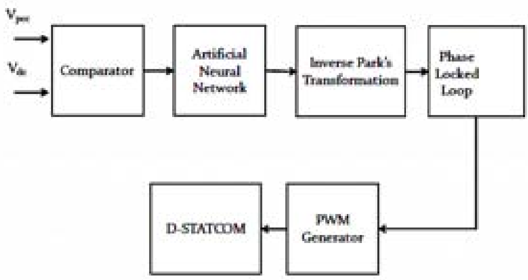

Figure 2: Block Diagram

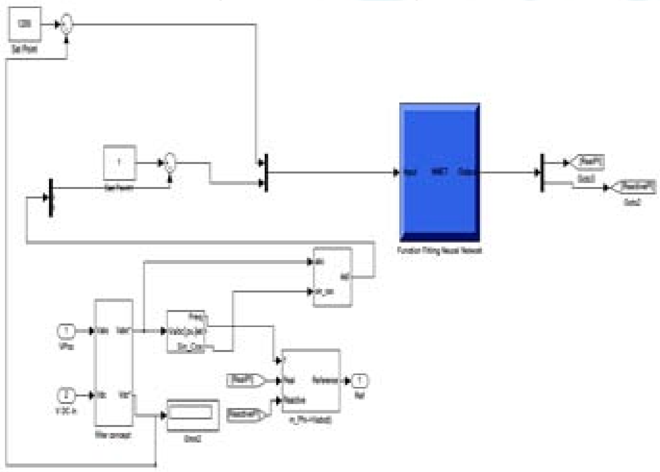

Figure 3: ANN Controller

First, in order to create the neural network fitting tool box training of neural network is done with number of input and output data that are stored in the work space which is taken from the conventional PI controller. The levenberg-marquardt back propagation algorithm is used for the training purpose.

The ANN training is stopped, if the number of maximum epoch to train is reached or the time is beyond the maximum limit or the performance is minimized to the goal or the performance gradient falls below minimum gradient or initial blending factor (mu) beyond maximum mu or the performance of the validation has increased more than the Maximum validation failures. In this work the best validation performance is 0.00030248 at epoch 61. Now the ANN is trained offline to control the DSTATCOM. After the completion of offline training the created neural network fitting toolbox is placed in the replacement of PI controller.

Then the voltage at the point of common coupling is compared with the reference voltage and dc link voltage is compared with the reference voltage is given as the input layer of the ANN. The designed ANN controller has 3 layers composed of 2 input layers, 10 hidden layers and 2 output layers. After the training is complete the output produced is real and reactive. The aim of the control scheme is to maintain constant voltage magnitude at the point where a sensitive load is connected, under system disturbances. The main function of a DSTATCOM control system is to detect the disturbances occurring in the system and compute the missing voltage to generate gate pulses using Discrete PWM generator, then the IGBT converter converts the input DC voltage to a sinusoidal AC voltage through an LC filter and injection transformer. The reactive power depends on the 0 to 1's. If the voltage magnitude is below 1 then it represents the voltage sag. If the voltage magnitude is above 1 then it represents voltage swell.

The compensating current injected by the DSTATCOM system is stopped, only after the absence of the disturbance. In this work, the inverse park's transformation is used to calculate the missing voltage. The dqo to abc transformation is transformed the dq rotating coordinate system to 3Φ stationary coordinate system.

The dq coordinate which is compared with the reference value, will calculate the disturbance in the dq coordinate and these can be transformed again to abc coordinate. The Phase Locked Loop (PLL) measures the system frequency and gives the phase synchronous angle θ for the dq coordinate system. The comprehensive result for the above mentioned controllers are presented to investigate the performance of controller in the proposed system.

4.2 Simulation

The SIMULINK model of proposed DSTATCOM is shown in fig. And it is simulated in MATLAB SIMULINK to test the performance of the control system.

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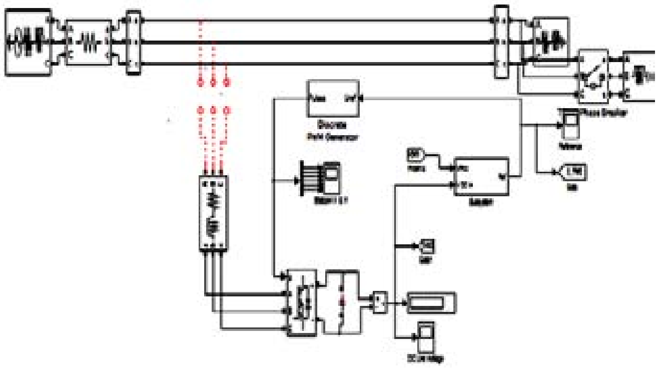

Figure 4: Simulation model of test system to measure voltage sag, detection by Neural Network and mitigation by DSTATCOM.

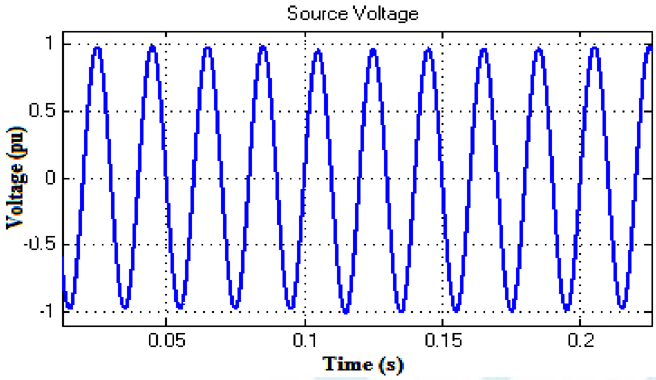

Figure 5: Source Voltage

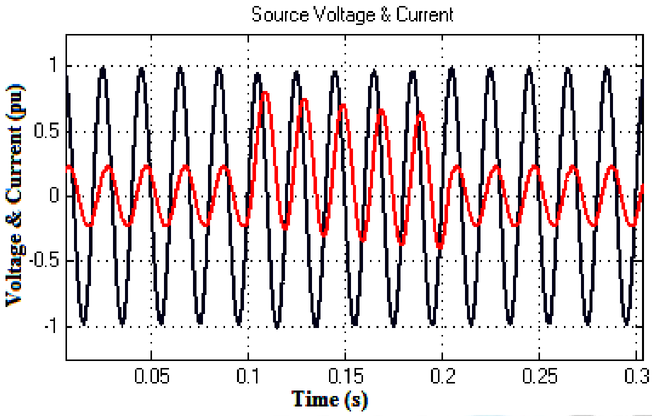

Figure 6: Compensated source voltage and current

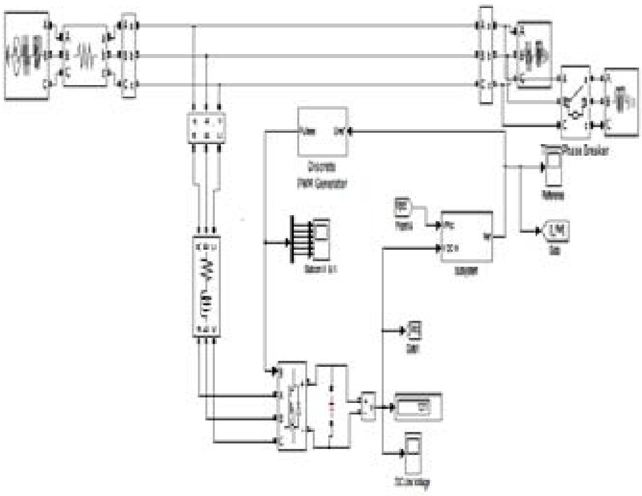

Figure 7: Simulation model of test system to measure voltage sag, detection by Neural Network and mitigation by DSTATCOM

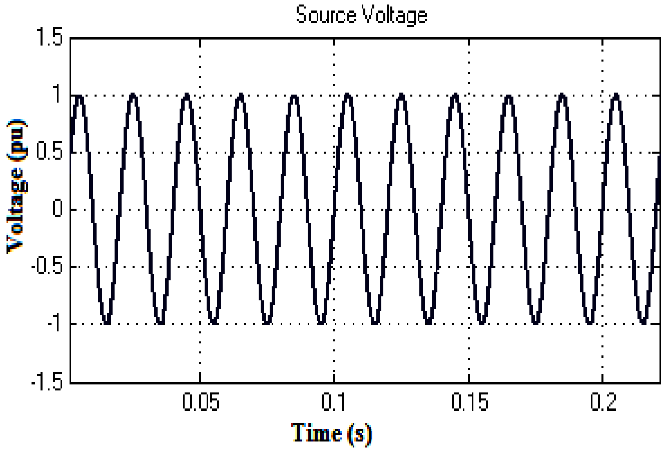

Figure 8: Source voltage

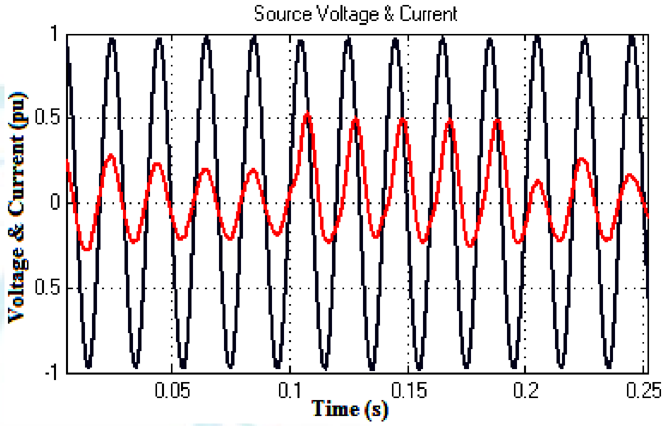

Figure 9: Compensated source voltage and current

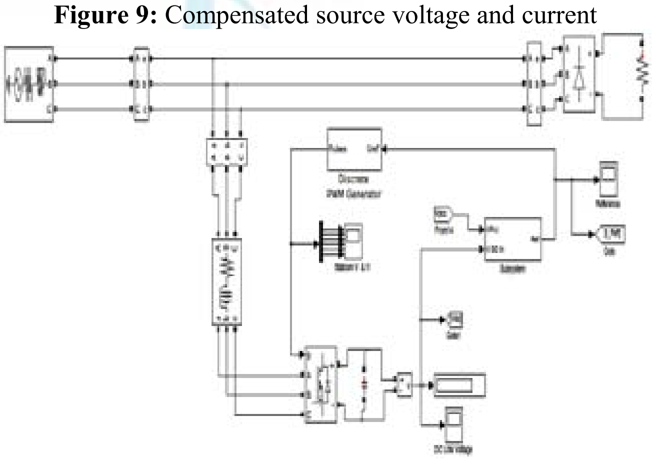

Figure 10: Simulation model of test system to measure voltage sag, detection by Neural Network and mitigation by DSTATCOM

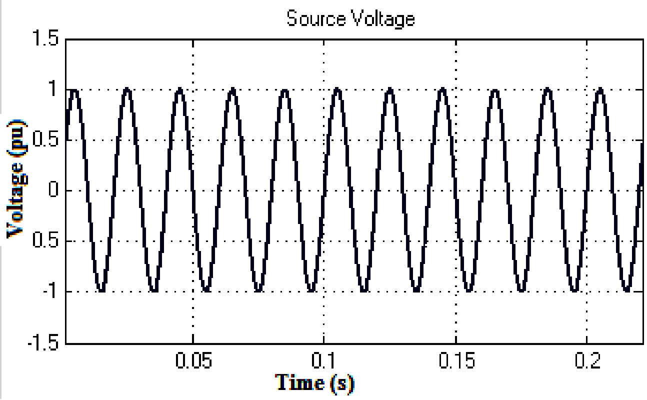

Figure 11: Source voltage

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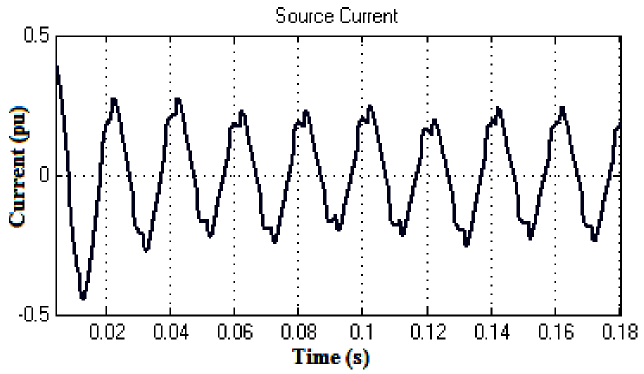

Figure 12: Source current

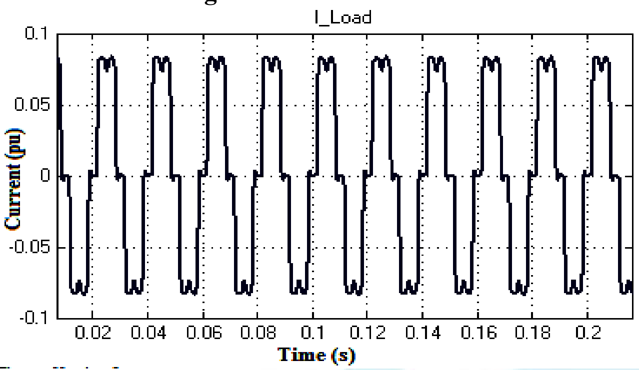

Figure 13: Load current

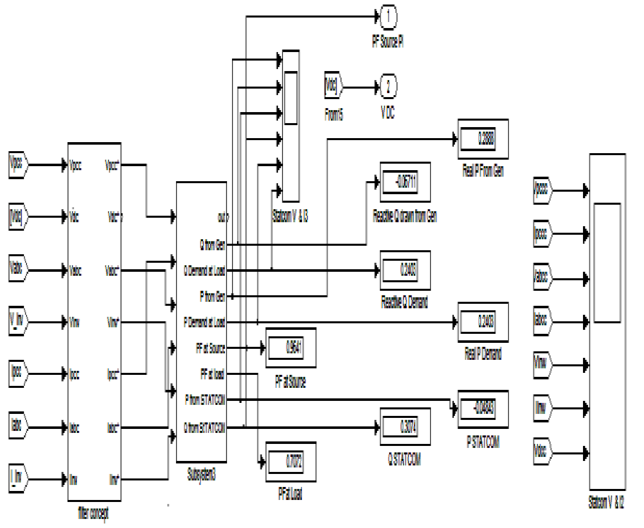

Figure 14: Simulation model of test system to measure voltage sag, detection by Neural Network and mitigation by DSTATCOM

Figure 14 shows the performance of ANN Aided DSTATCOM with a load having 0.9 p.f lagging. It is observed that supply voltages and currents are in phase when DSTATCOM is connected. Therefore, designed DSTATCOM is able to improve P.F of supply to unity. The power factor level is improved in load side or utility side by using the DSTATCOM. The directly source signal is supplying through the load to affect the sensitive loads and linear loads. These above problems are overcome by using DSTATCOM to improve the power factor in load side level. Similarly, it is also reducing the Total Harmonic Distortion (THD) [7].

$$THD = \frac{\text{Sum of square of amplitudes of all harmonics}}{\text{Fundamental component}} \quad (3)$$

Table 1: THD Analysis

	Source Voltage	Source Current
Without DSTATCOM	0.11%	27.24%
With ANN controlled DSTATCOM	0.10%	10.72%

5. Conclusion

Considering the neural network controlled DSTATCOM, it is observed that the power quality of the interconnected power system is improved. The results can be tested for both linear and nonlinear loads in MATLAB/SIMULINK. The performance of ANN controlled DSTATCOM is more effective rather than other conventional controllers. By adding neural network control to DSTATCOM it reduces the harmonic content, improve the power factor and also reduce the voltage sag and maintain the quality of power supply.

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