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# Dynamic performance of DSTATCOM using BP algorithm under nonlinear loads

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*Abstract*: **This paper presents an implementation of a three phase distribution static compensator (DSTATCOM) using a back propagation (BP) control algorithm for its functions such as harmonic elimination, load balancing and reactive power compensation for power factor correction, and zero voltage regulation under nonlinear loads. A BP-based control algorithm is used for the extraction of the fundamental weighted value of active and reactive power components of load currents which are required for the estimation of reference source currents. A prototype of DSTATCOM is developed using a digital signal processor, and its performance is studied under various operating conditions. The performance of DSTATCOM is found to be satisfactory with the proposed control algorithm for various types of loads. A DSTATCOM is proposed for compensation of reactive power and unbalance caused by various loads in distribution system.**

*Keywords:* **DSTATCOM, back propagation algorithm, reactive power compensation, voltage unbalance, weights.**

## I. INTRODUCTION

The quality of available power has a direct economic impact on industrial and domestic sectors which affects the growth of any nation. This issue is more serious in electronic based systems. The level of harmonics and reactive power demand are popular parameters that specify the degree of distortion and reactive power demand at a particular bus of the utility. The harmonic resonance is one of the most common problems reported in low- and medium-level distribution systems. It is due to capacitors which are used for power factor correction (PFC) and source impedance.

Power converter-based custom power devices (CPDs) are useful for the reduction of power quality problems such as PFC, harmonic compensation, voltage sag/swell compensation, resonance due to distortion, and voltage flicker reduction within specified international standards. These CPDs include the distribution static compensator (DSTATCOM), dynamic voltage restorer, and unified power quality conditioner in different configurations. Some of their new topologies are also reported in the literature such as the indirect matrix converter-based active compensator where the dc-link capacitor can be removed. Other new configurations are based on stacked multicell converters where the main features are on the increase in the number of output voltage levels, without transformer operation and natural self-balancing of flying capacitor voltage, etc.. The performance of any custom power device depends very much upon the control algorithm used for the reference current estimation and gating pulse generation scheme. Some of the classical control algorithms are the Fryze power theory, Budeanu theory, p-q theory and SRF theory, Lyapunov-function-based control and nonlinear control technique, etc.

Adaptive learning, self-organization, real-time operation, and fault tolerance through redundant information are major advantages of these algorithms. Feedforward back propagation (BP) artificial neural network (ANN) consists of various layers such as the input layer, hidden layer, and output layer. It is based on feedforward BP with a high ability to deal with complex nonlinear problems. The BP control algorithm is also used to design the pattern classification model based on decision support system. The standard BP model has been used with the full connection of each node in the layers from input to the output layers. Some applications of this algorithm are as to the identification of user faces, industrial processes, data analysis, mapping data, control of power quality improvement devices, etc.

The control of power quality devices by neural network is a latest research area in the field of power engineering. The extraction of harmonic components decides the performance of compensating devices. The BP algorithm which trained the sample can detect the signal of the power quality problem in real time. Its simulation study for harmonic detection is presented. Many neural network-based algorithms are reported with theoretical analysis in single phase system, but their implementation to DSTATCOM is hardly reported in the available literature.

## II. SYSTEM CONFIGURATION AND CONTROL ALGORITHM

The VSC based DSTATCOM is connected through three phase ac mains to three phase non linear loads with internal grid impedence which is as shown in figire 1. The performance of DSTATCOM depends upon the accuracy of harmonic current detection. For reducing ripple in compensating currents, the tuned values of interfacing inductors ($L_f$ ) are connected at the ac output of the VSC. A three phase series combination of capacitor ($C_f$ ) and a resistor ($R_f$ ) represents the shunt passive ripple filter which is connected at a point of common coupling (PCC) for reducing the high frequency switching noise of the VSC. The DSTATCOM currents ($i_{Cabc}$) are injected as required compensating currents to cancel the reactive power components and harmonics of the load currents so that loading due to reactive power component/ harmonics is reduced on the distribution system. For the considered three phase nonlinear load with approximately 24 kW, the compensator data are given in Appendix A.

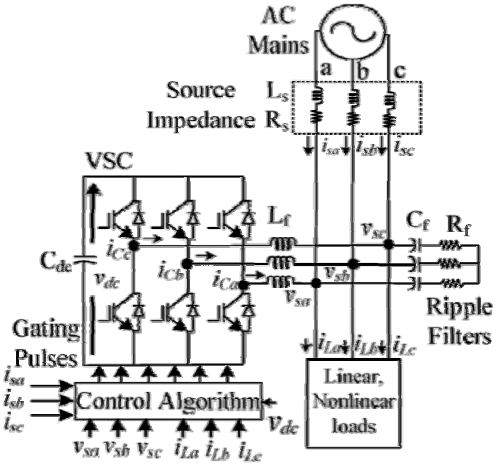


Fig. 1. Schematic diagram of VSC based DSTATCOM

Fig. 2 shows the block diagram of the BP training algorithm for the estimation of reference source currents through the weighted value of load active power and reactive power current components. In this algorithm, the phase PCC voltages ($v_{sa}$, $v_{sb}$, and $v_{sc}$), source currents ($i_{sa}$, $i_{sb}$, and $i_{sc}$), load currents ($i_{La}$, $i_{Lb}$, and $i_{Lc}$) and dc bus voltage ($v_{dc}$) are required for the extraction of reference source currents ($i^*_{sa}$, $i^*_{sb}$, and $i^*_{sc}$). There are two primary modes for the operation of this algorithm: The first one is a feedforward, and the second is the BP of error or supervised learning. The detail application of this algorithm for the estimation of various control parameters is given as follows.

### *A. Estimation of Weighted Value of Average Fundamental Load Active and Reactive Power Components*

A BP training [32], [33] algorithm is used to estimate the three phase weighted value of load active power current components ($w_{ap}$, $w_{bp}$, and $w_{cp}$) and reactive power current components ($w_{aq}$ , $w_{bq}$ , and $w_{cq}$ ) from polluted load currents using the feedforward and supervised principle. In this estimation, the input layer for three phases (a, b, and c) is expressed as

$$I_{Lap} = w_o + i_{La}u_{ap} + i_{Lb}u_{bp} + i_{Lc}u_{cp} \quad (1)$$

$$I_{Lbp} = w_o + i_{Lb}u_{bp} + i_{Lc}u_{cp} + i_{La}u_{ap} \quad (2)$$

$$I_{Lcp} = w_o + i_{Lc}u_{cp} + i_{La}u_{ap} + i_{Lb}u_{bp} \quad (3)$$

where $w_o$ is the selected value of the initial weight and $u_{ap}$, $u_{bp}$, and $u_{cp}$ are the in-phase unit templates.

In-phase unit templates are estimated using sensed PCC phase voltages ($v_{sa}$, $v_{sb}$, and $v_{sc}$). It is the relation of the phase voltage and the amplitude of the PCC voltage ($v_t$). The amplitude of sensed PCC voltages is estimated as

$$v_t = \sqrt{\frac{2\left(v_{sa}^2 + v_{sb}^2 + v_{sc}^2\right)}{3}}. \quad (4)$$

The inphase unit templates of PCC voltages $u_{ap}$,$u_{bp}$ and $u_{cp}$ are estimated as

$$u_{ap} = \frac{v_{sa}}{v_t}, \quad u_{bp} = \frac{v_{sb}}{v_t}, \quad u_{cp} = \frac{v_{sc}}{v_t}. \quad (5)$$

The extracted values of ILap, ILbp and ILcp are passed through a sigmoid function as an activation function, and the output signals of feedforward section (Zap,Zbp and Zcp) are expressed as

$$Z_{ap} = f(I_{Lap}) = 1/(1 + \mathrm{e}^{-ILap}) \quad (6)$$

$$Z_{bp} = f(I_{Lbp}) = 1/(1 + \mathrm{e}^{-ILbp}) \quad (7)$$

$$Z_{cp} = f(I_{Lcp}) = 1/(1 + \mathrm{e}^{-ILcp}). \quad (8)$$

Where wo1,wap,wbp and wcp are the selected values of initial weights in the hidden layer and the updated values of three phase weights using the average weighted value(wp) of the active power current component as a feedback signal, respectively.

The updated weight of phase ”a” active power current components of load current “wap” at the nth sampling instant is expressed as

$$w_{ap}(n) = w_p(n) + \mu\left\{w_p(n) - w_{ap1}(n)\right\} f'(I_{ap1}) z_{ap}(n) \quad (12)$$

Where wp(n) and wap(n) are the average weighted value of active power component of load currents and the updated weighted values of phase “a” at the nth sampling instant, respectively , and wap1(n) and Zap(n) are the phase “a” fundamental weighted amplitude of the active power component of the load current and output of feedforward section of the algorithm at the nth instant, respectively, f’(Iap1) and μ are represented as the derivative of Iap1 component and the learning rate.

Similarly for phase “b” and phase “c”, the updated weighted values of the active power current components and the load current are expressed as

$$w_{bp}(n) = w_p(n) + \mu\left\{w_p(n) - w_{bp1}(n)\right\} f'(I_{bp1}) z_{bp}(n) \quad (13)$$

$$w_{cp}(n) = w_p(n) + \mu\left\{w_p(n) - w_{cp1}(n)\right\} f'(I_{cp1}) z_{cp}(n). \quad (14)$$

The extracted values of Iap1, Ibp1, and Icp1 are passed through a sigmoid function as an activation function to the estimation of the fundamental active components in terms of three phase weights wap1, wbp1 and wcp1 as

$$w_{ap1} = f(I_{ap1}) = 1/(1 + \mathrm{e}^{-I_{ap1}}) \quad (15)$$
$$w_{bp1} = f(I_{bp1}) = 1/(1 + \mathrm{e}^{-I_{bp1}}) \quad (16)$$
$$w_{cp1} = f(I_{cp1}) = 1/(1 + \mathrm{e}^{-I_{cp1}}). \quad (17)$$

The average weighted amplitude of the fundamental active power components (wp) is estimated using the amplitude sum of three phase load active power components (wap1,wbp1 and wcp1) divided by three. It is required to realize load balancing features of DSTATCOM. Mathematically it is expressed as

$$w_p = (w_{ap1} + w_{bp1} + w_{cp1})/3. \quad (18)$$

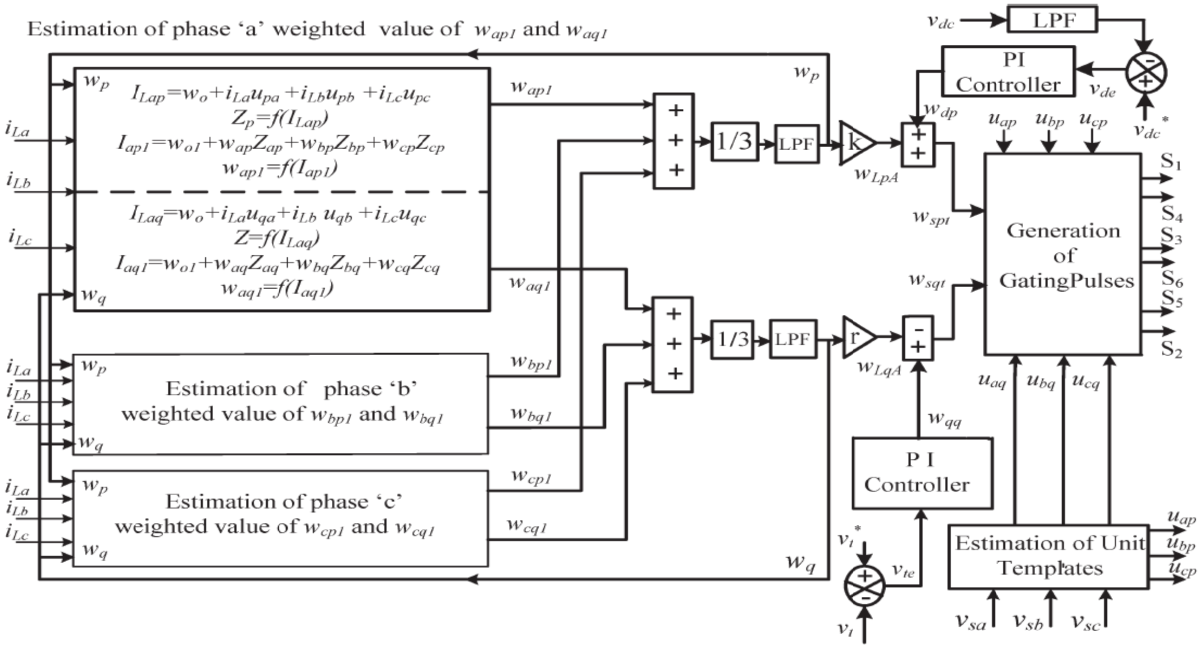


Fig. 2. Estimation of reference currents using BP control algorithm

First order low pass filters are used to separate the low frequency components. “k” denotes the scaled factor of extracted active power components of current in the algorithm which is shown in fig. 2. After separating the low frequency components and scaling to the actual value because the output of activation function is between 0 and 1, it is represented as wLpA.

Similarly the weighted amplitudes of reactive power components of the load currents (waq,wbq, and wcq) of the fundamental load current are extracted as

$$I_{Laq} = w_o + i_{La}u_{aq} + i_{Lb}u_{bq} + i_{Lc}u_{cq} \quad (19)$$
$$I_{Lbq} = w_o + i_{Lb}u_{bq} + i_{Lc}u_{cq} + i_{La}u_{aq} \quad (20)$$
$$I_{Lcq} = w_o + i_{Lc}u_{cq} + i_{La}u_{aq} + i_{Lb}u_{bq} \quad (21)$$

Where wo is the selected value of the initial weight and uaq, ubq and ucq are the quadrature components of the unit template.

The quadrature unit templates (uaq,ubq and ucq) of the phase PCC voltage are estimated as

$$u_{aq} = \frac{(-u_{bp} + u_{cp})}{\sqrt{3}}, \quad u_{bq} = \frac{(3u_{ap} + u_{bp} - u_{cp})}{2\sqrt{3}}$$
$$u_{cq} = \frac{(-3u_{ap} + u_{bp} - u_{cp})}{2\sqrt{3}}. \quad (22)$$

The extracted values of ILaq, ILbq and ILcq are passed through a sigmoid function as an activation function to the estimation of Zaq,Zbq and Zcq

$$Z_{aq} = f(I_{Laq}) = 1/(1 + \mathrm{e}^{-I_{Laq}}) \quad (23)$$
$$Z_{bq} = f(I_{Lbq}) = 1/(1 + \mathrm{e}^{-I_{Lbq}}) \quad (24)$$
$$Z_{cq} = f(I_{Lcq}) = 1/(1 + \mathrm{e}^{-I_{Lcq}}). \quad (25)$$

The estimated values of Zaq, Zbq and Zcq are fed to the hidden layer as input signals. The three phase outputs of this

layer (Iaq1,Ibq1, and Iq1) before the activation function can be represented as

$$I_{aq1} = w_{o1} + w_{aq}Z_{aq} + w_{bq}Z_{bq} + w_{cq}Z_{cq} \qquad (26)$$

$$I_{bq1} = w_{o1} + w_{bq}Z_{bq} + w_{cq}Z_{cq} + w_{aq}Z_{aq} \qquad (27)$$

$$I_{cq1} = w_{o1} + w_{cq}Z_{cq} + w_{aq}Z_{aq} + w_{bq}Z_{bq} \qquad (28)$$

Where wo1,waq, wbq, and wcq are the selected value of the initial weight in the hidden layer and the updated three weights using the average weighted value of the reactive power components of currents (wq) as a feedback signal, respectively.

The updated weight of the phase "a" reactive power components of load currents "waq" at the nth sampling instant is expressed as

$$w_{aq}(n) = w_q(n) + \mu\left\{w_q(n) - w_{aq1}(n)\right\} f'(I_{aq1}) z_{aq}(n) \qquad (29)$$

Wq(n) and waq(n) are the average weighted value of the reactive power component of load currents and the updated weight in the nth sampling instant, respectively, and waq1(n) and zaq(n) are the phase "a" weighted amplitude of the reactive power current component of load currents and the output of the feedforward section of the algorithm at the nth instant, respectively. F'(Iaq1) and µ are presented as the derivative of Iaq1 components and the learning rate.

Similarly for phase "b" and "c" the updated weighted values of the reactive power current components of the load current are expressed as

$$w_{bq}(n) = w_q(n) + \mu\left\{w_q(n) - w_{bq1}(n)\right\} f'(I_{bq1}) z_{bq}(n) \qquad (30)$$

$$w_{cq}(n) = w_q(n) + \mu\left\{w_q(n) - w_{cq1}(n)\right\} f'(I_{cq1}) z_{cq}(n). \qquad (31)$$

The extracted values of Iaq1, Ibq1 and Icq1 are passé through an activation function to the estimation of the fundamental reactive component in terms of three phase weights waq1, wbq1 and wcq1 as

$$w_{aq1} = f(I_{aq1}) = 1/(1 + e^{-Iaq1}) \qquad (32)$$

$$w_{bq1} = f(I_{bq1}) = 1/(1 + e^{-Ibq1}) \qquad (33)$$

$$w_{cq1} = f(I_{cq1}) = 1/(1 + e^{-Icq1}). \qquad (34)$$

The average weight of the amplitude of the fundamental reactive power current components(wq) is estimated using the amplitude sum of the three phase load reactive power component of the load current (waq1,wbq1 and wcq1) divided by three. Mathematically it is expressed as

$$w_q = (w_{aq1} + w_{bq1} + w_{cq1})/3. \qquad (35)$$

First order low pass filters are used to separate the low frequency component. "r" denotes the scaled factor of the extracted reactive power components in the algorithm which is shown in fig 2. After separating low frequency components and scaling to the actual value because the output of the activation function is between 0 and 1, it is represented as wLqA.

### *B. Amplitude Of Active Power Current Components Of Reference Source Currents*

An error in the dc bus voltage is obtained after comparing the reference dc bus voltage v*dc and the sensed dc bus voltage vdc of a VSC, anad this error at the nth sampling instant is expressed as

$$v_{de}(n) = v^*_{dc}(n) - v_{dc}(n). \qquad (36)$$

This voltage error is fed to a PI controller whose output is required for maintaining the dc bus voltage of the DSTATCOM. At the nth sampling instant, the output of the PI controller is as follows:

$$w_{dp}(n) = w_{dp}(n-1) + k_{pd}\left\{v_{de}(n) - v_{de}(n-1)\right\} + k_{id}\, v_{de}(n) \qquad (37)$$

Where kpd and kid are the proportional and integral gain constants of the dc bus PI controller. Vde(n) and vde(n-1) are the dc bus voltage errors in the nth and (n-1)th instant, and wdp(n) and wdp(n-1) are the amplitude of the active power component of the fundamental reference current at the nth and (n-1)th instant, respectively.

The amplitude of the active power current components of the reference source currnet(wspt) is estimated by the addition of output of the dc bus PI controller (wdp) and the average magnitude of the load active currents (wLpA) as

$$w_{spt} = w_{dp} + w_{LpA}. \qquad (38)$$

### *C. Amplitude of Reactive Power Components of Reference Source Currents*

An error in the ac bus voltage is achieved after comparing the amplitudes of the reference ac bus voltage $v_t$* and the sensed ac bus voltage $v_t$ of a VSC. The extracted ac bus voltage error $v_{te}$ at the *n*th sampling instant is expressed as

$$v_{te}(n) = v^*_t(n) - v_t(n). \qquad (39)$$

The weighted output of the ac bus PI controller wqq for regulating the ac bus terminal voltage at the nth sampling instant is expressed as

$$w_{qq}(n) = w_{qq}(n-1) + k_{pt}\left\{v_{te}(n) - v_{te}(n-1)\right\} + k_{it}\, v_{te}(n) \qquad (40)$$

where $w_{qq}$ (*n*) is part of the reactive power component of the source current and it is renamed as $w_{qq}$ . $k_{pt}$ and $k_{it}$ are the proportional and integral gain constants of the ac bus voltage PI controller.

The amplitude of the reactive power current components of the reference source current ($w_{sqt}$) is calculated by subtracting the output of the voltage PI controller ($w_{qq}$ ) and the average load reactive currents ($w_{LqA}$) as

$$w_{sqt} = w_{qq} - w_{LqA}. \tag{41}$$

### *D. Estimation of Reference Source Currents and Generation of IGBT Gating Pulses*

Three phase reference source active and reactive current components are estimated using the amplitude of three phase (a, b, and c) load active power current components, PCC voltage in-phase unit templates, reactive power current components, and PCC quadrature voltage unit templates as

$$i_{sap} = w_{spt}\, u_{ap}, i_{sbp} = w_{spt}\, u_{bp}, i_{scp} = w_{spt}\, u_{cp} \tag{42}$$

$$i_{saq} = w_{sqt}\, u_{aq}, i_{sbq} = w_{sqt}\, u_{bq}, i_{scq} = w_{sqt}\, u_{cq}. \tag{43}$$

The addition of reference active and reactive current components is known as reference source currents, and these are given as

$$i^*_{sa} = i_{sap} + i_{saq}, \quad i^*_{sb} = i_{sbp} + i_{sbq}, \quad i^*_{sc} = i_{scp} + i_{scq}. \tag{44}$$

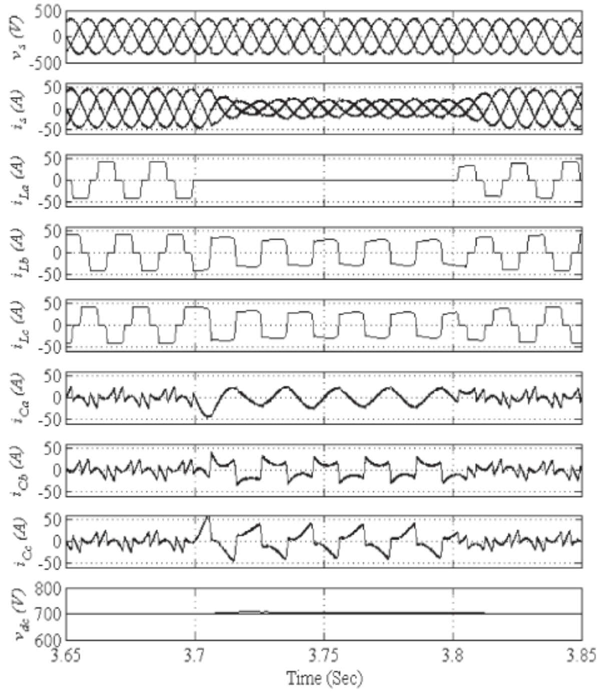
The sensed source currents ($i_{sa}$, $i_{sb}$, $i_{sc}$) and the reference source currents ($i^*_{sa}$, $i^*_{sb}$, $i^*_{sc}$) are compared, and current error signals are amplified through PI current regulators; their outputs are fed to a pulse width modulation (PWM) controller to generate the gating signals for insulated-gate bipolar transistors (IGBTs) $S_1$ to $S_6$ of the VSC used as a DSTATCOM.

## III. SIMULATION RESULTS AND DISCUSSION

MATLAB with SIMULINK and Sim Power System tool boxes is used for the development of the simulation model of a DSTATCOM and its control algorithm. The performance of the control algorithm is observed under non linear loads.

### *A. Performance of DSTATCOM under non linear load*

The dynamic performance of DSTATCOM was studied at PCC. The active current component and reactive current component injection was found successful and power factor correction was studied. The dynamic performance of a VSC-based DSTATCOM is studied for PFC mode at nonlinear loads. The performance indices are the phase voltages at PCC ($v_s$), balanced source currents ($i_s$), load currents ($i_{La}$, $i_{Lb}$, and $i_{Lc}$), compensator currents ($i_{Ca}$, $i_{Cb}$, and $i_{Cc}$), and dc bus voltage ($v_{dc}$) which are shown in Fig. 3 under varying load (at $t$ = 3.7 to 3.8 s) conditions. The waveforms of the phase "a" voltage at PCC ($v_{sa}$), source current ($i_{sa}$), and load current ($i_{La}$) are shown in Fig. 4(a)–(c), respectively. The total harmonic distortion (THD) of the phase "a" at PCC voltage, source current, and load cur-rent are found to be 2.86%, 2.94%, and 24.82%, respectively. It is observed that the DSTATCOM is able to perform the functions of load balancing and harmonic elimination with high precision.



### *B. Performance of DSTATCOM in ZVR mode*

The performance of DSTATCOM in ideal zero voltage regulation mode will be done in further studies.

## APPENDIX A

AC supply source: three-phase, 415 V (L-L), 50 Hz. Source impedance: $R_s$ = 0.04 Ω and $L_s$ = 2 mH. Nonlinear: three phase full bridge uncontrolled rectifier with $R$ = 13 Ω and $L$ = 200 mH. Rating of VSC = 10 kVA (approximately 30% higher than the rated value). Ripple filter: $R_f$ = 5 Ω and $C_f$ = 10 $\mu$F. Switching frequency of inverter = 10 kHz. Reference dc bus voltage: 700 V. Interfacing inductor ($L_f$ ) = 2.75 mH. Gains of PI controller for dc bus voltage: $k_{pd}$ = 3.1 and $k_{id}$ = 0.9. Gains of voltage PI controller: $k_{pt}$ = 2.95 and $k_{it}$ = 4. Se-lected initial weights: $w_o$ = 0.4 and $w_{o1}$ = 0.2. Learning rate ($\mu$) = 0.6. Cutoff frequency of low-pass filter used in dc bus voltage = 15 Hz. Cutoff frequency of low-pass filter used in ac bus voltage = 10 Hz.

## IV. REFERENCES

[1] Bhim Singh, Fellow, IEEE, and Sabha Raj Arya "Back-Propagation Control Algorithm for Power Quality Improvement Using DSTATCOM", VOL. 61, NO. 3, MARCH 2014**.**

[2] Ortiz, C. Gherasim, M. Manana, C. J. Renedo, L. I. Eguiluz, and R. J. M. Belmans, "Total harmonic distortion decomposition depending on distortion origin," IEEE Trans. Power Del., vol. 20, no. 4, pp. 2651– 2656, Oct. 2005.

[3]T. L. Lee and S. H. Hu, "Discrete frequency-tuning active filter to suppress harmonic resonances of closed-loop distribution power systems," IEEE Trans. Power Electron., vol. 26, no. 1, pp. 137–148, Jan. 2011.

[4]K. R. Padiyar, FACTS Controllers in Power Transmission and Distribution. New Delhi, India: New Age Int., 2008.

[5] IEEE Recommended Practices and Requirement for Harmonic Control on Electric Power System, IEEE Std.519, 1992.

[6] T.-L. Lee, S.-H. Hu, and Y.-H. Chan, "DSTATCOM with positive-sequence admittance and negative-sequence conductance to mitigate voltage fluctuations in high-level penetration of distributed generation systems," IEEE Trans. Ind. Electron., vol. 60, no. 4, pp. 1417–1428, Apr. 2013.

[7] Singh, P. Jayaprakash, and D. P. Kothari, "Power factor correction and power quality improvement in the distribution system," Elect. India Mag., 40–48, Apr. 2008.

[8] Singh and J. Solanki, "A comparison of control algorithms for DSTATCOM," IEEE Trans. Ind. Electron., vol. 56, no. 7, pp. 2738–2745, Jul. 2009.

[9] J.C. Wu, H. L. Jou, Y. T. Feng, W. P. Hsu, M. S. Huang, and W. J. Hou, "Novel circuit topology for three-phase active power filter," IEEE Trans.Power Del., vol. 22, no. 1, pp. 444–449, Jan. 2007.

[10] Vasanthavalli. C, Veliaiswamy. S, "Optimization Technique for Power Quality Improvement Using DSTATCOM", IJERT, vol 4, issue 4, April 2014.

[11] Tejas Zaveri, Bhalja Bhavesh, and Naimish Zaveri,"Control Technique for power quality improvement in delta connected load using DSTATCOM" ,IEEE 2011.