

Conductance Estimation Control Algorithm for Shunt Compensation in Neural Network

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ABSTRACT: The paper intends to develop the artificial neural network control algorithm for the control of DSTATCOM for the improvement of power quality. The presence of nonlinear loads makes the voltage to be deviated and current to be distorted from its sinusoidal waveform quality. Thus harmonics elimination, load balancing and voltage regulation is the heavy task that has to be accomplished to maintain the quality of the power. The performance of any device depends on the control algorithm used for the reference current estimation and gating pulse generation scheme. Thus the artificial neural network based Back Propagation (BP) algorithm has been proposed to generate the triggering pulses for the three phase H bridge inverter (DSTATCOM). The fundamental weighted value of active and reactive power components of load currents which are required for the estimation of reference source current is calculated by using BP-based control algorithm. Based on the difference of the target voltage and the generated voltage, the triggering pulse for the inverter is obtained by the BP algorithm. Then the voltage is injected at the point of common coupling to compensate the reactive power. Thus by regulating the voltage and compensation of reactive power, the power quality can be improved. The simulation modelling of the Back propagation algorithm controlled DSTATCOM and the PWM controlled DSTATCOM and the comparative analysis of the algorithms is presented in this paper.

KEYWORDS: DSTATCOM, Artificial Neural Network, Back propagation (BP) control algorithm, Reference current Estimation, Power quality.

I. INTRODUCTION

The objective of an electric utility is to supply consumer with a sinusoidal voltage and constant magnitude and frequency. Almost all industrial, commercial and residential loads draw non sinusoidal currents and demand high amount of reactive power due to nonlinear and lagging power factor loads [1]. System power quality has been adversely affected severe problems have been encountered in power system operation, owing to the load current harmonics. Voltage Distortion, power losses, solid state device malfunction and communication interference are some examples. Power filtering is one of the technologies to solve power quality problems which are created by nonlinear loads. Due to development of signal processing techniques, an active filter has taken the leads in practical applications. New active filters have multifunction nature such as harmonics suppression, reactive power compensation, and load balancing in power factor correction (PFC) and zero voltage regulation (ZVR) modes [1]. This improved compensating device is known as a distribution static compensator (DSTATCOM) [2]. Some standards also provide specification and application of components, protection, and control of power quality improvement devices [3]–[5]. Suppression of harmonics distortion, reactive power compensation at ac mains which is created by various consumers may be achieved by using compensators connected between ac mains and loads [6]–[9]. Response and accuracy of the DSTATCOM depend on the control algorithm for generation of reference currents and design of power circuit elements [10]–[11]. A

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neural network (NNs) has the compatibility to improve control of power electronic systems. NNs have self-adapting and super-fast computing features that make them well suited to handling nonlinearities, uncertainties and parameter variations that can occur in a controlled plant [12]. It is used for increasing the processing speed, response, convergence, robustness, accuracy, precision, tracking ability, adaptive ability, steady-state and transient stabilities, etc. [13]–[15]. Neural network (NN) based algorithms are used to extract required information after processing of signals by learning or training and activation function [16]–[17]. Neural network based control have created much attention in electrical engineering including power quality problems such as load balancing, reactive power compensation, harmonics elimination and neutral current compensation in a four wire distribution system. In this paper we use three phase four wire distributed system which is mainly concerned about the neural network controller implemented in a shunt connected compensating device known as DSTATCOM for the extraction of active power and reactive power components of three-phase distorted load currents. Proposed control algorithm is used for PFC and ZVR modes of operation to maintain a balanced and sinusoidal supply current with a self-supporting dc bus of VSC of DSTATCOM, for this purpose Kohonen learning method has been used. Kohonen learning is used to extract the fundamental components of load current in terms of conductance and susceptance.

II.MOTIVATION

Power quality in distribution systems affects all the electrical and electronics equipment that are connected. This measures the deviation in the measurement of frequency, current and Voltage of the system. The use of power converters in power supplies, adjustable speed drives, is continuously increasing in recent years. This equipment draws harmonics currents from AC mains and increases the supply demands. The classification of loads includes linear (lagging power factor loads), nonlinear (current or voltage source type of harmonic generating loads), unbalanced and mixed types of loads. The power quality problems associated with these loads include, load unbalancing, harmonics, high reactive power burden, voltage variation. The power quality problems are compensated in a distribution system by the Custom Power devices. These custom power devices are classified as the DSTATCOM (Distribution Static Compensator), DVR (Dynamic Voltage Restorer) and UPQC (Unified Power Quality Conditioner). The power quality at the Point of common coupling is governed by standards such as IECSC77A, IEEE519-1992, IEEE-1531-2003 and IEC- 61000.

III.DSTATCOM MECHANISM

The D-STATCOM is a three phase shunt connected reactive power compensation equipment, whose output can be varied so as to maintain control of specific parameters of the electric power system by the generation and /or absorption of the reactive power. The DSTATCOM consists of three phase GTO/IGBT voltage source inverter (VSI), a coupling transformer with a leakage reactance and DC capacitor. The DSTATCOM topologies can be classified based on of switching devices, use of transformers for isolation, use of transformers for neutral current compensation. The ac voltage difference across the leakage reactance power exchange between the Power system and the DSTATCOM at the bus bar can be regulated to improve the voltage profile of the power system. This constitutes the primary duty of the DSTATCOM. However, a secondary damping function is added in to the DSTATCOM for enhancing power system oscillation stability. The D-STATCOM employs solid state power switching devices and provides rapid controllability of magnitude and the phase angle of the phase voltages. The DSTATCOM provides operating characteristics that of the rotating Synchronous compensator without the mechanical inertia.

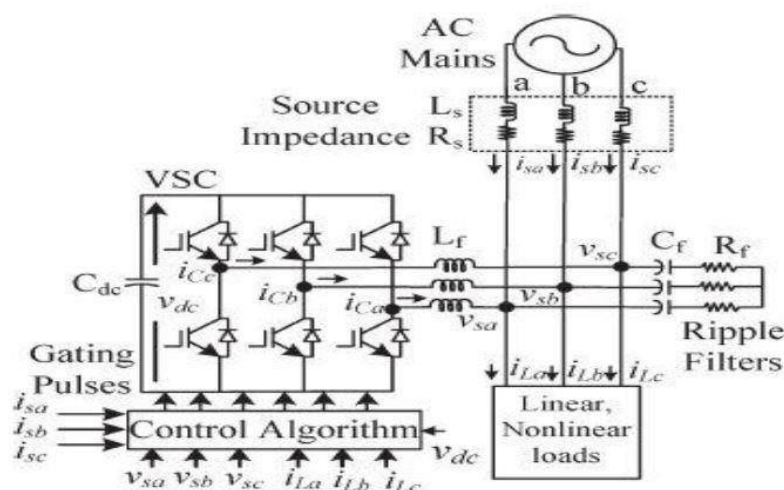


Fig 1: Circuit Diagram of VSC- Based DSTATCOM

IV. LITERATURE SURVEY

1. Artificial Neural Network Controlled DSTATCOM for Power Quality Improvement

A three phase VSC based DSTATCOM has been implemented for compensation of nonlinear loads using BPT control algorithm to verify its effectiveness. The proposed algorithm has been used for extraction of reference source currents to generate the switching pulses for IGBTs of VSC of DSTATCOM. Various functions of DSTATCOM such as, load balancing and harmonic elimination have been demonstrated in PFC mode with DC voltage regulation of DSTATCOM. From simulation and implementation results, it is concluded that DSTATCOM and its control algorithm have been found suitable for compensation of nonlinear loads. These results show satisfactory performance of the BP control algorithm for harmonics elimination according to IEEE-519 guidelines in order of less than 5%. The DC bus voltage of the DSTATCOM has also been regulated to rated value without any overshoot or undershoots during load variation. Large training time in the application of complex system, selection of number of hidden layer in system is the disadvantage of this algorithm.

2. Control Algorithm for Conductance Estimation Using Neural Network Controller for a DSTATCOM

A control algorithm based on load conductance estimation using neural network for control of DSTATCOM has been implemented in a three phase four wire distribution system. The main factors for deciding the performance of DSTATCOM has been observed for detection of power quality problems in real-time and its accuracy. Test results have proved the effectiveness of proposed neural network algorithm for reactive power compensation, harmonics elimination, load balancing, neutral current compensation and increases efficiency under linear/nonlinear loads.

3. Power Quality Enhancement in Distribution System using ANN based DSTATCOM

VSC based DSTATCOM has been accepted as the most preferred solution for power quality improvement and to maintain rated PCC voltage. A three phase DSTATCOM has been implemented for compensation of nonlinear loads using BPT control algorithm to verify its effectiveness. The proposed BPT control algorithm has been used for extraction of reference source currents to generate the switching pulses for IGBTs of VSC of DSTATCOM. Various functions of DSTATCOM such as, harmonic elimination, load balancing and DC voltage regulation of

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DSTATCOM have been demonstrated. From simulation and implementation results, it is concluded that DSTATCOM and its control algorithm have been found suitable for compensation of nonlinear loads. The DC bus voltage of the DSTATCOM has also been regulated to rated value without any overshoot or undershoots during load variation. Large training time in the application of complex system, selection of number of hidden layer in system is the disadvantage of this algorithm.

4. Power Quality Improvement by Back Propagation Control Algorithm

A VSC based DSTATCOM has been accepted as the most preferred solution for power quality improvement as power factor correction and to maintain rated PCC voltage. A three phase DSTATCOM has been implemented for compensation of nonlinear loads using BPT control algorithm to verify its effectiveness. The proposed BPT control algorithm has been used for extraction of reference source currents to generate the switching pulses for IGBTs of VSC of DSTATCOM. Various functions of DSTATCOM such as, harmonic elimination and load balancing have been demonstrated in PFC and ZVR modes with DC voltage regulation of DSTATCOM. From simulation and implementation results, it is concluded that DSTATCOM and its control algorithm have been found suitable for compensation of nonlinear loads. A simulation model is designed with ANFIS and its performance is studied under various operating conditions. The performance of ANFIS is found satisfactory with proposed control algorithm for various types of loads. Its performance has been found satisfactory for this application because extracted reference source currents exactly tracing the sensed source currents during steady state as well as dynamic conditions. The DC bus voltages of the DSTATCOM have also been regulated to rated value without any overshoot or undershoot during load variation. Large training times in the application of complex system, selection of number of hidden layer in system are the disadvantage of this algorithm.

5. Fuzzy logic based BPC strategy for a Grid connected STATCOM

A VSC-based DSTATCOM has been accepted as the most preferred solution for power quality improvement as PFC and to maintain rated PCC voltage. A three phase DSTATCOM has been implemented for the compensation of nonlinear loads using a BPT control algorithm to verify its effectiveness. The proposed BPT control algorithm has been used for the extraction of reference source currents to generate the switching pulses for IGBTs of the VSC of DSTATCOM. Various functions of DSTATCOM such as harmonic elimination and load balancing have been demonstrated in PFC and ZVR modes with dc voltage regulation of DSTATCOM. From the simulation and implementation results, it is concluded that DSTATCOM and its control algorithm have been found suitable for the compensation of nonlinear loads. Its performance has been found satisfactory for this application because the extracted reference source currents exactly traced the sensed source currents during the steady state as well as dynamic conditions. The dc bus voltage of the DSTATCOM has also been regulated to the rated value without any overshoot or undershoots during load variation. Large training time in the application of the complex system and the selection of the number of hidden layers in the system are the disadvantages of this algorithm

V.SCHEMATIC DIAGRAM OF DSTATCOM

A DSTATCOM is a device which is used in an AC distribution system where, harmonic current mitigation, reactive current compensation and load balancing are necessary. The building block of a DSTATCOM is a voltage source converter (VSC) consisting of self-commutating semiconductor valves and a capacitor on the DC bus. The device is shunt connected to the power distribution network through a coupling inductance that is usually realized by the transformer leakage reactance. In general, the DSTATCOM can provide power factor correction, harmonics compensation and load balancing. The major advantages of DSTATCOM compared with a conventional static VAR compensator (SVC) include the ability to generate the rated current at virtually any network voltage, better dynamic response and the use of a relatively small capacitor on the DC bus.

It shows the schematic diagram of a DSTATCOM connected to a three phase AC mains feeding three phase loads. Three phase loads may be a lagging power factor load or an unbalanced load or non-linear loads or mixed of these loads. For reducing ripple in compensating currents, interfacing inductors (L_f) are used at AC side of the voltage source converter (VSC). A small series connected capacitor (C_f) and resistor (R_f) represent the ripple filter installed at PCC in parallel with the loads and the compensator to filter the high frequency switching noise of the voltage at PCC. The harmonics/reactive currents (i_{CabC}) are injected by the DSTATCOM to cancel the harmonics /reactive power component of the load currents so that the source currents are harmonic free (reduction in harmonics) and load reactive power is also compensated. The rating of the switches is based on the voltage and current rating of the required compensation.

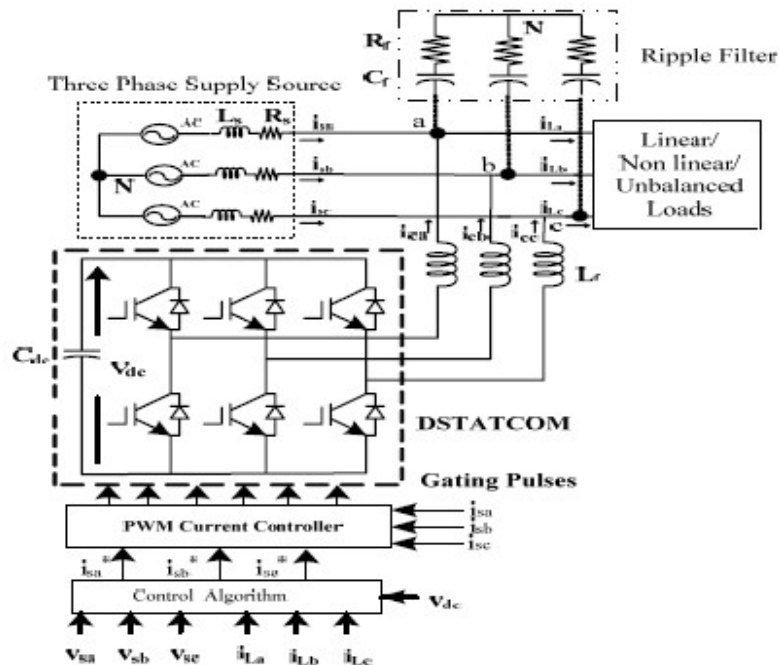


Fig 2: Schematic diagram of a DSTATCOM

VI.MECHANISM OF DSTATCOM

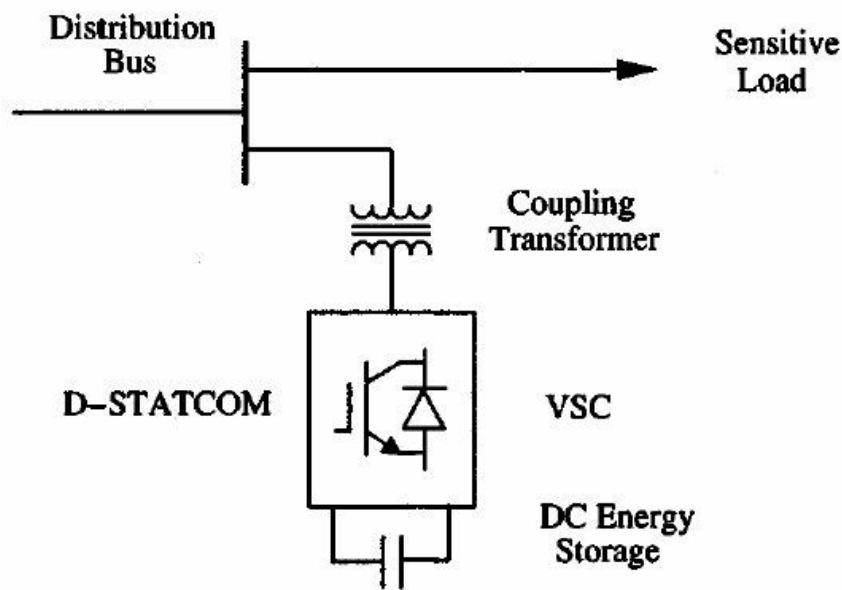


Fig 3: Mechanism of DSTATCOM

The Distribution Static Compensator (DSTATCOM) is a voltage source inverter based static compensator that is used for the correction of line currents. Connection (shunt) to the distribution network is via a standard power distribution transformer. The DSTATCOM is capable of generating continuously variable inductive or capacitive shunt compensation at a level up to its maximum MVA rating. The DSTATCOM continuously checks the line waveform with respect to a reference ac signal, and therefore, it can provide the correct amount of leading or lagging reactive current compensation to reduce the amount of voltage fluctuations. The major components of a DSTATCOM are shown in Fig.2. It consists of a dc capacitor, one or more inverter modules, an ac filter, a transformer to match the inverter output to the line voltage, and a PWM control strategy. In this DSTATCOM implementation, a voltage-source inverter converts a

dc voltage into a three-phase ac current that is synchronized with, and connected to, the ac line through a small tie reactor and capacitor (ac filter). Application of DSTATCOM for Reactive Power compensation and Voltage Regulation Initial application of DSTATCOM (using IGBT devices) was primarily for the control of (Fundamental Frequency) reactive power control and voltage regulation. SVCs have been applied for this purpose earlier. A major advantage relates to the improved speed of response, capacity for transient overload (up to one second) in addition to the improved performance at reduced voltages.

1. *Limiting voltage swells caused by capacitor switching.*
2. *Reduction of voltage sags due to common feeder faults.*
3. *Controlling the voltage fluctuations caused by customer load variations. It was found 2.5% to 0.2% with DSTATCOM. This reduces voltage flicker substantially.*
4. *Based on the control algorithm, the frequency of mechanical switching operations (involving load tap changing (LTC) transformers and mechanically switched capacitors) is reduced that is beneficial for maintenance.*

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5. Increase in the maximum load ability of the system (in particular, increase in the induction motor load that can remain stable through a major disturbance, such as a loss of primary in feed). The controller of DSTATCOM suggested in has three levels given below:
6. Fast voltage regulator.
7. Fast current limiter and overload management control.
8. Slow reset control.

The voltage regulator has a response time of few cycles. The second level of control allows the inherent short-term overload capability of DSTATCOM to be utilized for better performance while protecting the equipment. The third level of control involving slow reset ensures that the DSTATCOM does not remain near limits over an extended period of time. The objective is to ensure that the DSTATCOM remains ready to respond quickly to subsequent disturbances. The reset control acts on the voltage reference (within limits) and works with a delay (of typically 2 minutes). The output of DSTATCOM is ramped back to lie within a specified dead band of +1.2 or -1.2MVAR, at a rate of 0.5MVAR per minute. The control is co-coordinated with existing mechanically switched devices. The voltage flicker can be reduced by 50% from applying a DSTATCOM in comparison with a SVC. The controller design of a DSTATCOM based on analytical model is present and the predictions on the performance are validated by experimental results. A unified control to mitigate voltage sag and flicker is presented, based on kalman filter.

VII. DSTATCOM CONTROL ALGORITHM

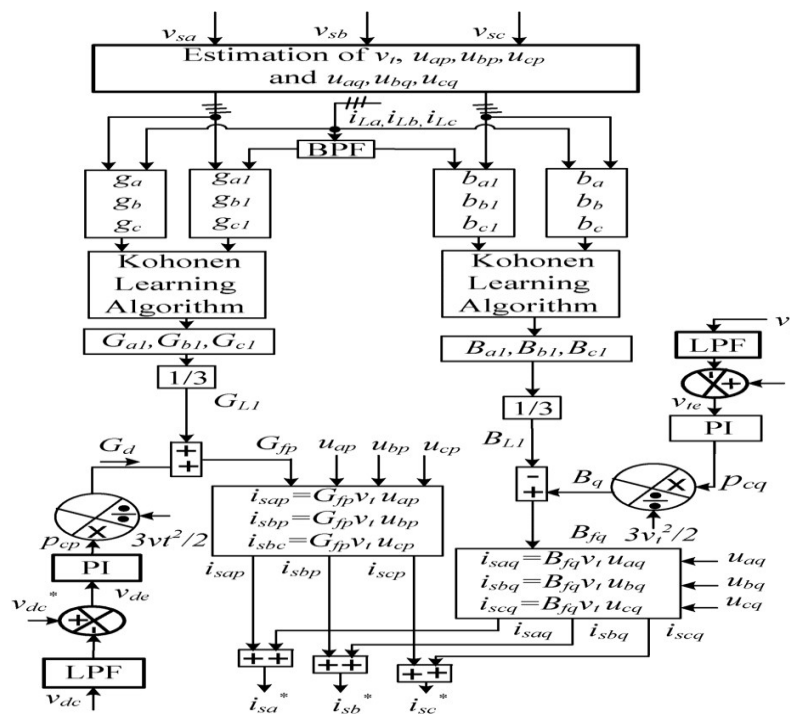


Fig 4: Mechanism of DSTATCOM Control Algorithm

Fig. 4 shows a block diagram of control algorithm for estimation of reference supply currents. In this algorithm, phase PCC voltages (V_{sa}, V_{sb}, V_{sc}), load currents (I_{La}, I_{Lb}, I_{Lc}), and dc link voltage (V_{dc}) are required for extraction of reference supply currents ($i_{sa}^*, i_{sb}^*, i_{sc}^*$). In case of distorted voltages of AC mains, three phase PCC voltages are fed through band pass filters (BPFs) to filter noise and harmonics. To take care of unbalanced in PCC voltages, amplitude

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of each of these three phase voltages are estimated through squaring them and then fed through low pass filters (LPFs) as

$$V_{ta} = \sqrt{\left[2 \left(\frac{v_{sa}^2}{2}\right)\right]} \quad V_{tb} = \sqrt{\left[2 \left(\frac{v_{sb}^2}{2}\right)\right]} \quad V_{tc} = \sqrt{\left[2 \left(\frac{v_{sc}^2}{2}\right)\right]} \quad (1)$$

Where $V_{sa} = V_s \sin \omega t$, $V_{sb} = V_s \sin(\omega t - 2\pi/3)$, and $V_{sc} = V_s \sin(\omega t - 4\pi/3)$

Constant amplitudes of three phase PCC voltage are represented as, V_{ta}, V_{tb} and V_{tc} . These are obtained after processing through low pass filters. In phase unit template with phase voltages (V_{ap}, V_{bp}, V_{cp}) are estimated as

$$u_{ap} = \frac{v_{sa}}{V_{ta}} \quad u_{bp} = \frac{v_{sb}}{V_{tb}} \quad u_{cp} = \frac{v_{sc}}{V_{tc}} \quad (2)$$

Amplitude of phase voltage (V_{tp}) at the PCC (V_{sa}, V_{sb} , and V_{sc}) is computed as

$$v_{tp} = \sqrt{\frac{2(v_{sa}^2 + v_{sb}^2 + v_{sc}^2)}{3}} \quad (3)$$

This amplitude V_{tp} may have ripples in it because of fundamental negative sequence voltage present in PCC voltages. This V_{tp} is processed through LPF to achieve amplitude of fundamental positive sequence PCC voltages and it is represented as V_t . Generally, power drawn (s) by nonlinear loads consists of total active power (P_t), reactive power (q_t) including harmonic components and others. Consider that phase “a” VA power drawn from ac mains is as

$$s_a = p_{ta} + q_{ta} \quad (4)$$

The instantaneous value of conductance (g_a) of phase “a” is estimated in distorted load current as

$$g_a = \frac{(p_{ta})}{(v_{ta})^2} \quad (5)$$

Similarly, instantaneous value of phases “b” and “c” conductance’s (g_b, g_c) are estimated as

$$g_b = \frac{(p_{tb})}{(v_{tb})^2} \quad (6)$$

$$g_c = \frac{(p_{tc})}{(v_{tc})^2} \quad (7)$$

Where V_{ta}, V_{tb}, V_{tc} and P_{ta}, P_{tb}, P_{tc} are the amplitude of individual phase (a, b and c) voltages and active power of connected loads. The value of P_{ta}, P_{tb}, P_{tc} are considered as multiplication of ($V_t V_{ap} i_{La}$), ($V_t V_{bp} i_{Lb}$), and ($V_t V_{cp} i_{Lc}$), respectively. The instantaneous approximate fundamental value of three load conductance’s (g_{a1}, g_{b1}, g_{c1}) are calculated using band pass filter (BPF) in load currents and respective constant PCC phase voltages. Its accuracy depends upon the cut off frequency of BPF. Updated value of fundamental active components of three phase load conductance (G_{a1}, G_{b1}, G_{c1}) at r^{th} sampling instant are written as

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$$G_{a1} = g_{a1}(r + 1) = g_{a1}(r) - \tau \{g_a(r) - g_{a1}(r)\} \quad (8)$$

$$G_{b1} = g_{b1}(r + 1) = g_{b1}(r) - \tau \{g_b(r) - g_{b1}(r)\} \quad (9)$$

$$G_{c1} = g_{c1}(r + 1) = g_{c1}(r) - \tau \{g_c(r) - g_{c1}(r)\} \quad (10)$$

Where (g_a-g_{a1}) , (g_b-g_{b1}) , and (g_c-g_{c1}) are considered as conductance due to nonfundamental quantity. These are presented as g_{ah} , g_{bh} and g_{ch} , respectively. Performance of algorithm depends upon learning rate (τ). Its best value is found 0.11 for this application and varies between zero to one. After iterations, unique value of G_{a1} , G_{b1} and G_{c1} are obtained. Details of used Kohonen learning algorithm is given in Appendix B. Average conductance is responsible to maintain balanced supply currents even at unbalanced loads. It is also applicable in unbalanced PCC voltages. Average conductance due to active power of the three phase load is presented as G_{L1} and it is calculated as

$$G_{L1} = \frac{(G_{a1} + G_{b1} + G_{c1})}{3}. \quad (11)$$

Reference dc bus voltage V_{dc}^* and sensed dc bus voltage of a VSC used as DSTATCOM are compared and error in dc bus voltage at r^{th} sampling instant is expressed as

$$v_{de}(r) = v_{dc}^*(r) - v_{dc}(r). \quad (12)$$

The dc link voltage of VSC is regulated using a proportional-integral (PI) controller. The dc link voltage error (V_{de}) is processed through a PI controller. The output of dc link voltage PI controller for maintaining dc link voltage of the DSTATCOM of the r^{th} sampling instant is expressed as

$$p_{cp}(r) = p_{cp}(r - 1) + k_{dp} \{v_{de}(r) - v_{de}(r - 1)\} + k_{di} v_{de} \quad (13)$$

Where $P_{cp}(r)$ considered as the active power component drawn from ac mains and k_{dp} and k_{di} are the proportional and integral gain constants of the dc link PI voltage controller. It is denoted by P_{cp} for calculation purpose. Active power losses of VSC is compensated using this component. The conductance (G_d) corresponding to output of dc link voltage controller P_{cp} is calculated as

$$G_d = \frac{2p_{cp}}{(3v_t^2)}. \quad (14)$$

The total conductance corresponding to active power of the supply is calculated as

$$G_{fp} = G_d + G_{L1}. \quad (15)$$

In-phase components of reference supply currents are estimated as

$$i_{sap} = G_{fp} v_t u_{ap} \quad i_{sbp} = G_{fp} v_t u_{bp} \quad i_{scp} = G_{fp} v_t u_{cp}. \quad (16)$$

The quadrature unit templates (V_{aq} , V_{bq} , V_{cq}) are estimated as

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$$\begin{aligned} u_{aq} &= \frac{(-u_{bp} + u_{cp})}{\sqrt{3}} \\ u_{bq} &= \frac{(3u_{ap} + u_{bp} - u_{cp})}{2\sqrt{3}} \\ u_{cq} &= \frac{(-3u_{ap} + u_{bp} - u_{cp})}{2\sqrt{3}}. \end{aligned} \quad (17)$$

The instantaneous value of susceptance (b_a) of phase “a” is estimated as

$$b_a = \frac{(q_{ta})}{(v_{ta})^2}. \quad (18)$$

Similarly, instantaneous value of phase “b” and phase “c” susceptances (b_b , b_c) are estimated as

$$b_b = \frac{(q_{tb})}{(v_{tb})^2} \quad (19)$$

$$b_c = \frac{(q_{tc})}{(v_{tc})^2} \quad (20)$$

Where b_a , b_b , b_c are the susceptances corresponding to reactive power (q_{ta} , q_{tb} , q_{tc}) for linear and nonlinear part of connected loads. The value of q_{ta} , q_{tb} , q_{tc} are considered as multiplication of $(V_t V_{aq} i_{La})$, $(V_t V_{bq} i_{Lb})$, and $(V_t V_{cq} i_{Lc})$ for respective phases. Approximate instantaneous fundamental value of three load Susceptances (b_{a1} , b_{b1} , b_{c1}) is calculated using band pass filter in load currents and respective constant PCC phase voltages. Updated value of fundamental reactive power components of three phase load susceptances (B_{a1} , B_{b1} , B_{c1}) at r^{th} sampling instant are written as

$$B_{a1} = b_{a1}(r + 1) = b_{a1}(r) - \tau \{b_a(r) - b_{a1}(r)\} \quad (21)$$

$$B_{b1} = b_{b1}(r + 1) = b_{b1}(r) - \tau \{b_b(r) - b_{b1}(r)\} \quad (22)$$

$$B_{c1} = b_{c1}(r + 1) = b_{c1}(r) - \tau \{b_c(r) - b_{c1}(r)\} \quad (23)$$

Where $(b_a - b_{a1})$, $(b_b - b_{b1})$, and $(b_c - b_{c1})$ are considered as susceptances due to non-fundamental quantity. These are represented as b_{ah} , b_{bh} , and b_{ch} , respectively.

Average susceptance due to reactive power components of the loads is presented as B_{L1} and it is calculated as

$$B_{L1} = \frac{(B_{a1} + B_{b1} + B_{c1})}{3} \quad (24)$$

The PCC voltage is regulated using a PI voltage controller. The terminal voltage error V_{te} is difference of the reference and sensed amplitude of load terminal voltage at the r^{th} sampling instant as

$$v_{te}(r) = v_t^*(r) - v_t(r) \quad (25)$$

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Where $V_t^*(r)$ is the amplitude of the reference PCC voltage and $V_t(r)$ is the amplitude of the sensed and filtered three-phase ac voltages at r^{th} instant. The output of the PI voltage controller, $P_{cq}(T)$ for maintaining the PCC voltage at a constant value at the r^{th} sampling instant is expressed as

$$p_{cq}(r) = p_{cq}(r - 1) + k_{tp} \{v_{te}(r) - v_{te}(r - 1)\} + k_{ti}v_{te}(r) \quad (26)$$

Where k_{tp} and k_{ti} are the proportional and integral gain constants of the PCC PI voltage controller, $V_{te}(r)$ and $V_{te}(r-1)$ are the voltage errors in the r^{th} and $(r-1)^{\text{th}}$ instants and $p_{cq}(r-1)$ is the required reactive power at the $(r-1)^{\text{th}}$ instant. Term $p_{cq}(r)$ is represented as p_{cq} . It is extra leading reactive power components which is required to compensate PCC voltage drop. In this case, nature of supply current is leading with respect to PCC voltage and amplitude depends upon the required voltage compensation. The susceptance (B_q) corresponding to p_{cq} is calculated as

$$B_q = \frac{2p_{cq}}{(3v_t^2)}. \quad (27)$$

The susceptance of reactive power components of supply is calculated as

$$B_{fq} = B_q - B_{L1}. \quad (28)$$

The quadrature components of reference supply currents are estimated as

$$i_{saq} = B_{fq}v_t u_{aq} \quad i_{sbq} = B_{fq}v_t u_{bq} \quad i_{scq} = B_{fq}v_t u_{cq}. \quad (29)$$

The total reference supply currents (i_{sa}^* , i_{sb}^* , and i_{sc}^*) are calculated as sum of in phase and quadrature component reference supply currents of individual phases as given in form of equations

$$i_{sa}^* = i_{sap} + i_{saq} \quad i_{sb}^* = i_{sbp} + i_{sbq} \quad i_{sc}^* = i_{scp} + i_{scq}. \quad (30)$$

These reference supply currents (i_{sa}^* , i_{sb}^* , and i_{sc}^*) and sensed supply currents (i_{sa} , i_{sb} , and i_{sc}) are compared and their current errors are amplified through PI current controllers. The output of PI current controller is fed to the PWM current controller to generate the gating pulses of the IGBTs (Insulated Gate Bipolar Transistors) of the VSC. Control of DSTATCOM using above procedure is defined as indirect extraction of current error components between supply current and extracted reference supply current. Only in phase components of reference supply currents are used in PFC mode for generation of switching pulses.

VIII.FLOW OF THE SYSTEM

The architecture of Kohonen learning is similar to the competitive network. Principle of this learning is based on training over an extended region of the network centered on the maximally active mode. Only one neuron per clustered is ready as an output signal at any condition. The concept behind this network is that the inputs are clustered together to obtain a fired output neuron. It consists of two layers one is input layer and other is competitive layer. Input layer takes available load currents as a reflection in terms of conductances and susceptances. Competitive layer processes the input data and compete each other for the success to respond as a winning neuron in term of output from clustered input data.

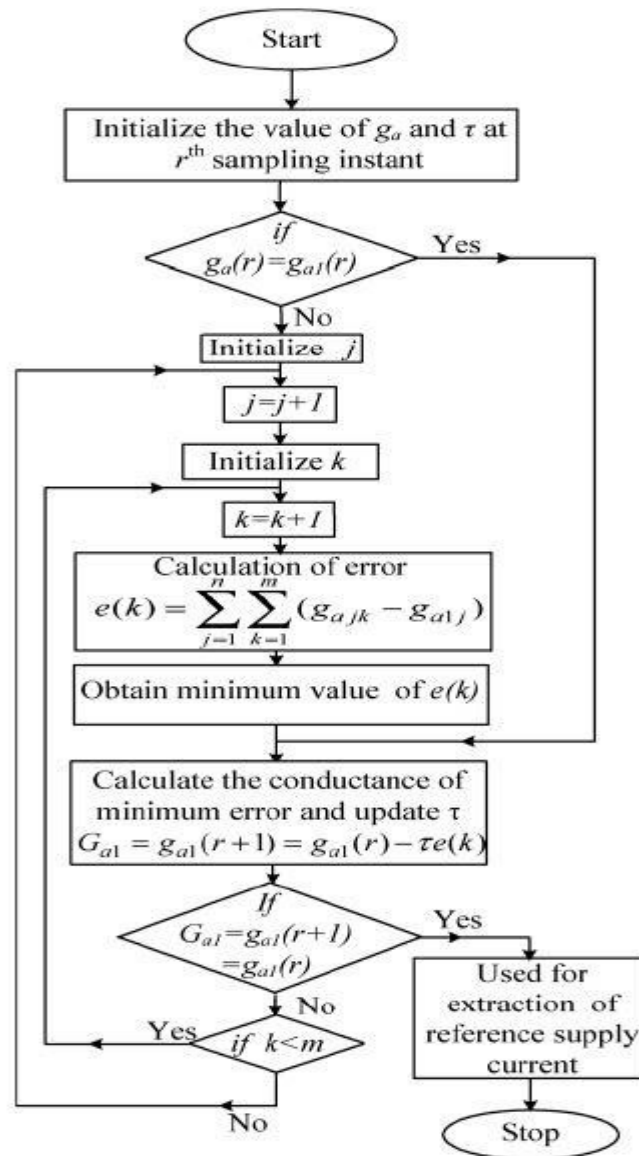


Fig 5: Flow chart of Kohonen learning algorithm for training of phase “a” conductance

IX.SIMULATION RESULT

MATLAB based simulation of DSTATCOM is developed for validation of proposed control algorithm. The proposed control algorithm based on load conductance estimation using neural network is implemented on a TMS320F240 DSP processor (dSPACE1104) for control of DSTATCOM. The dc link voltage of DSTATCOM is maintained at a reference value and test results are recorded at balanced/unbalanced linear and nonlinear loads. Specifications used in simulation are as follows: AC mains: 3-Phase, 110 V (L-L), 50 Hz; Load: (1) Linear: 0.471 kVA, 0.94 pf (DPF) lagging, (2) Nonlinear loads: Three single phase full bridge uncontrolled rectifier with $R = 20\Omega$ and $L = 150$ mH; dc link capacitance: $1650\mu\text{F}$; Reference dc link voltage: 200 V; interfacing inductor (L_f) = mH; Passive ripple filter: $R_f = 5\Omega$, $C_f = 10\mu\text{F}$; Learning rate(τ) =

0.11; Sampling time (t_s) = $50\mu\text{s}$; Gains of PI controller for dc link voltage: $k_{pp} = 0.45$, $k_{pi} = 0.02$; Cut off frequency of low pass filter used in dc link = 15Hz, Cut off frequencies of band pass filter used in load currents = 25 Hz to 100 Hz. The performance of the neural network based control algorithm for the three-phase DSTATCOM is simulated for PFC (Power Factor Correction) and ZVR (Zero Voltage Regulation) modes of operation with unbalance in the loads currents. The dc link voltage of DSTATCOM is maintained at a reference value and test results are recorded at balanced/unbalanced linear and nonlinear loads The response of proposed control algorithm of DSTATCOM is observed as follows:

A. Performance of Control Algorithm

Fig. 3 shows the various intermediate signals of the control algorithm which include fundamental active power components of load current, reactive power components of load current, average amplitude value of active power component of load currents and reactive currents, output of DC bus PI controller and voltage PI controller, amplitude of active and reactive power component of reference source current, three phase source reference active power and reactive power components of current and three phase reference current respectively. The signals are shown with respect to AC supply mains voltage and load currents. It clearly demonstrates the accurate extraction of control signals even under distorted load currents.

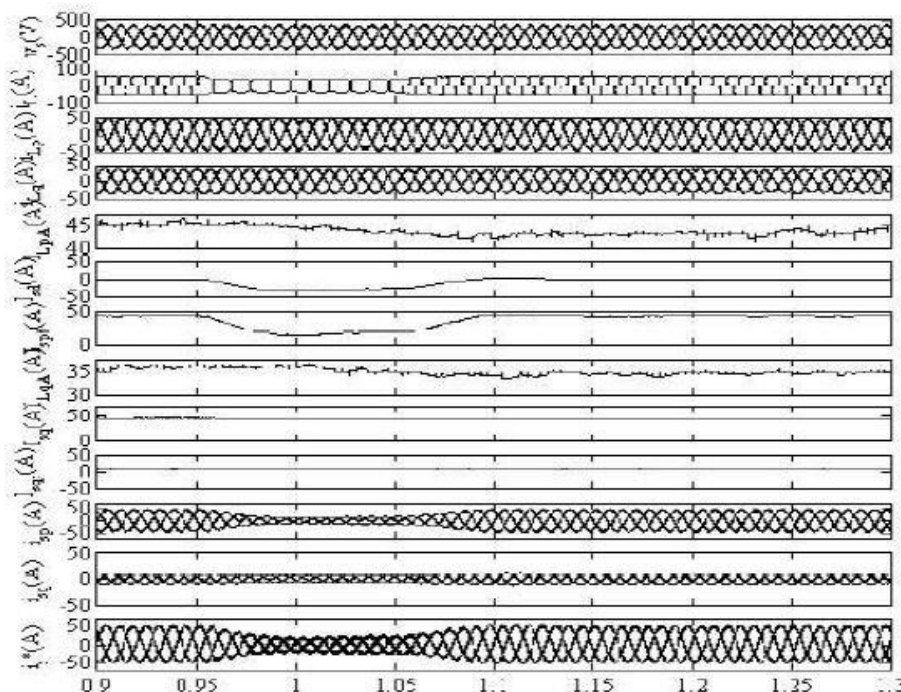
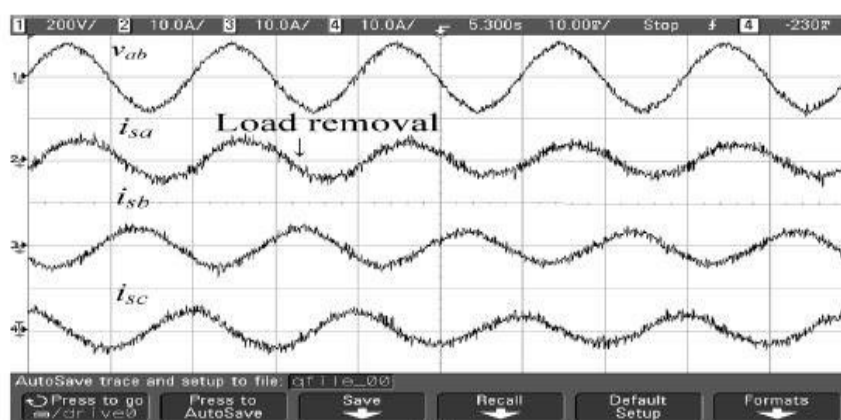


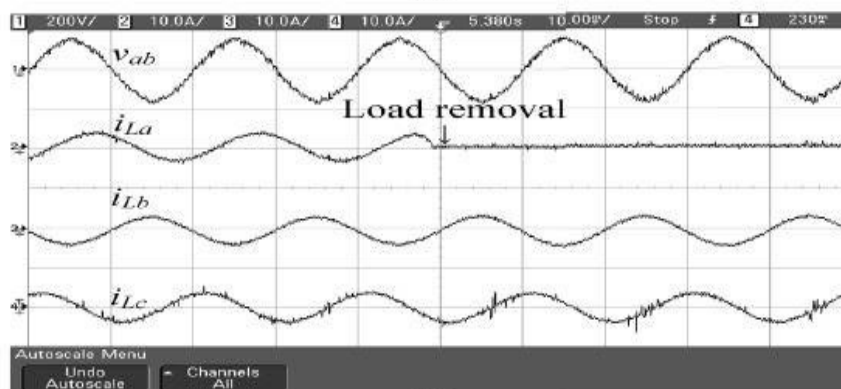
Fig 6: Characteristics of intermediate signals for estimation of supply current.

B. Dynamic Performances of DSTATCOM

Under Linear Loads It show the waveform of supply currents (i_{sa} , i_{sb} , i_{sc}) and load currents (i_{La} , i_{Lb} , i_{Lc}) with PCC line voltage (v_{ab}) under unbalanced linear loads. Unbalanced load is realized by removal of load in phase “a.” Changes in supply current (i_{sa}), DSTATCOM current (i_{Ca}) and load current (i_{La}) are shown with dc link voltage in under varying load conditions. It shows the balanced supply currents when load currents are unbalanced. The function of neutral current compensation can be observed from Fig where load neutral current (i_{Ln}) and T connected transformer neutral terminal point (i_{Tn}) current are equal and opposite in phase at the time of load removal.



(a)



(b)

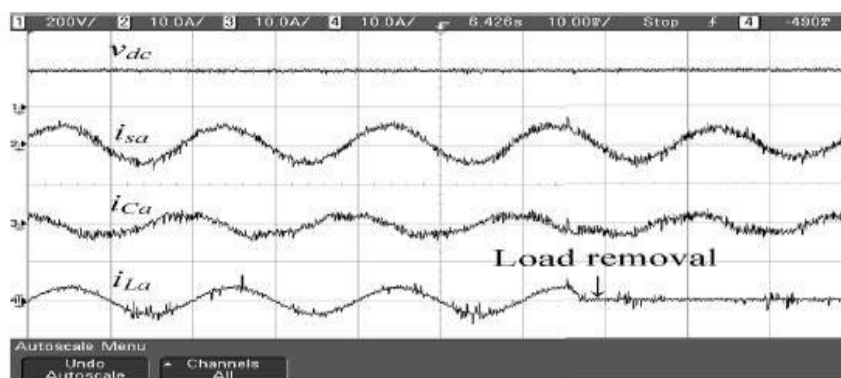


Fig 7: Dynamic performance of DSTATCOM

C. Dynamic Performances of DSTATCOM under Non Linear Loads

Three supply currents with a harmonic spectrum of phase “a” supply current, load current with harmonic spectrum of phase “a” load current and phase “a” compensating current are shown in Fig.7. After power factor correction, THD of supply current and load current are 3.8 and 39.6%, respectively. Fig.8 shows the waveforms of load neutral current, transformer neutral current. Fig.8 shows the value of supply VAR, load VAR and total harmonic distortion on the phase “a” PCC voltage are 10 VAR, 71 VAR and 2.8%, respectively. These results show the function of DSTATCOM with proposed control algorithm for harmonics suppression and neutral current compensation. Fig.8 shows the waveforms of supply current and DSTATCOM currents in dynamic condition with respect to PCC voltage under nonlinear loads. Fig.8(c) shows the waveform of supply current, compensating current and load current with dc link voltage under load removal. The function of neutral current compensation is shown in Fig.7 where phase “a” supply current, load neutral current, T connected transformer neutral point current are shown with dc link voltage. Magnitude and nature of load neutral current and T connected transformer neutral point current are equal and opposite in phase. Fig.8 shows the waveform of supply current, compensating current and load current with dc link voltage and PCC voltage under load injection. These results demonstrate satisfactory performance of control algorithm of DSTATCOM under dynamic conditions.

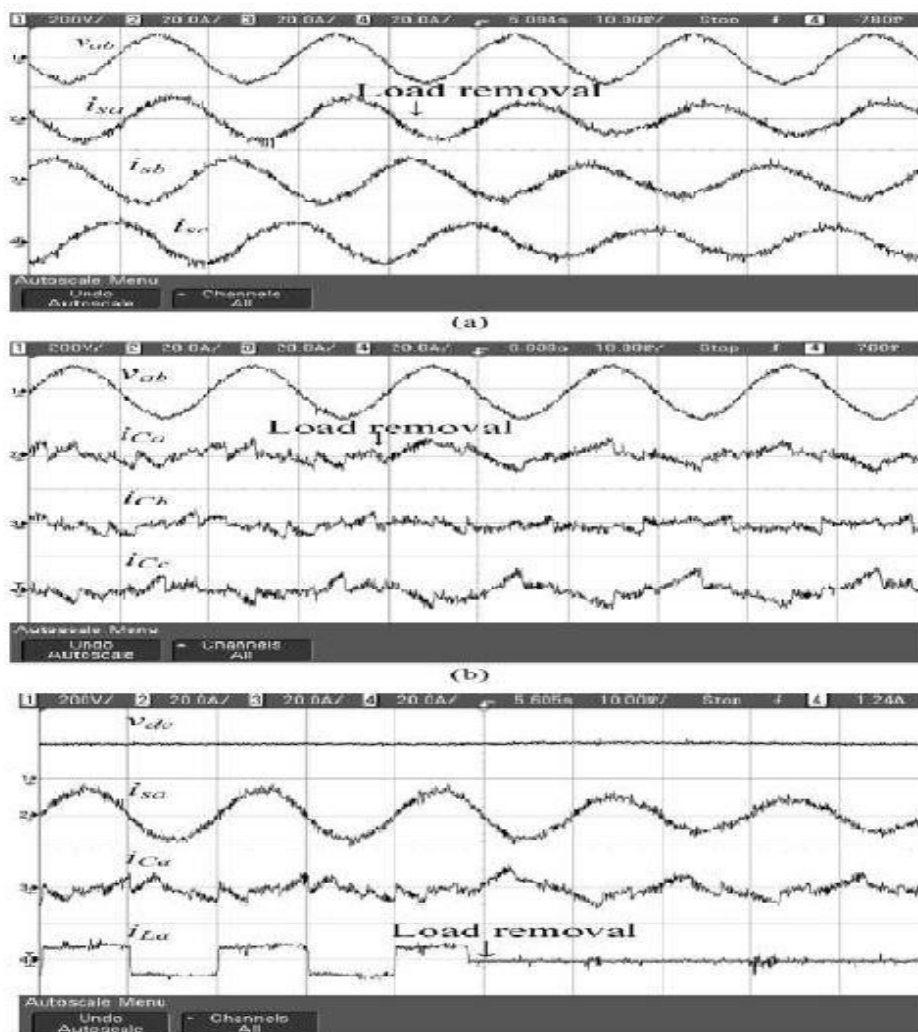


Fig 8: Dynamic performance of DSTATCOM under nonlinear loads.

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CONCLUSION

A control algorithm based on load conductance estimation using neural network for control of DSTATCOM has been implemented in a three phase four wire distribution system. The main factors for deciding the performance of DSTATCOM has been observed for detection of power quality problems in real-time and its accuracy. Test results have proved the effectiveness of proposed neural network algorithm for reactive power compensation, harmonics elimination, load balancing, neutral current compensation and increases efficiency under linear/nonlinear loads.

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