Power Quality Improvement by Back Propagation Control Algorithm Using DSTATCOM

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Abstract: **This project exhibits the execution of a three stage distribution static compensator (DSTATCOM) by utilizing a back propagation (BP) control algorithm for its capacities, for example, load balancing and reactive power compensation zero voltage regulation under nonlinear loads .For the extraction of the crucial weight estimation of dynamic here we are utilizing BP-based control algorithm. And BP based control algorithm is also used for the estimation of receptive power parts of burden streams which are required for the estimation of reference source streams. Control of power quality devices by neural networks is a latest research area in filed of power engineering. Extraction of harmonic components decides the performance of compensating devices. Here we are using DSTATCOM and UPFC as compensating devices. A model of DSTATCOM is created utilizing a computerized signal processor, and its execution is concentrated on under different working conditions. The execution of DSTATCOM is observed to be acceptable with the proposed control algorithm for different sorts of burdens.**

A BP based control algorithm is used for extraction of fundamental weighted value of active and reactive power components of load currents. Back propagation algorithm which is trained the sample can detect the signal of power quality problem in real-time. Continuity, differentiability, non-decreasing momotomy are the main characteristics of this algorithm. The operation of UPFC is similar to the DSTATCOM but the only advantage is that it does not make the system shut down under worse conditions. 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. The proposed system is verified by the results of MATLAB/Simulink.

Keywords: **BP control algorithm, Harmonics, Load balancing, Weights, Power quality and ANFS.**

I. INTRODUCTION

The major problem today the distribution system facing is power quality. The quality of power that is given to the end users is not up to the mark. Because of this there is a failure in the devices. In order to overcome this problem that means to improve the quality of the power we are implementing certain devices in the transmission system. Power converter based custom power devices (CPDs) are useful for reduction of power quality problems such as power factor correction, harmonics compensation, reduction in transients, voltage sag/swell compensation, resonance due to distortion, voltage flicker reduction within specified time and range. These CPDs include DSTATCOM, DVR and UPQC in different Configurations. Many non-model and training based alternative control algorithms are reported in the literature with application of soft computing technique such as neural network, fuzzy logic and adaptive neuro-fuzzy etc. A VSC based DSTATCOM has been introduced for better power quality improvement and thereby improving power factor correction and maintaining rated PCC voltage. For power quality improvement as power factor correction and to maintain rated PCC voltage a voltage source converter (VSC) based DSTATCOM has been preferred in the distribution systems.. A three phase DSTATCOM has been implemented for compensation of nonlinear loads using BPT control algorithm to verify its worthiness. For the extraction of reference source currents to generate the switching pulses for IGBTs of VSC of DSTATCOM has been made by the proposed BPT algorithm. Various functions of DSTATCOM are as follows, harmonic elimination and load. MATLAB with SIMULINK and Sim Power System (SPS) toolboxes are used for the development of simulation model of a DSTATCOM and its control algorithm. By examining the simulation results the performance of the DSTATCOM with BPT algorithm has been found satisfactory for this application because extracted reference source currents performed well in tracing the sensed source currents during steady state as well as under dynamic conditions. The DC bus voltage of the DSTATCOM has also been regulated to rated value without any overshoot or undershoots during load variation that is under varying loads.

This paper presents minimum conditions for the losses in distribution systems and experimentally achieving them by using UPFC. The main advantage of UPFC here is that we can independently control the active and reactive powers when needed. Enhanced power quality improvement is the essential necessity of any electrical equipment. Almost all power quality problems originate from disturbances in the distribution networks. The most common problem that is reported in low and medium level distribution system is harmonic resonance. So we have to overcome this by using certain filters. It has numerous points of interest, for example, most extreme use of electrical types of gear, improved stacking ability, zero voltage regulation, and power factor correction and so on. Wellsprings of poor power quality can be separated in view of purchaser burdens also, subsystem of a conveyance framework. These purchaser burdens can be named straight, nonlinear, or blended sort of loads. So to overcome the problems that are neglected by DSTATCOM we are using UPFC.UPFC consists of a series and a shunt converter which is connected back –to-back through a common DC link. In order to overcome these limitations Back Propagation (BP) has been implemented. An improved Back Propagation control algorithm and linear sinusoidal tracer control algorithm is implemented on a DSTATCOM for the extraction of load currents and fundamental components in three phase consumer loads that is on the consumer side. Internal parameters of this algorithm have clear physical understanding and easy adjustable to optimal value that is to our required value. It is obtained by continuously training the algorithm, which shows the simplicity of this algorithm. Frequency- and time-domain characteristics of the ILST are not affected due to external environment changes and this is another advantage of using artificial neural networks on the distribution system. Detection accuracy and speed of the dynamic response can be tuned after adjusting the algorithm's internal parameters. In this algorithm, extracted reference source currents from the trained network exactly follows the actual source currents that are in the nonlinear distribution system during steady-state as well as dynamic conditions. For this reason, three phase source currents have smooth variation during load perturbations which is a preferable condition.

This control algorithm is implemented on a DSTATCOM which is on the distribution system lines for compensation of linear and nonlinear loads. The advantages of these systems are as follows, (i) This method will not be affected by the initial gain settings, changes of system conditions, and the limits of human experience and judgment, Self-tuning process,(ii)Better response for dynamic system, Voltage Regulation, power factor correction is achieved.(iii)Power quality issues are gaining significant attention due to the increase in the number of sensitive loads on the end user side. Many of these loads use equipment that are sensitive to distortions or dips in supply voltages. So it may cause a failure in the system or complete shutdown of the grid which is not acceptable. Regulations is applied in many places on the distribution system which limit the distortion, transients and unbalanced conditions that a customer can inject into a distribution system. These regulations may require the installation of compensators (filters) on customer premises. It is also expected that a utility will supply a low distortion balanced voltage to its customers, especially those with sensitive loads because increase in distortions leads to burning of the systems on customer side. A distribution static compensator (DSTATCOM) is a voltage source inverter (V_{S1}) based power electronic device. Usually, this device is supported by short-term energy stored in a DC capacitor. Because we know that a capacitor is a energy storing device. So it is connected back to back in the system. When a DSTATCOM is associated with a particular load, it can inject compensating current they are also called as injection currents. Because we are injecting these currents in the place where the system is unbalanced. So that the total demand meets the specifications for utility connection. The shunt converter is also connected in parallel with the transmission line by transformer which allows to control the UPFC's bus voltage shunt reactive power and the DC capacitor voltage. Apart from this, it can also clean up the voltage of a utility bus from any unbalance, overshoots, transients and harmonic distortion. The mitigation of power quality problems can be achieved in two ways. It can be done from either the customer side or utility side. First approach used is load conditioning and other is line conditioning.

II. SYSTEM CONFIGURATION AND CONTROL ALGORITHM

One of the major considerations while using DSTATCOM for load compensation is the generation of the reference compensator currents that are taken from the load line. There are several training methods that have been developed for the use of the compensator when it tracks these reference currents, and thereby injecting these three-phase currents in the AC system to cancel out the disturbances caused by the load in the distribution system. The execution of DSTATCOM depends upon the exactness of music streams, tuned esteem of interfacing conductors (L_f) are joined at air conditioning yield of the VSC>For all the methods are present for suppression of harmonics there is a common belief that the voltage at the point of common coupling is tightly regulated and cannot be influenced by the currents injected by the shunt device which is connected externally on the distribution system. The DSTATCOM employs an inverter to convert the DC link voltage of adjustable magnitude and phase i.e.to an alternating one. It is basically connected near to the load because we can inject dc components on to the load. So here we are employing inverter which converts DC to AC and vice versa. The schematic diagram of a VSC based DSTATCOM is shown on the below fig which is connected in shunt to the distribution network along with the controller.

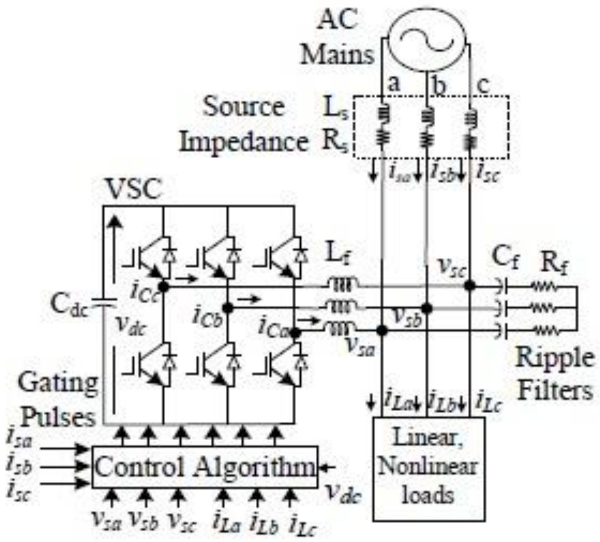

Fig 1. Schematic diagram of VSC based DSTATCOM

There are two different modes in which a DSTATCOM can operate. They are (1) voltage mode and (2)current mode. The basic operation that is carried out in a voltage control mode is the DSTATCOM is connected at a utility bus to maintain a balanced voltage at that bus, irrespective of unbalance or distortion on either side of the bus. In this mode, responsibility of the utility is the operation and maintenance of the DSTATCOM effectively. In a voltage control mode, it can make the voltage of the bus to which it is connected a balanced sinusoid, irrespective of the unbalance and distortion in voltage in the supply side or line current. Alternatively, in the current control mode, the DSTATCOM compensates for any unbalance or distortion in the load. Ideally, it should draw a balanced load current from the system, irrespective of any unbalance or harmonics in either the source or load side. Similarly when operated in a current control mode, it can force the source side currents to become balanced sinusoids. It is also assumed that the DSTATCOM is placed at a utility bus on customer. The phase of the output voltage of the thyristor based inverter, V_i is controlled in the same way as the distribution system voltage v_s.

A DSTATCOM is capable of compensating either bus voltage or line current. Three load buses. It is assumed that consumers are supplied from these buses. A DSTATCOM can be connected in any of these buses, depending on whether it belongs to the utility or a particular customer. For example, if the voltage at bus 3 is distorted, it affects customers both at buses 3 and 4. The utility may then install a DSTATCOM at this bus to clean up its voltage. On the other hand, suppose that the consumer at bus 4 has loads that draw unbalanced and distorted current from the supply. In order to avoid a penalty, one option for the consumer is to install a DSTATCOM on its premises, so that the current drawn from bus 4 is a balanced. VSCs using PWM controllers are the mainstay of modern power electronics controllers, such as STATCOM, DVR and HVDC-VSC stations. One of the many advantages of VSCs using PWM control is that they can produce quasi-sinusoidal voltage waveforms, having almost any desired phase relationship with an existing AC system waveform, thus dictating the direction and magnitude of the active and reactive power exchanged with the AC system.

In practice, the high harmonic frequencies generated by the VSC could be filtered out by high-frequency harmonic filter [101, but in real time the operation of such filters will not be perfect or they may not even be operating. Moreover, harmonic interactions between the VSC and the electric network will always take place. This interaction may produce harmonic resonances which can only be predicted with realistic models of the VSC and the electric network. Comprehensive models for power converters have been reported in the open literature. In power systems harmonic studies, switching functions have found widespread acceptance in the modeling of converters based on thyristor, where the commutation period of the thyristors has been included in the switching functions. As an extension, switching functions have also been used in the modeling of converters based on GTOs or IGBTs, showing even greater adequacy than in the former application.

III. CONTROL ALGORITHM

The back propagation algorithm looks for the minimum of the error function in weight space using the method of gradient descent. This numerical method was used by different contexts. The combination of weights which minimizes the error function is considered to be a solution of the learning problem. Since this method requires computation of the gradient of the error function at each iteration step, we must guarantee the continuity and differentiability of the error function. Obviously we have to use a kind of activation function other than the step function used in perceptron's because the composite function produced by interconnected perceptron's is discontinuous, and therefore the error function too. Since this method requires computation of the gradient of the error function at each iteration step, we must guarantee the continuity and differentiability of the error function. Obviously we have to use a kind of a activation function. Here we are using sigmoid function as activation function. Multilayered networks are capable of computing a wider range of Boolean functions than networks with a single layer of computing units. However the computational effort needed for finding the correct combination of weights increases substantially when more parameters and more complicated topologies are considered. In this chapter we discuss a popular learning method capable of handling such large learning problems - the back propagation algorithm. This numerical method was used by different research communities in different contexts, was discovered and rediscovered, until in 1985 it found its way into connectionist AI mainly through the work of the PDP group. It has been one of the most studied and used algorithms for neural networks learning ever since.

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

The back propagation algorithm looks for the minimum of the error function in weight space using the method of gradient descent. This method is not only more general than the usual analytical derivations, which handle only the case of special network topologies, but also much easier to follow. The combination of weights which minimizes the error function is considered to be a solution of the learning problem. Since this method requires computation of the gradient of the error function at each iteration step, we must guarantee the continuity and differentiability of the error function. Obviously we have to use a kind of activation function other than the step function used in perceptron's, because the composite function produced by interconnected perceptron's is discontinuous, and therefore the error function too.

A BP training algorithm is mainly used to estimate the three phase weighted value of load active power current components $(w_{aq}, w_{bq}\ and\ w_{cq})$ and reactive power current components $(w_{aq}, w_{bq}\ and\ w_{cq})$ from the polluted load currents using the feed forward and supervised principle. In this estimation, the input layer for three phases is given as follows

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

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

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

Where w_o *the selected value of the initial is* weight and $u_{ap}, u_{bp}\ and\ u_{cp}$ are the in-phase unit templates. The In-phase unit templates are estimated using the 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

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

In-phase unit templates of PCC voltages $(u_{ap}, u_{bp}\ and\ u_{cp}$ are estimated as

$$u_{ap} = \frac{V_{sa}}{V_t}, u_{bp} = \frac{V_{sb}}{V_t}, u_{cp} = \frac{V_{sc}}{V_t} \quad (5)$$

The extracted values of $I_{Lap}, I_{Lbp}\ and\ I_{Lcp}$ are passed through a sigmoid function as an activation function, and the output signals $(Z_{ap}, Z_{bp}\ and\ Z_{cp})$ of the feed forward section are mostly expressed as

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

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

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

The estimated values of $Z_{ap}, Z_{bp}\ and\ Z_{cp}$ are fed to a hidden layer as input signals. Differentiable activation functions the back propagation algorithm looks for the minimum of the error function. The three phase outputs of this layer before the activation function are expressed as

$$I_{apI} = w_{o1} + w_{ap}z_{ap} + w_{bp}z_{bp} + w_{cp}z_{cp} \quad (9)$$

$$I_{bpI} = w_{o1} + w_{bp}z_{bp} + w_{cp}z_{cp} + w_{ap}z_{ap} \quad (10)$$

$$I_{cpI} = w_{o1} + w_{cp}z_{cp} + w_{ap}z_{ap} + w_{bp}z_{bp} \quad (11)$$

Where $w_{o1}, w_{ap}, w_{bp}\ and\ w_{cp}$ are the selected value of the initial weights in the hidden layer and the updated values of three phase weights using the average weighted value (w_p) of the active power current component as a feedback signal, respectively. The updated weight of phase "a" active power current components of load current "w_{ap}" at the nth sampling instant is expressed as

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

where $w_p(n)$ and $w_{ap}(n)$ are the average weighted value of the active power component of load currents and the updated weighted value of phase "a" at the n^{th} sampling instant, respectively, and $w_{apl}(n)$ and $z_{ap}(n)$ are the phase "a" fundamental weighted amplitude of the active power component of the load current and the output of the feed forward section of the algorithm at the nth instant, respectively. $f'(I_{apI})$ and μ are represented as the derivative of $Iap1$ components and the learning rate. Similarly, for phase "b" and phase "c," the updated weighted values of the active power current components of the load current are given as follows

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

$$w_{cp}(n) = w_p(n) + \mu\{w_p(n) - w_{cpl}(n)\} f'(I_{cpI})\ z_{cp}(n) \quad (14)$$

The extracted values of $I_{apI}, I_{bpI}\ and\ I_{cpI}$ are then passed through a sigmoid function which is an activation function for the estimation of the fundamental active components in terms of three phase weights $w_{ap1}, w_{bp1}\ and\ w_{cp1}$ as

$$w_{ap1} = f(I_{ap1}) = 1/(1 + e^{-Iap1}) \quad (15)$$

$$w_{bp1} = f(I_{bp1}) = 1/(1 + e^{-Ibp1}) \quad (16)$$

$$w_{cp1} = f(I_{cp1}) = 1/(1 + e^{-Icp1}) \quad (17)$$

IV. SIMULATION RESULTS AND DISCUSSION

The DSTATCOM performance is depends upon the accurateness of harmonic current detection. For reducing ripple in compensating currents, the tuned values of interfacing inductors (L_f) are connected at the output of an AC Voltage Source Converter. A three phase series combination of a resistor $(R_f)$and capacitor (C_f) correspond to the shunt passive ripple filter which is associated at a point of common coupling (PCC) for reducing the high frequency switching noise of the VSC. The currents (i_{Cabc}) of DSTATCOM 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.

(i) Performance of DSTATCOM in PFC Mode

The dynamic execution of a VSC-based DSTATCOM is considered for PFC mode at nonlinear burdens. The execution files are the stage voltages at PCC adjusted source streams v_s, burden ebbs and flows (i_{La} , i_{Lb} *and* i_{Lc}) , compensator ebbs and flows (i_{Ca} , i_{Cb} *and* i_{Cc}), and dc transport voltage v_{dc} which are appeared in Fig. under fluctuating burden (at t = 3.7 to 3.8 s) conditions.

The waveforms of the stage "a" voltage at PCC (v_{sa}), source current (i_{sa}),and burden current (i_{La}), are appeared in Fig3.The total harmonic distortion (THD) of the stage "an" at PCC voltage, source current, and burden current are observed to be 3.90%, 2.00%, and 27.90%, separately. It is watched that the DSTATCOM has the capacity perform the elements of burden adjusting and harmonic disposal with high accuracy.

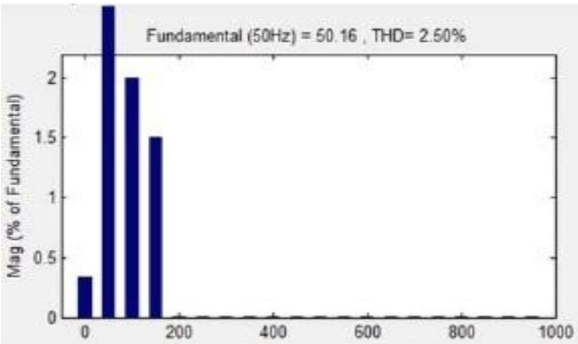

Fig 2.a. PCC voltage of phase "a"

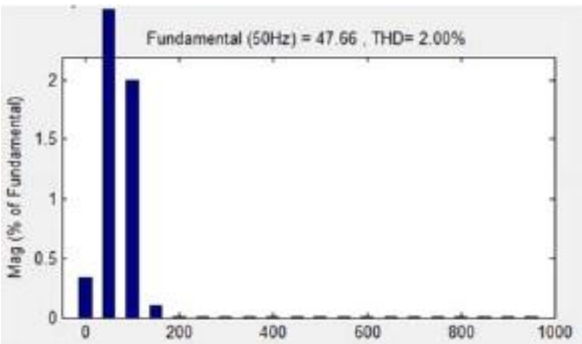

Fig 2.b source current of phase "a"

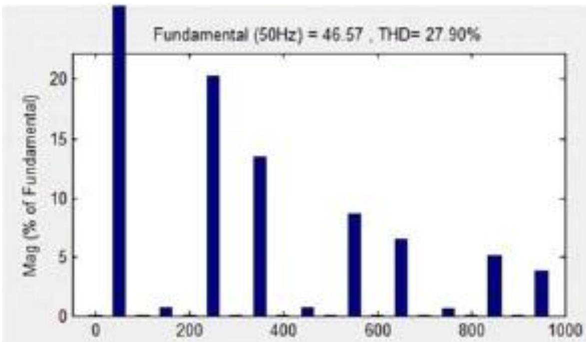

Fig 2.c. load current of phase "a"

(ii)Performance of DSTATCOM in ZVR Mode

In ZVR mode, the amplitude of the PCC voltage is managed to the reference sufficiency by infusing additional driving receptive force segments. The dynamic execution of DSTATCOM as far as PCC stage voltages (versus), adjusted source streams (i_s), burden ebbs and flows (i_{La} , i_{Lb} *and* i_{Lc}), compensator ebbs and flows (i_{Ca} , i_{Cb} *and* i_{Cc}) , amplitude of voltages at PCC (v_t), and dc transport voltage (v_{dc}) waveforms is appeared in Fig. under uneven burden at once span of t = 3.7 to 3.8 s.

The consonant spectra of the stage "a" voltage at PCC (v_{sa}), source current (i_{sa}), and burden current (i_{La}) are appeared in Fig.. The THDs of the stage "an" at PCC voltage, source current, load current are seen to be 4.63%, 2.50%, and 28.88%, individually. Three stage PCC voltages are directed up to the appraised esteem. The amplitude of the three stage voltages is controlled from 335.2 to 338.9 V under nonlinear burdens.

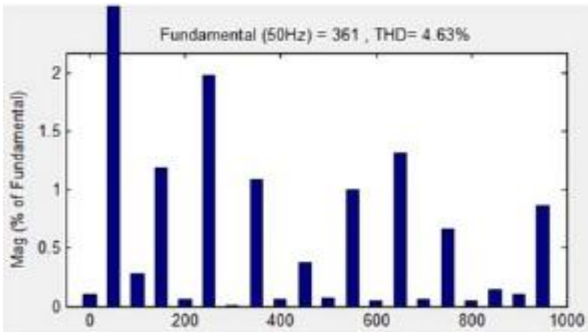

Fig 2.d. PCC voltage of phase "a"

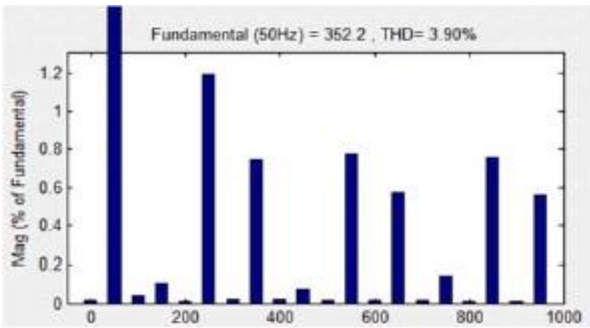

Fig 2.e. source current of phase "a"
Fig 2.f. load current of phase "a"

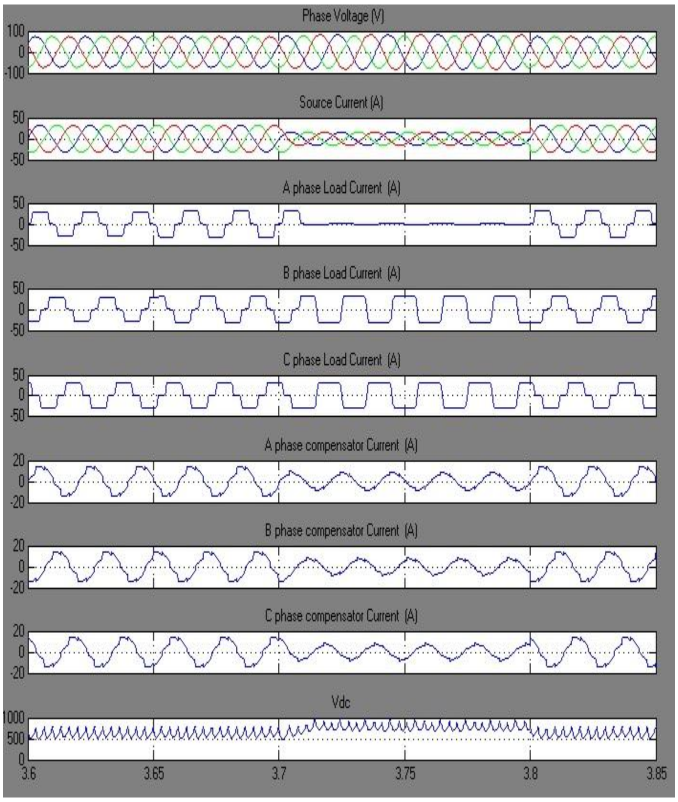

Fig 3. Dynamic performance of DSTATCOM under varying nonlinear loads in PFC mode

(iv) Performance of DSTATCOM in ZVR Mode

In ZVR mode, the amplitude of PCC voltage is regulated to the reference amplitude by injecting extra

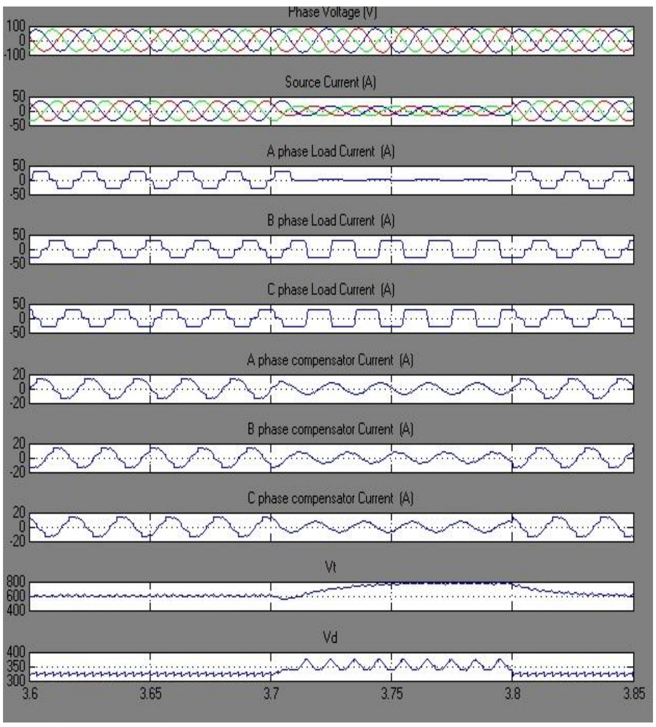

Fig 4.Dynamic performance of DSTATCOM under varying nonlinear loads

in ZVR mode leading reactive power components. The dynamic performance of DSTATCOM in terms of PCC phase voltages (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}) , amplitude of voltages at PCC (vt) and dc bus voltage (v_{dc}) waveforms are shown in Fig.4 under unbalanced load at time(t) =3.7s to 3.8s duration.

(V). Performance of ANFS at nonlinear loads

The basic principle of the ANFIS method is the use of the network neuron to optimize the membership's functions of the fuzzy controller in other words; an ANFIS is one optimized fuzzy inference system (FIS). In the Neuro Fuzzy controller, the simplicity of a Fuzzy controller is combined with the intelligent and adaptive nature of the Neuron Network optimization.

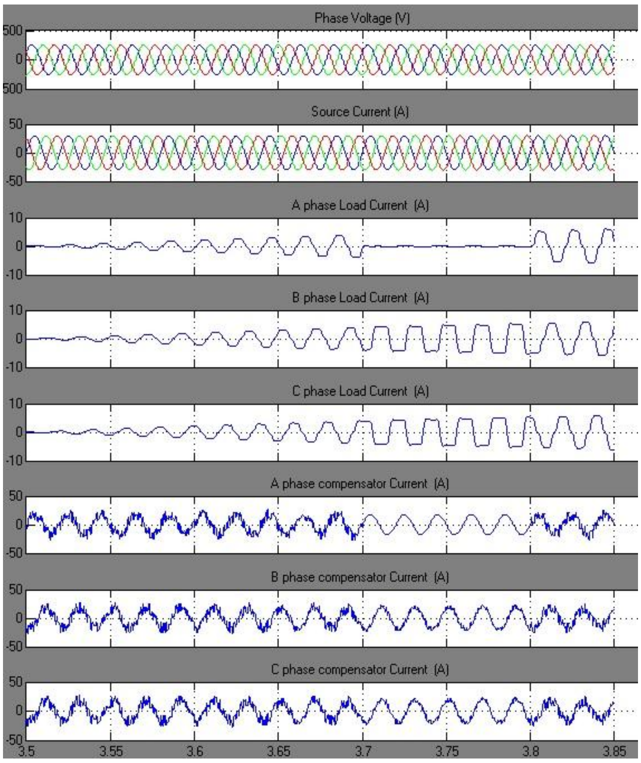

Fig 5. Dynamic performance of DSTATCOM under varying nonlinear loads in PFC mode

THDs of the phase 'a' at PCC voltage, source current, load current are observed 3.09%, 2.99% and 24.94% respectively. Three phase PCC voltages are regulated up to rated value. Amplitude of three phase voltages is regulated from 335.2 V to 338.9 V under nonlinear loads. It may be seen that the harmonics distortion of the source current and PCC voltage are within IEEE-519 standard limit of 5%. The PCC voltage is also regulated at different operating condition of loads. Table I shows the summarized simulation results demonstrating the performance of DSTATCOM. These results show satisfactory performance of DSTATCOM for harmonics elimination and load balancing of nonlinear loads.

Table1:PERFORMANCE OF DSTATCOM

TOTAL HARMONIC DISTORTATION	ZVR OPERATING MODE		PFC OPERATING MODE	
PARAMETERS	B.E.	A.E.	B.E.	A.E.
PCC voltage	2.64	2.63	2.56	0.13
Source current	2.44	2.36	2.38	0.14
Load current	24.67	11.08	24.27	13.28

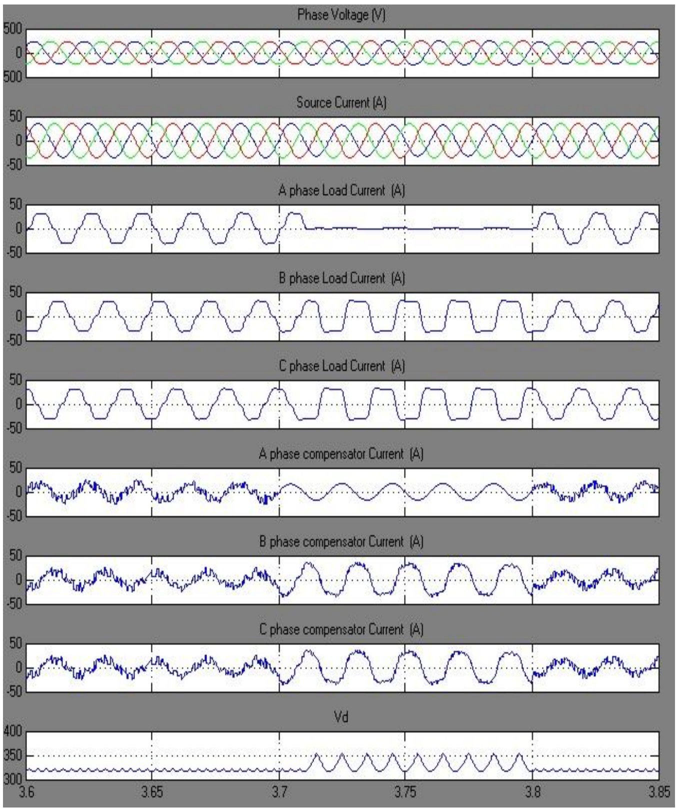

Fig 6. Dynamic performance of DSTATCOM under varying nonlinear loads

CONCLUSION

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.

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