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DESIGN AND ANALYSIS OF DSTATCOM USING BACK PROPAGATION ALGORITHM FOR HARMONIC CURRENT REDUCTION

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ABSTRACT

The main goal of this project is to develop the artificial neural network control algorithm for the controller of D-STATCOM for the improvement of power quality. The occurrence of nonlinear loads creates the voltage to be deviated and current to be distorted from its sinusoidal waveform quality. Thus harmonics elimination, load balancing and voltage regulation are essential to maintain power quality. The appearance of any device depends on the control algorithm used for the reference current estimation and gate pulse generation pattern. Thus the artificial neural network with Back Propagation (BP) algorithm has been proposed to make the triggering pulses for the three phase H bridge inverter(D-STATCOM).The BP-based control algorithm is used for the extraction of essential weighted value of active and reactive power components of load currents which are essential for the estimation of reference source current. Based on the variation of the target voltage and the generated voltage, the triggering pulse for the inverter is found 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 modeling of the Back propagation algorithm controlled D-STATCOM is demonstrated.

I.INTRODUCTION

Power quality in distribution systems affects all the connected electrical and electronics equipment. It is a extent of deviations in voltage, current, frequency of a specific system and connected components. In recent years, use of power converters in adjustable speed drives, power supplies etc. is ceaselessly increasing. This equipment draws harmonics currents from AC mains and raises the supply demands. These loads can be grouped as linear (lagging power factor loads), nonlinear (current or voltage source type of harmonic generating loads), unbalanced and varied types of loads. Some of power quality problems associated with these loads include harmonics, high reactive power burden, load unbalancing, voltage variation etc. A variety of practice power devices are developed and successfully applied to compensate various power quality problems in a distribution system. These custom power devices are classified as the D-STATCOM (Distribution Static Compensator), DVR (Dynamic Voltage Restorer) and UPQC (Unified Power Quality Conditioner). The D-STATCOM is a shunt-connected device, which can mitigate the current connected power quality problems.

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. Adaptive learning, self- organization, real-time operation, and fault tolerance through redundant information are main advantages of these algorithms. A neural network-based control algorithm such as the Hopfield-type neural network is also used for the estimation of the amplitude and phase angles of the fundamental component both with extremely distorted voltage by the assumption of known power frequency. Control algorithms reported in available texts such as the quantized Kernel least mean square algorithm radial basis function (RBF) networks and feedforward training can also be used for the controller of CPDs. An immune RBF neural network integrates the immune algorithm with the RBF neural network. This algorithm has the advantages in the learning speed and correctness of the astringent signal. So, it can detect the harmonics of the current timely and exactly in the power network. A multilayer perceptron neural network is suitable for the identification of nonlinear characteristics of the load. The main benefit of this method is that it requires only waveforms of voltages and currents. A neural network with memory is used to classify the nonlinear load admittance. As soon as training is attained, the neural network predicts the true harmonic current of the load when supplied with a clean sine wave. 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 capability to deal with complex nonlinear problems. The power quality at the PCC is governed by standards such as IEEE-519-1992, IEEE-1531-2003 and IEC- 61000, IECSC77A etc.

The efficiency of D-STATCOM depends upon the used control algorithm for generating the switching signals for the voltage source converter and significance of interfacing inductors. For the control of D-STATCOM, many control algorithms are described in the literature based on the instantaneous reactive power theory, deadbeat or predictive control instantaneous symmetrical component system nonlinear control technique , modified power balance theory, enhanced phase locked loop technique, Adaline control technique, synchronous reference frame control method, ANN and fuzzy based controller, SVM based controller, correlation and cross-correlation constants based control algorithm etc.

In this Project, the problem of power quality of voltage sag is identified by artificial neural network then trained data and neural network output simulated in neural network block set, at that time it will be mitigated using D-STATCOM with neural network control block. A feed forward Artificial Neural Network (ANN) has been off-line trained to detect the initial time, the last time and the magnitude of voltage sags and swells. Also, the designed system will be applied to notice transient voltage in electrical power systems. The performance of the designed measure method will be tested done a simulation platform designed in MATLAB/Simulink through the analysis of some practical cases.

The controller of power quality devices by neural network is a modern research zone in the field of power engineering. The BP algorithm which trained the example can detect the signal of the power quality problem in actual time. Its simulation study for harmonic detection is obtainable. Many neural network-based algorithms are described with theoretical analysis in single phase system, but their implementation to D-STATCOM is hardly reported in the available literature. In this paper, a BP algorithm is implemented in a three phase shunt connected custom power device known as D-STATCOM for the extraction of the weighted value of load active power and reactive power current components in nonlinear loads.

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The recommended control algorithm is used for harmonic suppression and load balancing in PFC and zero voltage regulation (ZVR) modes with dc voltage regulation of D-STATCOM. In this BP algorithm, the training of weights has three stages. It includes the feedforward of the input signal training, calculation and BP of the error signals, and advance of training weights. It could have one or more than one layer. Continuity, differentiability, and no decreasing monotony are the main characteristics of this algorithm. In this application, the proposed control algorithm on a D-STATCOM is implemented for the compensation of nonlinear loads.

Problem Identification

The harmonic problem are now common not only in industrial application but in commercial buildings as well. D-STATCOM is used to mitigate the current harmonics. The back propagation algorithm is used for harmonics suppression and reactive power compensation. The improvement in power quality of the distribution line using D-STATCOM.

Objective

- To Identity power quality problems with nonlinear loads.
- To regulate voltage, compensate of reactive power and eliminate current harmonics using D-STATCOM

Block Diagram

The Block diagram of the proposed system consists of the three phase supply supplying the nonlinear load, D-STATCOM block, interfacing inductor, and the D-STATCOM controller.

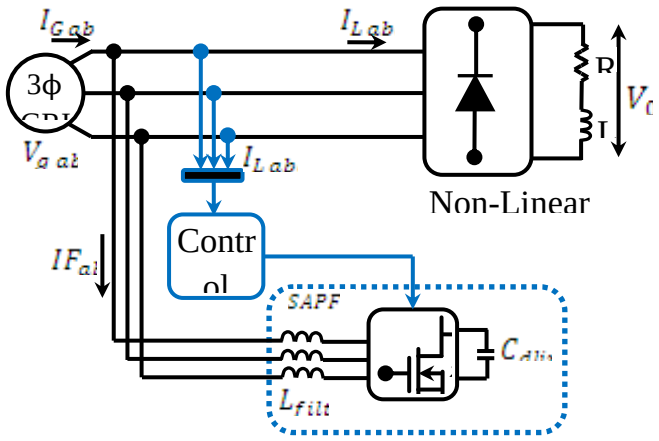

Fig 1 Block Diagram of VSC based D-STATCOM

Possible Solution for Problem Identified

❖The current Total harmonic distortion (THD) can be reduced using Artificial Neural Network with back propagation (BP) algorithm in order to generate the Pulse with modulation (PWM) gate pulse for voltage source converter.

FLEXIBLE ALTERNATING CURRENT TRANSMISSION SYSTEM

The world's electrical power systems today are widely interconnected due to commercial reasons to decrease the cost of electricity and to improve the reliability of the system. These interconnected networks are tough to operate and cannot utilize the full potential of a transmission system. In order to overcome these limits, power systems came up with the concept of mechanical controllers in the past but these mechanical controllers had

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numerous intrinsic problems. Advanced power system engineers presented the concept of power electronic devices to control the power system limitations known as Flexible AC Transmission System (FACTS) devices.

FACTS Uses: In interconnected as well as in long transmission power systems practical problems occur which limits the load ability and reliability of the system. In long-distance transmission, TCSC or SSSC offers advantages equaling effectiveness against the rating, complexity and costs.

Opportunities for FACTS Controllers

Opportunities rise through the ability of FACTS Controllers to control the interrelated parameters that manage the operation of transmission systems including series impedance, shunt impedance, current, voltage, phase angle, and the damping of oscillations at several frequencies below the rated frequency. FACTS are an allowing technology, and not a one-on-one additional for mechanical switches. The FACTS technology is not a single high-power Controller, but somewhat a collection of Controllers, which can be applied individually or in coordination with others to control one or more of the interrelated system parameters stated above.

A well-chosen FACTS Controller can overcome the specific limitations of a designated transmission line or a corridor. For all FACTS Controllers signify applications of the same basic technology, their production can ultimately take advantage of technologies of scale. FACTS technology also lends itself to extend usable transmission limits in a step-by-step manner with incremental investment as and when required

II. INTRODUCTION TO D-STATCOM

The D-STATCOM is a three phase and shunt connected power electronics created reactive power compensation equipment, which creates and /or absorbs the reactive power whose output can be varied so as to maintain control of specific parameters of the electric power system. The D-STATCOM basically consists of a coupling transformer with a leakage reactance, a three phase GTO/IGBT voltage source inverter (VSI), and a dc capacitor. The D-STATCOM 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 through the leakage reactance power exchange between the D-STATCOM and the Power system, such that the AC voltages at the bus bar can be regulated to improve the voltage profile of the power system, which is primary duty of the D-STATCOM.

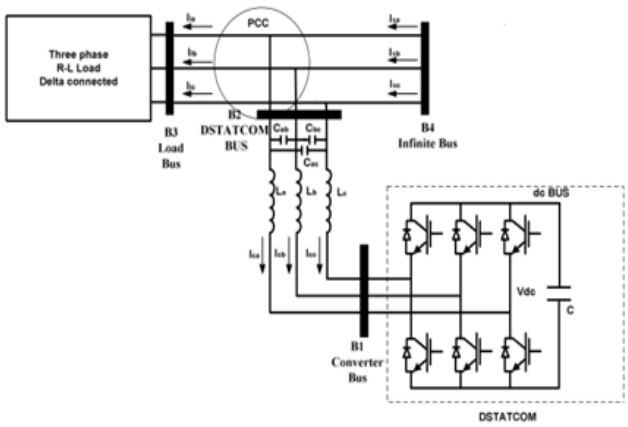

Figure:2 Schematic of a typical Distribution System compensated by D-STATCOM

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The D-STATCOM employs solid state power switching devices and provides fast controllability of the three phase voltages, both in magnitude and phase angle. The D-STATCOM employs an inverter to convert the DC link voltage Vdc on the capacitor to a voltage source of variable magnitude and phase. Therefore the D-STATCOM can be treated as a voltage controlled source. The D-STATCOM can also be seen as a current controlled source. A voltage source converter (VSC)-based D-STATCOM is connected to a three phase ac mains feeding three phase linear/nonlinear loads with internal grid impedance.

Three phase loads may be a lagging power factor load or an unbalance load or a nonlinear load. For reducing ripples in compensating current, interfacing inductors are used at AC side of VSC. A RC filter is linked to the system in parallel with the load and the compensator to decrease switching ripples in the PCC voltage injected by switching of D-STATCOM. The performance of D-STATCOM depends upon the accuracy of harmonic current detection.

The D--STATCOM is operated for the compensation of lagging power factor balanced load to correct the power factor at source side or to regulate the voltage at PCC. In ZVR mode, D-STATCOM injects currents to regulate the PCC voltage at the preferred reference value of the voltage and the source currents may be leading or lagging currents depending on the reference value of PCC voltage.

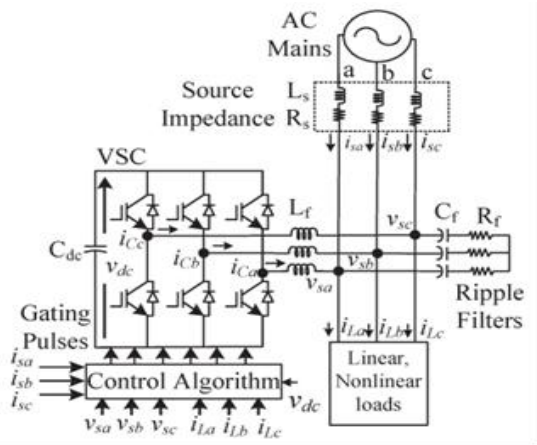

Figure: 3 Circuit Diagram of VSC- Based D-STATCOM

The D-STATCOM currents (i_{Cabc}) are injected as required compensating currents to withdraw 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. The controller of the D-STATCOM is used to run the inverter in such a way that the phase angle between the inverter voltage and the line voltage is by dynamism adjusted so that the D-STATCOM generates or absorbs the desired VAR at the point of connection. The phase of the output voltage of the inverter $V_{i,}$ is controlled in the same way as the distribution system voltage. The D-STATCOM is worked for the compensation of lagging power factor balanced load to correct the power factor at source side or to regulate the voltage at PCC

III. EXISTING SYSTEM WITH SINUSOIDAL PULSE WIDTH MODULATION CONTROL

In pulse width modulation control, the converter switches are turned on and off some times during a half cycle and output voltage is controlled by variable the width of the pulses. The gate signals are generated by relating a

triangular wave with a DC signal. The lower order harmonics can be excluded or reduced by selecting the number of pulses per half cycle. However increasing the number of pulses would also raise the magnitude of higher order harmonics which can simply be filtered out.

The width of the pulses can be changed to control the output voltage. However the pulse width of pulses could be changed. It is possible to choose the widths of pulses in such a way that certain harmonics can be eliminated. The most common method of varying the width of the pulses is the Sinusoidal Pulse Width Modulation. In SPWM the displacement factor is unity and the power factor is developed. The lower order harmonics are eliminated and reduced. The SPWM pulses are generated and the D-STATCOM is controlled in the open loop response.

IV. PROPOSED SYSTEM WITH ARTIFICIAL NEURAL NETWORK

The training-based alternative control algorithms are stated in the literature with application of soft computing technique such as neural network, fuzzy logic and adaptive neuro-fuzzy, etc. Adaptive learning, self-organization, real-time operation, and fault tolerance through redundant data are main benefits of these algorithms. A neural network-based control algorithm such as the Hopfield-type neural network is also used for the estimation of the amplitude and phase angles of the important component both with highly distorted voltage by the theory of known power frequency.

The control of power quality devices by neural network is a modern research area in the field of power engineering. The extraction of harmonic components adopts the performance of compensating devices. The BP algorithm which trained the sample can detect the signal of the power quality problem in real time. Their simulation studies for harmonic detection. Many neural network-based algorithms are reported with theoretical analysis in single phase system, but their implementation to D-STATCOM is hardly reported in the available literature. A BP algorithm is implemented in a three phase shunt connected custom power device known as D-STATCOM for the extraction of the weighted value of load active power and reactive power current components in nonlinear loads. The proposed control algorithm is used for harmonic suppression and load balancing in PFC and zero voltage regulation (ZVR) modes with dc voltage regulation of D-STATCOM. In this BP algorithm, the training of weights has three stages.

- Feed forward of the input signal training,
- Control and BP of the error signals,
- Improvement of training weights.

It may have one or more than one layer. Continuity, differentiability and non-decreasing monotony are the main features of this algorithm. It is based on a mathematical formula and does not need special features of function in the learning process. It also has smooth variation on weight correction due to batch informing features on weights. In the training process, it is slow due to more number of learning steps, but after the training of weights, this algorithm produces very fast trained output response. In this application, the proposed control algorithm on a D-STATCOM is implemented for the compensation of nonlinear loads. The training method most commonly used is the back propagation algorithm. The primary output pattern is related with the desired

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output pattern and the weights are adjusted by the algorithm to reduce the error. The iterative process qualities when the error becomes near null.

V. ESTIMATION OF REFERENCE CURRENT USING BPC ALGORITHM

A BP training 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 feed forward 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

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

The in-phase unit templates of PCC voltages (u_{ap}, u_{bp}, and u_{cp}) are estimated as [13]

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

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 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. The three phase outputs of this layer (I_{ap1}, I_{bp1} and I_{cp1}) before the activation function are expressed as

$$I_{ap1} =w_{o1} + w_{ap}Z_{ap}+ w_{bp}Z_{bp}+ w_{cp}Z_{cp} \quad (9)$$

$$I_{bp1} =w_{o1} + w_{bp}Z_{bp}+ w_{cp}Z_{cp}+ w_{ap}Z_{ap} \quad (10)$$

$$I_{cp1} =w_{o1} + w_{cp}Z_{cp}+ w_{ap}Z_{ap}+ w_{bp}Z_{bp} \quad (11)$$

Where w_{o1}, w_{ap}, w_{bp}, and w_{cp} are the particular value of the initial weight in the hidden layer and the updated values of three phase weights using the normal 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

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

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 nth sampling instant, correspondingly, and w_{ap1} (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

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the feed forward section of the process at the nth instant, respectively. f '(I_{ap1}) and μ are represented as the derivative of I_{ap1} components and the learning rate.

Likewise, for phase "b" and phase "c," the updated weighted values of the active power current components of the load current are expressed as

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

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

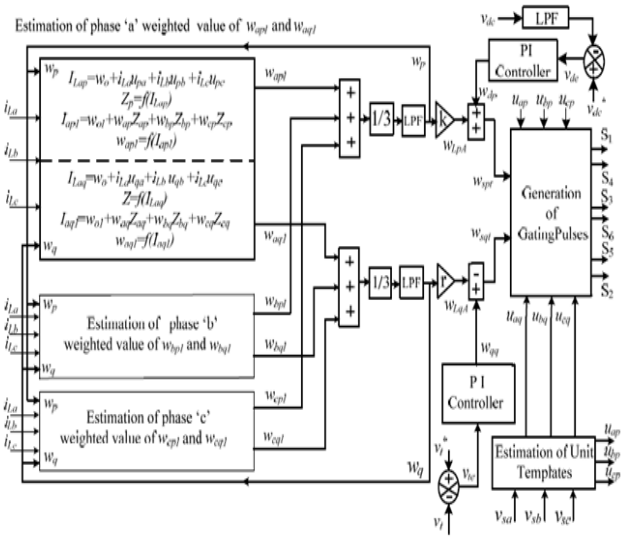

Figure: 4.Estimation of reference currents using BP algorithm

The extracted values of I_{ap1}, I_{bp1}, and I_{cp1} are passed through a sigmoid function as an activation function to the estimation of the essential active components in terms of three phase weights w_{ap1}, w_{bp1}, and w_{cp1} as

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

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

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

The average weighted amplitude of the fundamental active power components (w_p) is estimated using the amplitude sum of three phase load active power components (w_{ap1}, w_{bp1} and w_{cp1}) divided by three. It is required to realize load balancing features of D-STATCOM. Mathematically, it is expressed as

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

First-order low-pass filters are used to separate the low frequency components. "K" indicates the scaled factor of the extracted active power components of current in the algorithm. After separating the 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 w_{LpA}.

Likewise, the weighted amplitudes of the reactive power components of the load currents (w_{aq}, w_{bq}, and w_{cq}) of the fundamental load current are extracted as

$$I_{Laq}=w_o+ i_{La}u_{aq}+ i_{Lb}u_{bq}+ i_{Lc}u_{cq} \qquad (19)$$

$$I_{Lbq}= w_o+ i_{La}u_{aq}+ i_{Lb}u_{bq}+ i_{Lc}u_{cq} \qquad (20)$$

$$I_{Lcq}= w_o+ i_{La}u_{aq}+ i_{Lb}u_{bq}+ i_{Lc}u_{cq} \qquad (21)$$

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Where w_o is the selected value of the initial weight and u_{aq}, u_{bq} and u_{cq} are the quadrature components of the unit template. The quadrature unit templates (u_{aq}, u_{bq}, and u_{cq}) of the phase PCC voltage are estimated using (5) as

$u_{aq} = (-u_{bp} + u_{cp})/\sqrt{3}$, $u_{bq} = (3u_{ap} + u_{bp} - u_{cp})/2\sqrt{3}$,

$$u_{cq} = (-3u_{ap} + u_{bp} - u_{cp})/2\sqrt{3} \quad (22)$$

The extracted values of I_{Laq}, I_{Lbq}, and I_{Lcq} are passed through a sigmoid function as an activation function to the estimation of Z_{aq}, Z_{bq}, and Z_{cq}

$$Z_{aq}=f(I_{Laq}) = 1/(1 + e^{-ILaq}) \quad (23)$$

$$Z_{bq}=f(I_{Lbq}) = 1/(1 + e^{-ILbq}) \quad (24)$$

$$Z_{cq}=f(I_{Lcq}) = 1/(1 + e^{-ILcq}) \quad (25)$$

The estimated values of Z_{aq}, Z_{bq}, and Z_{cq} are fed to the hidden layer as input signals. The three phase outputs of this layer (I_{aq1}, I_{bq1}, and I_{cq1}) before the activation function can be represented as

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

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

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

Where w_{o1}, w_{aq}, w_{bq}, and w_{cq} are the selected value of the initial weight in the hidden layer and the updated three weights using the average weighted value. The reactive power components of currents (w_q) as a feedback signal, respectively.

The updated weight of the phase "a" reactive power a component of load currents "w_{aq}" at the nth sampling instant is expressed as

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

where $w_q(n)$ and $w_{aq}(n)$ are the average weighted value of the active power component of load currents and the updated weight in the nth sampling instant, respectively, and $w_{aq1}(n)$ and $z_{aq}(n)$ are the phase "a" weighted amplitude of the reactive power current component of load currents and the output of the feed forward section of the algorithm at the nth instant, respectively. $f'(I_{aq1})$ and μ are presented as the derivative of I_{aq1} components and

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

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

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

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

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

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

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

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

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

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. 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 w_{LqA}.

A. *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 v_{dc} of a VSC, and this error at the *n*th sampling instant is expressed as

$$v_{de}(n) = v_{dc}^*(n) - v_{dc}(n) \quad (36)$$

This voltage error is fed to a proportional-integral (PI) controller whose output is required for maintaining the dc bus voltage of the D-STATCOM. At the *n*th sampling instant, the output of the PI controller is as follows

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

Where k_{pd} and k_{id} are the proportional and integral gain constants of the dc bus PI controller. $v_{de}(n)$ and $v_{de}(n-1)$ are the dc bus voltage errors in the nth and (n-1)th instant, and $w_{dp}(n)$ and $w_{dp}(n-1)$ are the amplitudes 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 current (w_{spt}) is estimated by the addition of the output of the dc bus PI controller (w_{dp}) and the average magnitude of the load active currents (w_{LpA}) as

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

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

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

The weighted output of the ac bus PI controller w_{qq} for regulating the ac bus terminal voltage at the *n*th sampling instant is expressed as

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

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.

$$w_{sqt} = w_{qq} - w_{LqA} \quad (41)$$

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

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

$$i_{saq} = w_{sqt}\, u_{aq},\ i_{sbq} = w_{sqt}\, u_{bq},\ i_{scq} = w_{sqt}\, u_{cq} \quad (43)$$

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

$$I_{sa}^{*}= i_{sap}+ i_{saq},\ \ I_{sb}^{*}= i_{sbp}+ i_{sbq},\ \ \ I_{sc}^{*}= i_{scp}+ i_{scq} \qquad (44)$$

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) S1 to S6 of the VSC used as a D-STATCOM

RESULTS

Simulation Output

MATLAB with SIMULINK tool box is used for the development of simulation model of D-STATCOM and its control algorithm.

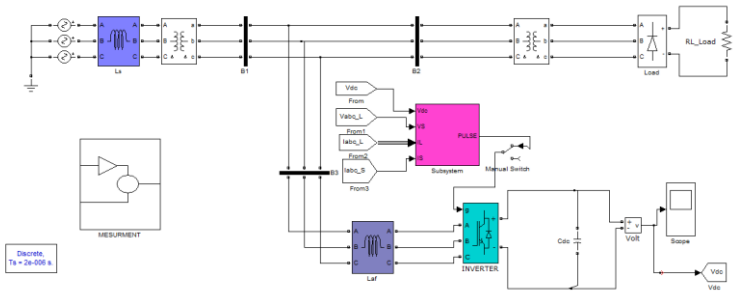

Figure 5 SIMULINK Model a simple power system with D-STATCOM

The performance of the back propagation algorithm in the time domain for the three phases D-STATCOM is simulated under non linear loads. The performance of a control algorithm is observed under non linear load. The D-STATCOM model is done based on Mat lab Simulink. Here simulation is carried out in different cases such as

1. Connection of D-STATCOM through Manual Switch in OFF Condition
2. Connection of D-STATCOM through Manual Switch in ON Condition

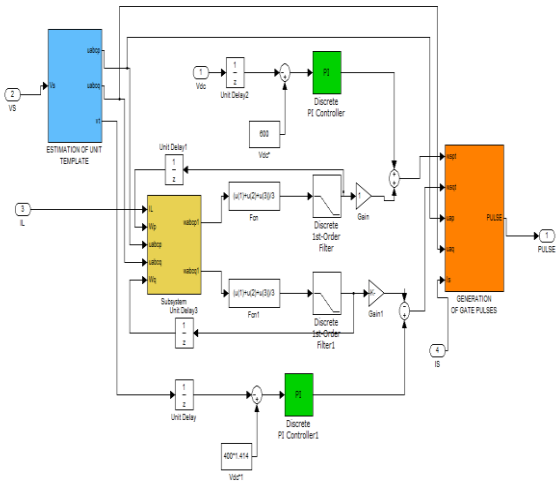

Figure 6 SIMULINK modal of D-STATCOM with BPC Algorithm.

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DISCUSSION ON OUTPUT

The performance of a VSC based on without D-STATCOM is studied under non linear load.

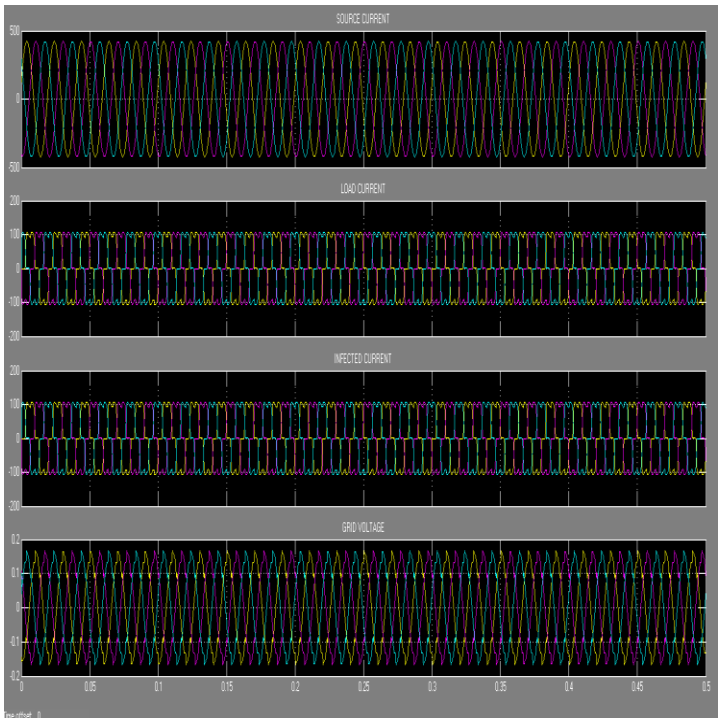

Figure 7 Connection of D-STATCOM through Manual Switch in OFF Condition

The performance indices are the grid voltage at PCC(v_s), balanced source current(i_s) ,load current(i_{La},i_{Lb},i_{Lc}) and injected current are shown

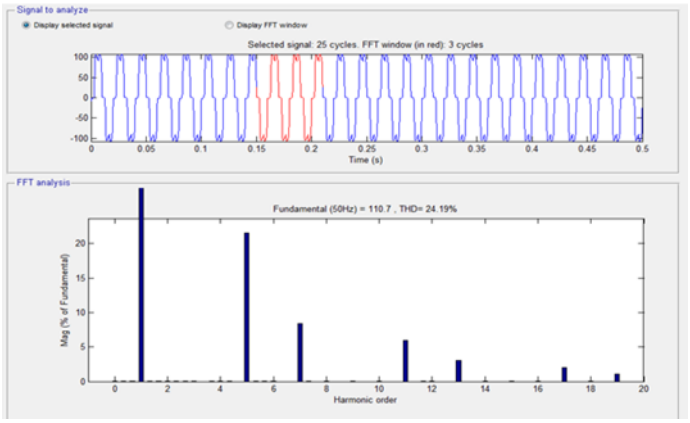

Figure 8 THD under Manual Switch in OFF condition

The total harmonic distortion (THD) of load current is found to be 24.19%. Its observed that without D-STATCOM the function of load balancing and harmonic elimination with low precision.

The performance of a VSC based on with D-STATCOM is studied under non linear load. The performance indices are the grid voltage at PCC, balanced source current ,load current and injected current.

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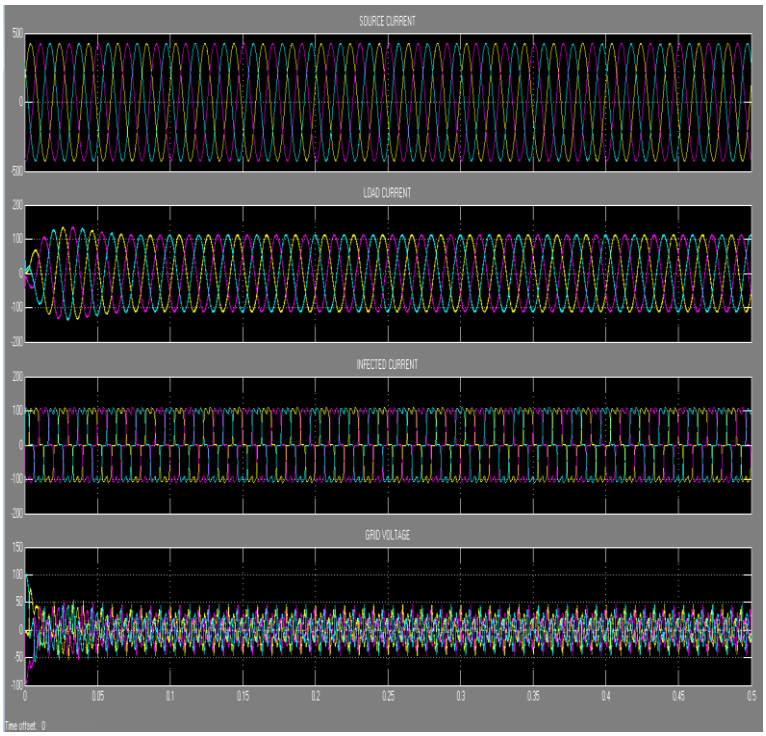

Figure 9 Connection of D-STATCOM through Manual Switch in ON Condition

The total harmonic distortion (THD) of load current is found to be 1.22%. Its observed that with D-STATCOM the function of load balancing and harmonic elimination with high precision.

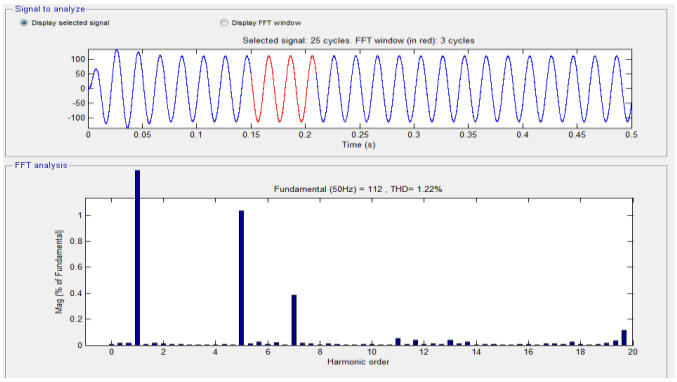

Figure 10 THD under Manual Switch in ON condition

The dynamic performance of D-STATCOM in terms of PCC phase and load current are synchronized waveform as shown

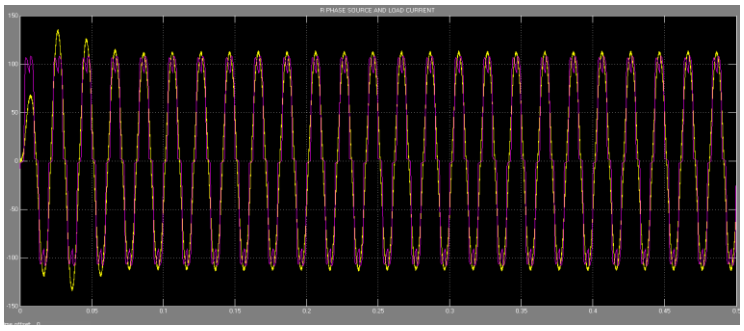

Figure 11 Synchronization of phase and load current

These results shown satisfactory performance of the Back Propagation Algorithm (BPC) for the harmonic elimination according to the IEEE-519 Guidelines on the order of less than 5% percentage.

Table 1.1 **PERFORMANCES OF D-STATCOM**

OPERATING MODE	**PERFORMANCE PARAMETER**	**PERCENTAGE**
WITHOUT D-STATCOM	Load current THD	24.19%
WITH D-STATCOM	Load current THD	1.22%

From the simulation and implementation results, it is concluded that D-STATCOM and its control algorithm have been found suitable for the compensation of nonlinear loads. . 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.

VI. CONCLUSION

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

From simulation and implementation results, it is concluded that D-STATCOM and its control algorithm have been found suitable for mitigation of harmonics in nonlinear loads. These results show satisfactory performance of the BP control algorithm for harmonics elimination according to IEEE-519 guidelines in the order of less than 5%.

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