A Comparative Study of Control Algorithms for DSTATCOM for Harmonic Elimination and Reactive Power Compensation

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Abstract—In this paper, two different control algorithms for DSTATCOM are presented. The evaluation of different methods is made to derive reference source current signals from the load current to generate the switching pulses for IGBTs of the VSC of the DSTATCOM for harmonic elimination and reactive power compensation. These methods are Back Propagation(BP) control algorithm and Synchronous Reference Frame(SRF)Theory. Back Propagation(BP) control algorithm is based on extraction of the fundamental weighted value of active and reactive power components of load currents which are required for the estimation for reference source current and SRF theory is based on the transformation of currents in synchronously rotating dq frame. Back propagation control algorithm and SRF theory based DSTATCOM are simulated with MATLAB using SIMULINK for linear and non linear loads. Here linear load used is three phase series RL load and non linear loads are three phase uncontrolled rectifier with RL load. The performance of DSTATCOM is studied with the proposed control algorithms for various types of loads

Keywords- Back propagation(BP) control algorithm, SRF theory harmonics,reactive power compensation, power quality

1. INTRODUCTION

In present day distribution systems, major power consumption has been in reactive loads, such as fans, pumps, etc. These loads draw lagging power-factor currents and therefore give rise to reactive power burden in the distribution system. Excessive reactive power demand increases feeder losses and reduces active power flow capability of the distribution system. Power quality in distribution systems affects all the connected electrical and electronics equipments. It is a measure of deviations in voltage, current, frequency of a particular system and associated components. In recent years, use of power converters in adjustable speed drives, power supplies etc is continuously increasing.

This equipment draws harmonics currents from AC mains and increases 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 mixed types of loads. Some of power quality problems associated with these loads include harmonics, high reactive power burden, load unbalancing, voltage variation etc. The presence of harmonics in the power system cause greater power loss in distribution, interference problem in communication system and, sometimes results in operation failure of electronic equipment's.

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 device is shunt connected to the power distribution network. In general, the DSTATCOM can provide power factor correction, harmonics compensation and load balancing. The major advantages of DSTATCOM compared with a conventional staticVAR 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.

The performance of DSTATCOM depends on the control algorithm used for extraction of reference current components. Some of these control algorithms are Instantaneous reactive power theory, Synchronous reference frame theory, Adaline based neural network and Back Propagation control.

In this paper, two different control algorithms used for the control of a DSTATCOM is analyzed and the performance of a DSTATCOM is studied through design and simulation.

2. SYSTEM CONFIGURATION

A voltage source converter (VSC)-based DSTATCOM is connected to a three phase ac mains feeding three phase linear/nonlinear loads with internal grid impedance which is shown in Fig.1. The performance of DSTATCOM depends upon the accuracy of harmonic current detection. For reducing ripple in compensating currents, the tuned values of interfacing inductors (L_f) are connected at the ac output of the VSC. The DSTATCOM currents (i_{cabc}) are injected as required compensating currents to cancel the reactive power components and harmonics of the load currents so that loading due to reactive power component/ harmonics is reduced on the distribution system.The voltage and current rating of the required compensation decides the rating of the switches.

The selection of the DC bus voltage, DC bus capacitor, AC inductors in the following sections and the obtained values are shown in appendix

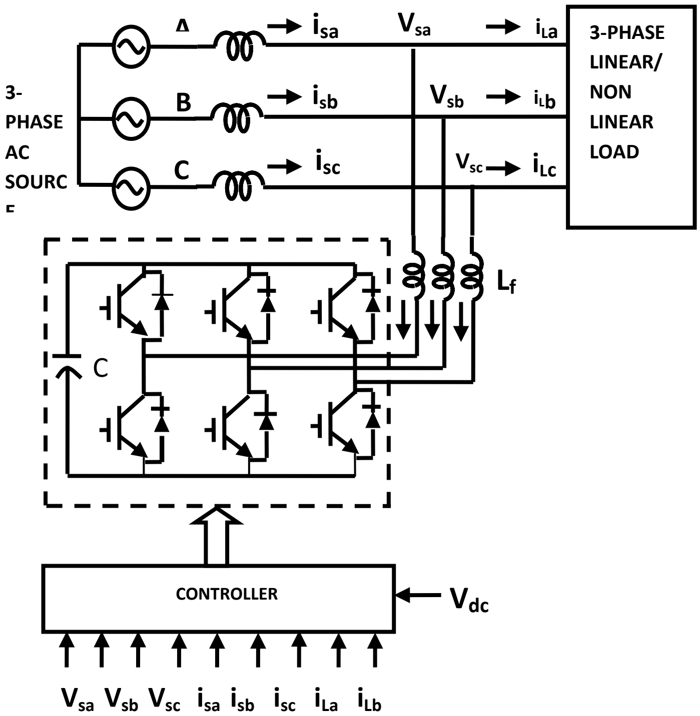


Fig. 1. Schematic diagram of VSC-based DSTATCOM

2.1. DC Capacitor Voltage

The value of DC bus voltage (V_{dc}) depends on the PCC voltage and its must be greater than amplitude of the AC mains voltage for successful PWM control of VSC of DSTATCOM. For a three-phase VSC, the DC bus voltage is defined as,

$$V_{dc} = \frac{2\sqrt{2}V_{LL}}{m*\sqrt{3}} \quad (1)$$

Where m is the modulation index and is considered as 1 and V_{LL} is the AC line output voltage of DSTATCOM.

2.2. DC Bus Capacitor

The design of the DC bus capacitor is governed by the depression in the DC bus voltage upon the application of the loads and rise in the DC bus voltage on removal of the loads. Using the principle of energy conservation, the equation governing C_{dc} is as,

$$C_{dc} = \frac{(\frac{X}{2} + 2X) * NOOFCYCLES * TIMEPERIOOCYCLE}{(1.8V_M)^2 - (1.4V_M)^2} \quad (2)$$

Where X is rating of converter and V_m is peak value of phase voltage

2.3 AC Inductor

The selection of the AC inductance depends on the ripple current, i_{cr} and switching frequency f_s, The AC inductance is given as,

$$L = \frac{V_{dc}}{4 * h * F_{s\max}}$$

$$h = \sqrt{\frac{K_1}{K_2} * \frac{2(m^2 - 1)F_{s\max}}{4m^2}} \quad (3)$$

$$m = \frac{1}{\sqrt{1 - \frac{F_{\min}}{F_{\max}}}}$$

3. COMPARISON OF CONTROL ALGORITHM

The performance of DSTATCOM depends on the control algorithm used for extraction of reference source current components. In this paper, Back propagation (BP) control algorithm and Synchronous reference frame (SRF)theory techniques are used to extract reference source currents components.

3.1 Back-Propagation Control Algorithm

Fig.2 shows the block diagram of the BP training algorithm for the estimation of reference source currents through the weighted value of load active power and reactive power current components. In this algorithm[1], the phase PCC voltages **(V_{sa}, V_{sb}, and V_{sc})**, source currents **(i_{sa}, i_{sb}, and i_{sc})**, load currents (i_{La}, i_{Lb}, and i_{Lc}) and dc bus voltage (**V_{dc}**) are required for the extraction of reference source currents **(i^*_{sa}, i^*_{sb}, and i^*_{sc}).** There are two primary modes for the operation of this algorithm: The first one is a feed forward, and the second is the BP of error or supervised learning[2]

3.2 Synchronous Reference Frame Method

SRF theory is based on the transformation of currents in synchronously rotating dq frame. Fig.3 shows the basic building blocks of this theory[4]. Sensed inputs **V_{sa}, V_{sb}**, and **V_{sc}** and **i_{La}, i_{Lb}**, and **i_{Lc}** are fed to the controller. Voltage signals are processed by a phase-locked loop (PLL) to generate unit voltage templates (sine and cosine signals). Current signals are transformed to dq frame, where these signals are filtered and transformed back to abc frame **(i_{sa}, i_{sb}, and i_{sc})**, which are fed to a sinusoidal PWM signal generator to generate signal switching signals fed to the DSTATCOM.

4. SIMULATION OF DSTATCOM

The parameters are given in appendix. The basic simulation model consists of a source, load, DSTATCOM and control block. The linear load connected is a combination of resistance and inductance in series for each phase and the nonlinear load are three phase uncontrolled and half controlled rectifier with RL load. This DSTATCOM is simulated with the above described Back propagation control algorithm and Synchronous

Reference Frame theory.

4.1 Without DSTATCOM

The simulation is carried out without connecting DSTATCOM to the system with a linear and nonlinear loads.

4.1.1 Linear Load

The output waveforms are shown in Fig.4(a,b and c) shows the Source currents, PCC voltages, and Load currents of a without DSTATCOM in case of linear load condition.

4.1.2 Nonlinear Load

4.1.2.1 Three phase Uncontrolled rectifier with RL load

The output waveforms are shown in Fig.5 (a,b and c) shows the Source currents, PCC voltages, and Load currents of system without DSTATCOM in case of nonlinear load condition

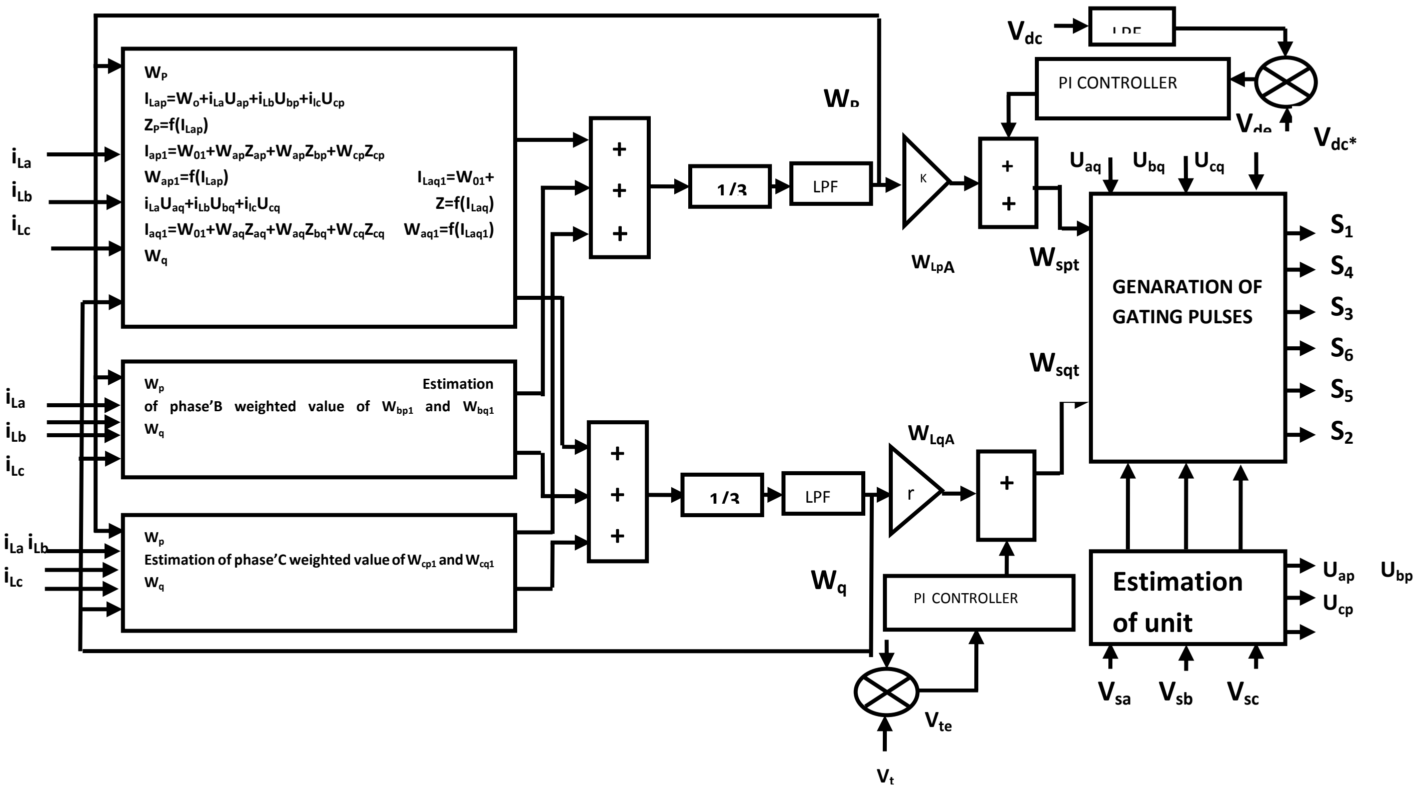


Fig.2 Block diagram of the reference current extraction using Back Propagation control algorithm

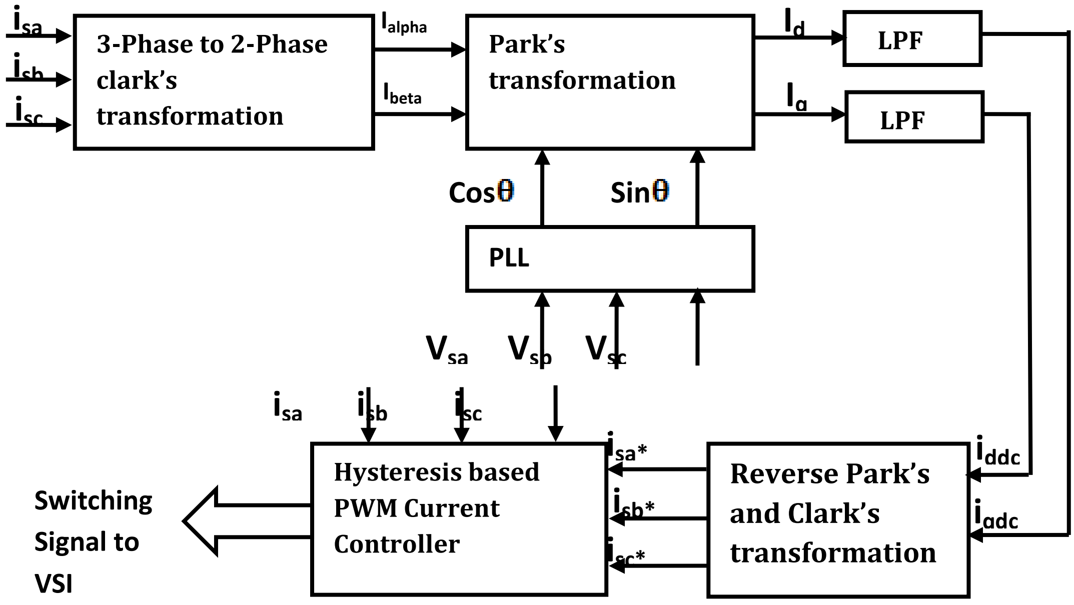


Fig.3 Block diagram of the control algorithm using Synchronous Reference Frame Method

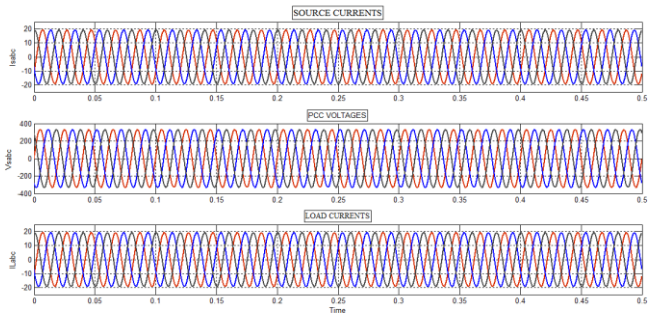


Fig.4 Outputs waveforms of linear load(without DSTATCOM)(a) Source currents,(b) PCC voltages,(c) Load currents

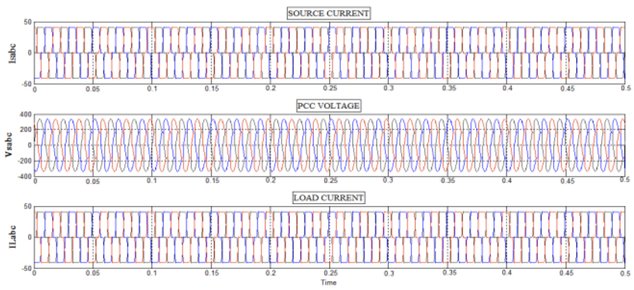
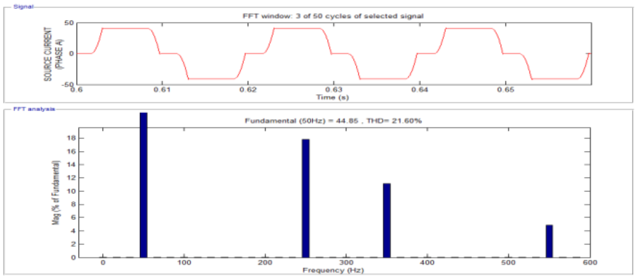


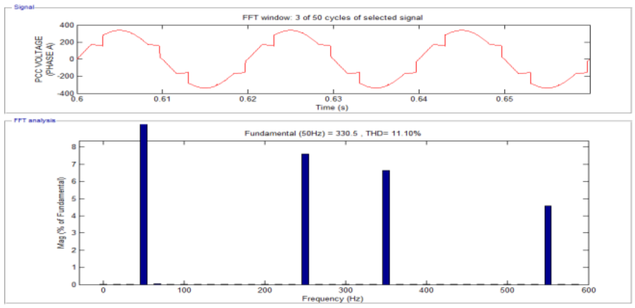
Fig.5 Outputs waveforms of non linear load

(a) Source currents,(b) PCC voltages,(c) Load currents

(without DSTATCOM)



(a)



(b)

Fig.6 Waveforms and harmonic spectra of (a) source current of phase “a,” (b) PCC voltage of phase “a,” under nonlinear load (Without DSTATCOM

THD calculation of source current and PCC voltage of phase A is as shown in Fig. 6(a) and 6(b) respectively. As seen the magnitude of source current is 44.85A and its THD is 21.60%. Similarly the magnitude of PCC voltage of phase A is 330.5V and its THD is 11.09%.

4.2 WITH DSTATCOM

4.2.1 Back Propagation Control Algorithm

Now the DSTATCOM is connected as shown in Fig.1. The performance of the BP algorithm in the time domain for the three phase DSTATCOM is studied for PFC and ZVR modes of operation under linear and nonlinear loads.

4.2.1.1 Performance of DSTATCOM in ZVR Mode

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

4.2.1.1.1 Linear Load

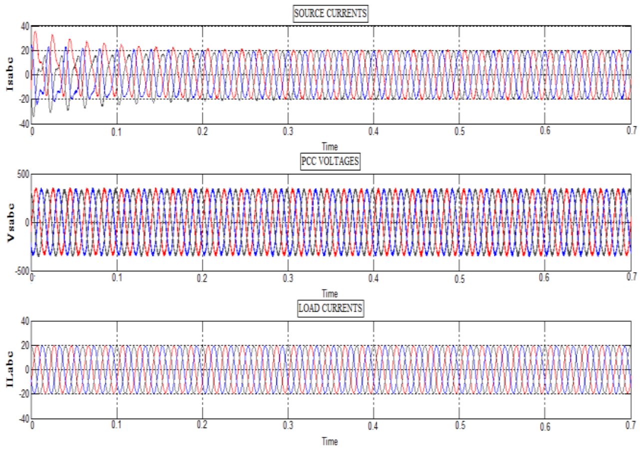


Fig.7 Output waveforms (Back propagation control) of

Linear Load(a) Source current, (b)PCC voltages, (c)Loadscurrents (ZVR mode)

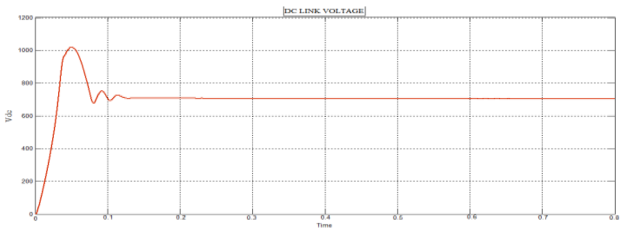


Fig.8 DC Link voltage (Back propagation control) of

Linear Load (ZVR mode)

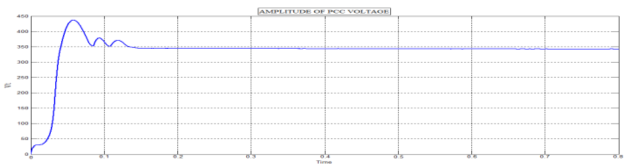


Fig.9 Amplitude of PCC Voltage(ZVR mode)

Fig.7 shows the source current, PCC voltage, and load currents. Here load draws a current of 19.6 amps in each phase.Fig.8 shows the DC link voltage of DSTATCOM. Here DC link voltage is maintained at 700V. Fig.9 shows the amplitude of PCC Voltage which is maintained at 340V equal to supply voltage.

4.2.1.1.2 Nonlinear Load

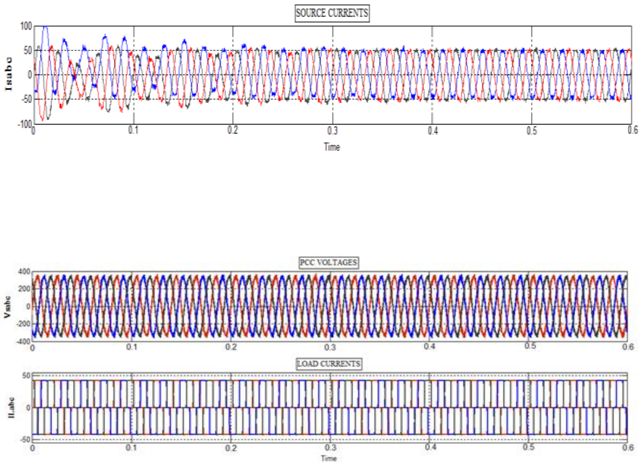
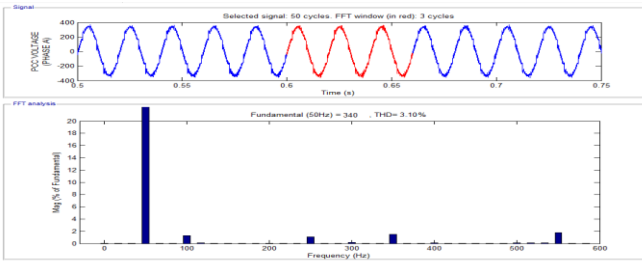
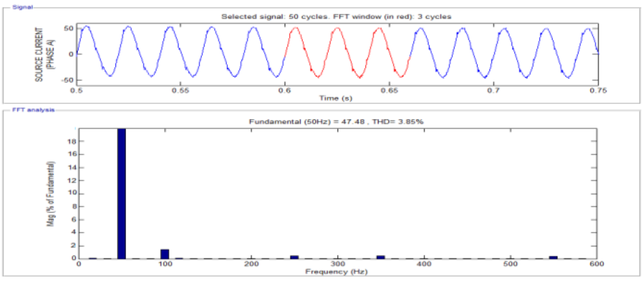


Fig.10 Output waveforms (Back propagation control) of Non Linear Load (a) Source current, (b)PCC voltages, (c)Loads current (ZVR mode)

Fig.10 shows the PCC voltage, load currents, and source currents.



(a)



(b)

Fig .11 Waveforms and harmonic spectra of (a) PCC voltage of phase “a,” (b) source current of phase “a,” in ZVR mode

The harmonic spectra of the phase “a” voltage at PCC, and source current are shown in Fig 11(a)–(b). The THDs of the phase “a” at PCC voltage, source current, load current are observed to be 3.10%, and 3.85% respectively. The amplitude of the three phase voltages is regulated from 330.4 to 338.9 V under nonlinear loads. It may be seen that the harmonic distortions of the source current and PCC voltage are within the IEEE-519 standard limit of 5%. Table I shows the summarized simulation results demonstrating the performance of DSTATCOM. These results show satisfactory performance of DSTATCOM for harmonic elimination of nonlinear loads.

4.2.1.2 *Performance* of DSTATCOM in PFC Mode

The dynamic performance of a VSC-based DSTATCOM is studied for PFC mode under linear and nonlinear loads conditions

4.2.1.2.1 Linear Load

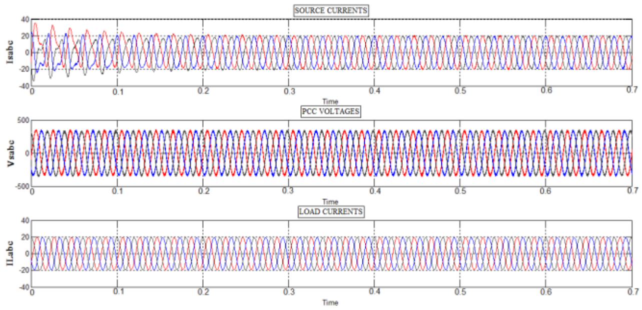


Fig.12 Output waveforms (Back propagation control) of Linear Load (a) Source current, (b)PCC voltages, (c)Loads currents(PFC mode)

4.2.1.2.2 Nonlinear Load

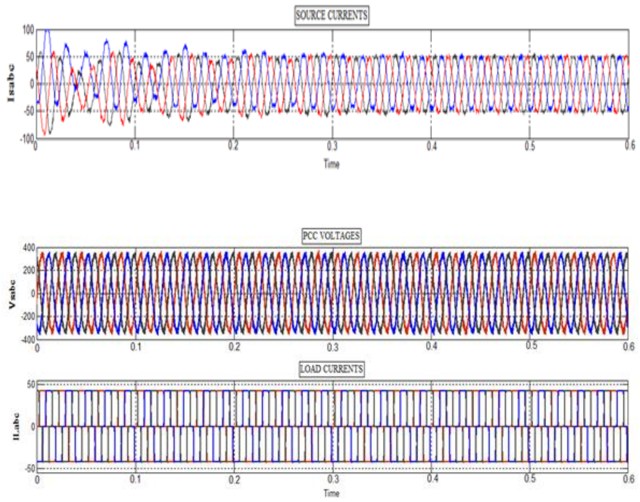
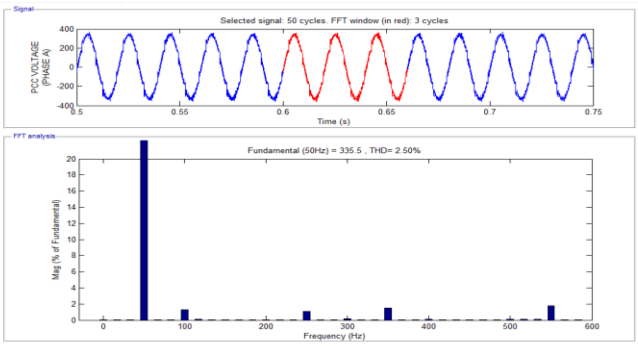
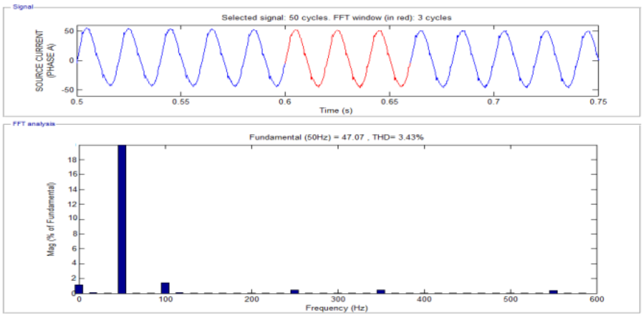


Fig.13 Output waveforms (Back propagation control) of Non Linear(Uncontrolled) Load (a) Source current, (b)PCC voltages, (c)Loads currents in PFC mode



(a)



(b)

Fig .14 Waveforms and harmonic spectra of (a) PCC voltage of phase "a," (b) source current of phase "a," under nonlinear load(With DSTATCOM) in PFC mode

The waveforms of non linear load for the phase "a" voltage at PCC(V_{sa}), source current (i_{sa}), and load current (i_{La}) are shown in Fig. 14(a)–(b), respectively. The total harmonic distortion (THD) of the phase "a" at PCC voltage and source current are found to be 2.50%, and 3.43% , respectively. It is observed that the DSTATCOM is able to perform the function of harmonic elimination with high precision.

4.2.2 Synchronous Reference Frame (SRF)Theory

4.2.2.1 Linear Load

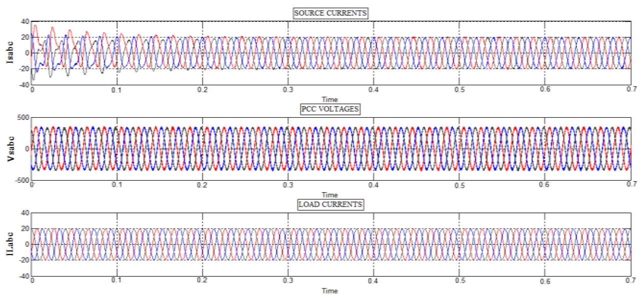


Fig.15 Output waveforms (SRF theory) of Linear Load with DSTATCOM (a) Source current, (b)PCC voltages, (c)Loads currents

4.2.2.2 Nonlinear Load

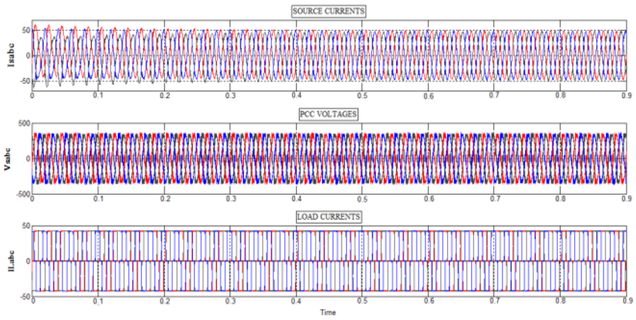
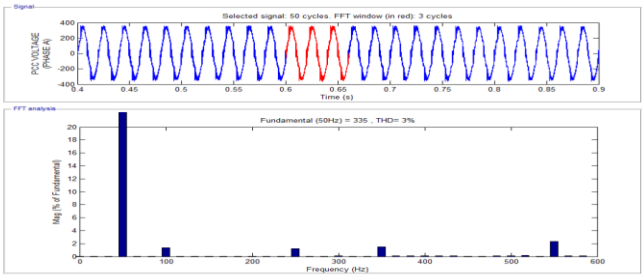
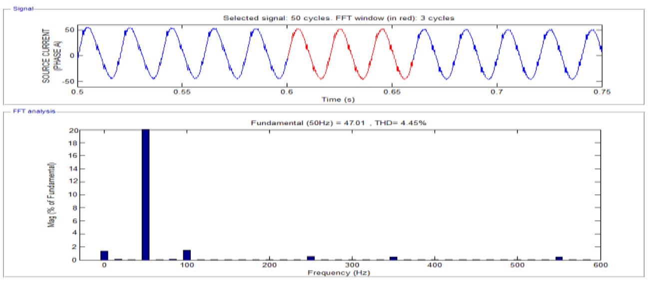


Fig.16 Output waveforms (SRF theory) of Non Linear Load with DSTATCOM(a) Source current, (b)PCC voltages, (c)Loads currents



(a)



(b)

Fig .17 Waveforms and harmonic spectra of (a) PCC voltage of phase "a," (b) source current of phase "a," under nonlinear load(With DSTATCOM) using SRF theory

The waveforms of the phase "a" voltage at PCC and source current are shown in Fig. 17(a)–(b), respectively. The total harmonic distortion (THD) of the phase "a" at PCC voltage and source current are found to be 3%, and 4.45% , respectively. It is observed that the DSTATCOM is able to perform the function of harmonic elimination with high precision

5. CONCLUSION AND FUTURE SCOPE

In this paper the comparison of control algorithms of DSTATCOM is carried out. These algorithms are Back Propagation(BP) Control Algorithm and Synchronous Reference Frame (SRF) Theory. The loads considered are Linear and Nonlinear loads for simulation. These two control algorithms are presented with the help of simulation results and THD calculations. The simulation is carried out in MATLAB environment. For comparison the parameters considered are THD of PCC voltage and source currents, DC link voltage, settling time for DC link voltage and power factor of linear and nonlinear loads. In case of nonlinear load, the THD of source currents are reduced with the help of DSTATCOM. In case of linear load the THD's of Voltage and currents are increased but within acceptable limits whereas both the voltage and current are regulated. The gating signals are generated by a Sinusoidal PWM technique. From the simulation results it can be concluded that Back propagation control algorithm provides a better performance in both the cases when compared to SRF theory. calculating the weights of hidden layer for desired output is important in BP control technique.

The future work on this project can be carried out by using Hysteresis PWM technique and SVPWM technique for the generation of pulses. And also comparison of other theories like Symmetrical component theory, Sliding Mode control, cross correlation theory etc. can be carried out. And also the experimental analysis can be done in a laboratory by developing a prototype model of DSTATCOM for these two methods.

APPENDIX

AC supply source: three-phase, 415 V (L-L), 50 Hz.

Source impedance: R_S = 0.04 Ω and L_S= 2 mH.

Loads:

Linear Load: 10KVA, 0.8 pf lag ,

Nonlinear Load:

1. Uncontrolled rectifier with R = 13Ωand L = 200 mH.

2. Half controlled rectifier with R = 13Ωand L = 200 mH

Rating of VSC = 10 kVA.

Switching frequency of inverter = 10 kHz

Reference dc bus voltage: 700 V

DC bus Capacitance(C_{dc})=4000ufarad

Interfacing inductor (L_f) = 2.75 mH

Gains of PI controller for dc bus voltage: k_{pd} = 3.1 and k_{id}=0.9

Gains of voltage PI controller: k_{pd}= 2.95 and k_{id} = 4

Selected initial weights: W_0 = 0.4 and W_{01} = 0.2

Learning rate (μ) = 0.6

Cut off frequency of low-pass filter used in dc bus voltage = 15 Hz

Cut off frequency of low-pass filter used in ac bus voltage = 10 Hz.

Weights of hidden layer for Back propagation control algorithm

Linear Load- $W_{ap}=W_{bp}=W_{cp}=0.4$

$W_{aq}=W_{bq}=W_{cq}=0.6$

Non Linear Load-1. Uncontrolled rectifier with RL load

$W_{ap}=W_{bp}=W_{cp}=0.35$

$W_{aq}=W_{bq}=W_{cq}=0.605$

TABLE-1

PERFORMANCE OF DSTATCOM

TYPE OF LOAD	PARAMETERS	WITHOUT DSTATCOM	WITH DSTATCOM		
			BP CONTROL ALGORITHM		SRF THEORY
			ZVR MODE	PFC MODE	
LINEAR LOAD (RL LOAD)	SOURCE CURRENT (A,THD)	13 A (0 %)	13.9 A (0.8 %)	13.7 A (0.87 %)	13.85 A (0.93 %)
	PCC VOLTAGE (V,THD)	234 V (0 %)	239.6 V (0.61 %)	237 V (0.7 %)	237 V (0.8 %)
NON LINEAR LOAD (UNCONTROLLED RECTIFIER WITH RL LOAD) $\alpha=0°$	SOURCE CURRENT (A,THD)	31.7 A (21.60 %)	33.57 A (3.85 %)	33.28 A (3.43 %)	33.23 A (4.45 %)
	PCC VOLTAGE (V,THD)	233.7 V (11.01 %)	239.6 V (3 %)	237.2 V (2.50 %)	239.6 V (3.10 %)

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