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Power Quality Improvement Using DSTATCOM by Back Propagation Control Algorithm

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Abstract:

Control of power quality devices by neural network is a latest research area in field of power engineering. Extraction of harmonic components decides the performance of compensating devices. Back-propagation algorithm which is trained the sample can detect the signal of power quality problem in real-time. Many neural network based algorithms are reported with theoretical analysis in single phase system but their implementation to DSTATCOM ishardly reported in the available literature. In this paper, a back-propagation (BP) algorithm is implemented in three phase shunt connected custom power device known as DSTATCOM for extraction of weighted value of load active power and reactive power current components in nonlinear loads.

Proposed control algorithm is used for harmonics suppression and load balancing in power factor correction (PFC) and zero voltage regulation (ZVR) modes with DC voltage regulation of DSTATCOM. In this BP algorithm, training of weights has three stages. It includes feed forward of the input signal training, calculation and back propagation of the error signals and upgrading of training weights. It may have one or more than one layer. Continuity, differentiability, non-decreasing monotony are the main characteristics of this algorithm. It is based on mathematical formula and does not need special features of function in learning process. It also has smooth variation on weight correction due to batch updating features on weights. In training process, it is slow due to more number of learning step but after training of weights, this algorithm produces very fast trained output response. In this application, proposed control algorithm on a DSTATCOM is implemented for compensation of nonlinear loads.

Keywords: Power quality, DSTATCOM, load balancing, power factor correction, proposed control algorithm and zero voltage regulation.

Introduction:

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

Power converter based custom power devices (CPDs) are useful for reduction of power quality problems such as power factor correction, harmonics compensation, voltage sag/swell compensation, resonance due to distortion, voltage flicker reduction within specified international standards. These CPDs include Distribution Static Compensator (DSTATCOM), Dynamic Voltage Restorer (DVR) and Unified Power Quality Conditioner (UPQC) in different configurations. Some new topologies of them are also reported in the literature such as indirect matrix converter (IMC) based active compensator

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where dc link capacitor can be removed. Other new configurations are based on stacked multicell converters where main features are on the increase in the number of output voltage levels, without transformer operation and natural self-balancing of flying capacitors voltage etc.

Performance of any custom power device depends very much upon control algorithm used for reference current estimation and gating pulse generationscheme. Some of the classical control algorithms are Fryzepower theory, Budeanu theory, p-q theory and SRF theory, Lyapunov-function-based control and nonlinear control technique etc. 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, fault tolerance through redundant information are major advantages of these algorithms. Neural network based control algorithm such as Hopfield type neural network is also used for estimation of amplitude and phase angles of the fundamental component both with highly distorted voltage by assumption of known power frequency.

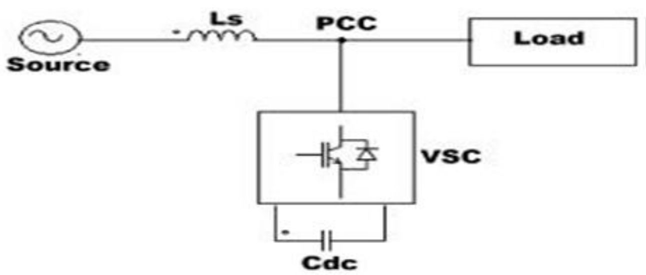
An improved adaptive detecting approach for extraction of error signal with variable learning parameters can be chosen for fast response to improve tracking speed, and low value in a stable period to improve accuracy. Wu et al. have proposed new control algorithm based on inverse control with neural network interface which applied for instantaneous calculation of switching on-off time in digital environment. A survey on iterative learning control (ILC) is presented by Ahn *et al*.and it is classified in different subsection within the wide range of application. The main idea of ILC is to find an input sequence such that the output of the system is as close as possible to a desired output. Control algorithms reported in available texts such as quantized Kernel least mean square algorithm, radial basis function networks feed forward training can also be used for control of CPDs.

The mitigation of power quality problems can be achieved in two ways. It can be done from either customer side or utility side. First approach used is load conditioning and the other is line conditioning. Load conditioning ensures that the equipment is less sensitive to power disturbances. They are based on PWM converters and connected in shunt or in series to low and medium voltage distribution system. Series active power filters operate in conjunction with shunt passive filters in order to compensate load current harmonics. Series active power filters operates as a controllable voltage source whereas shunt active power filters operate as a controllable current source.

DSTATCOM

Basic principle

A DSTATCOM is a controlled reactive source, which includes a Voltage Source Converter (VSC) and a DC link capacitor connected in shunt, capable of generating and/or absorbing reactive power. The operating principles of a DSTATCOM are based on the exact equivalence of the conventional rotating synchronous compensator.The AC terminals of the VSC are connected to the Point of Common Coupling (PCC) through an inductance, which could be a filter inductance or the leakage inductance of the coupling transformer, as shown in figure. The DC side of the converter is connected to a DC capacitor, which carries the input ripple current of the converter and is the main reactive energy storage element.



Basic figure of DSTATCOM

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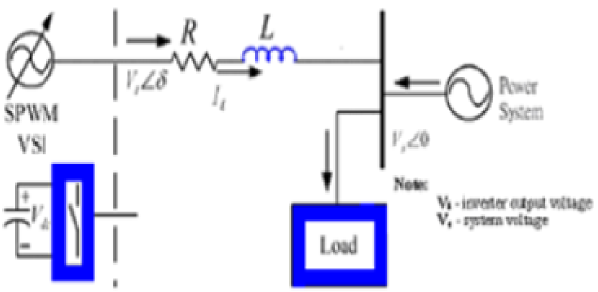
This capacitor could be charged by a battery source, or could be recharged by the converter itself. If the output voltage of the VSC is equal to the AC terminal voltage, no reactive power is delivered to the system. If the output voltage is greater than the AC terminal voltage, the DSTATCOM is in the capacitive mode of operation and vice versa. The quantity of reactive power flow is proportional to the difference in the two voltages. It is to be noted that voltage regulation at PCC and power factor correction cannot be achieved simultaneously. For a DSTATCOM used for voltage regulation at the PCC, the compensation should be such that the supply currents should lead the supply voltages; whereas, for power factor Correction, the supply current should be in phase with the supply voltages. The control strategies studied in this paper are applied with a view to studying the performance of a DSTATCOM for power factor correction and harmonic mitigation.

Basic Configuration and Operation of D-STATCOM

The D-STATCOM is a three-phase and shunt connected power electronics based device. It is connected near the load at the distribution systems. The major components of a DSTATCOM are shown in fig. It consists of a dc capacitor, three-phase inverter (IGBT, thyristor) module, ac filter, coupling transformer and a control strategy.

The basic electronic block of the D-STATCOM is the voltage-sourced inverter that converts an input dc voltage into a three-phase output voltage at fundamental frequency.



Basic building blocks of DSTATCOM

The D-STACOM employs an inverter to convert the DC link voltage *V*dcon the capacitor to a voltage source of adjustable 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. Fig.3.6 shows the inductance *L* and resistance *R* which represent the equivalent circuit elements of the stepdown transformer and the inverter will is the main component of the D-STATCOM. The voltage *Vi* is the effective output voltage of the D-STATCOM and δ is the power angle. The reactive power output of the D-STATCOM inductive or capacitive depending can be either on the operation mode of the DSTATCOM. The construction controller of the DSTATCOM is used to operate the inverter in such a way that the phase angle between the inverter voltage and the line voltage is dynamically 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 thyristorbased inverter, Vi, is controlled in the same way as the distribution system voltage, Vs.

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.

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. It also shows how the algorithm can be efficiently implemented in computing systems in which only local information can be transported through the network.

Differentiable activation functions the back propagation algorithm looks for the minimum of the error function in weight space using the method of gradient descent. 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 because the composite function produced by interconnected perceptron is discontinuous, and therefore the error function too. One of the more popular activation functions for backpropagation networks is the sigmoid, a real function sc: IR ! (0, 1) defined by the expression

$$s_c(x) = \frac{1}{1 + e^{-cx}}.$$

Stacked Multicell converter

A new Stacked Multicell (SM) converter based DSTATCOM for reactive power compensationand voltage sags and swells reduction and elimination in distribution system is proposed. The main properties of SM converter, which causes increase in the number of output voltage levels, are transformer-less operation and natural self-balancing of flying capacitors voltage and lower power rating and number of components. Indirect current control technique based on modified phase shifted sinusoidal PWM modulation method has been applied to DSTATCOM.

The Flying Capacitor Multicell (FCM) converter, and its derivatives have many attractive properties for medium voltage applications including, in particular, the advantage of transformer-less operation and the ability to naturally maintain the flying capacitors voltages at their target operating level. This important property is called natural self-balancing and allows the construction of such converters with a large number of voltage levels. Another alternative for multicell converters is the Stacked Multicell (SM) converter. The main future of this configuration is making possible to share the voltage constraint on several switches; so the voltage ratings of capacitors and the semiconductor losses are reduced. Also, the number of combinations to obtain a desired voltage level is increased (redundancy) in this topology.

The SM converter is based on a hybrid association of elementary commutation cells of FCM converter. This structure uses an *m* □□*n* array of cells that allow us to increase input voltage level compared with the imbricated cells converter, while decreasing the stored energy in the converter. In addition to transformerless operation and the natural selfbalancing ability of SM converter, increase (redundancy) in the number of combinations required to obtain a desired voltage level and reduction in the voltage ratings of capacitors and stored energy in the flying capacitors as well as the semiconductor losses are the other advantages of this converter.

Also, the number of flying capacitors is decreased in comparison with the equivalent FCM converter for the same number of output voltage levels while the number of semiconductors is the same since, the multicell converters are very interesting for high-power/medium-voltage applications and considerablyimprove the output voltage frequency spectrum, in this paper a SM converter based DSTATCOM has been proposed to improve the quality of DSTATCOM output voltage. In addition to transformer less operation and the natural self-balancing ability of SM converter, increase (redundancy) in the number of combinations required to obtain a desired voltage level and reduction in the voltage ratings of capacitors and stored energy in the flying capacitors as well as the semiconductor losses are the other advantages of this converter.

Also, the number of flying capacitors is decreased in comparison with the equivalent FCM converter for the same number of output voltage levels while the number of semiconductors is the same. Furthermore, in the proposed configuration, only two dc link is used for three phase full bridge SM converters. Therefore, the required dc capacitors for dc link are decreased from 6 to 2 and the output voltage levels and its RMS are doubled. As demonstrated in simulation results, the reactive power and voltage sag and swell compensation strategy and the applied detection and

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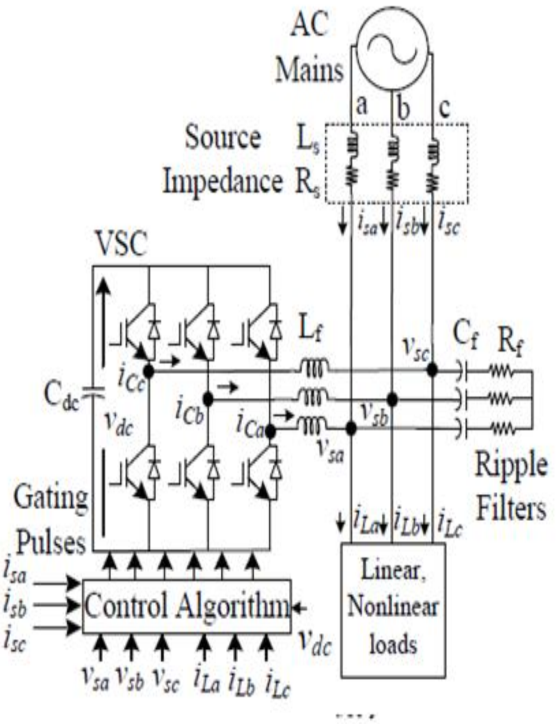
determination methods show desirable performance and good dynamic response time.

EXPERMENTAL RESULTS

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

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



Schematic diagram of VSC based DSTATCOM

$$I_{Lap}=w_0+ i_{La}u_{ap}+i_{Lb}u_{bp}+i_{Lc}u_{cp} \quad (1)$$
$$I_{Lbp}=w_0+i_{Lb}u_{bp}+i_{Lc}u_{cp}+i_{La}u_{ap} \quad (2)$$
$$I_{Lcp}=w_0+i_{Lc}u_{cp}+i_{La}u_{ap}+i_{Lb}u_{bp} \quad (3)$$

Where$w_o$is the selected value of initial weight and u_{ap}, u_{bp}, $u_{cp}$are in-phase unit-templates.In-phase unit-templates are estimated using sensed PCC phasevoltages (v_{sa}, v_{sb}, v_{sc}). It is the relation of phase voltage andamplitude of PCC voltage (v_t).

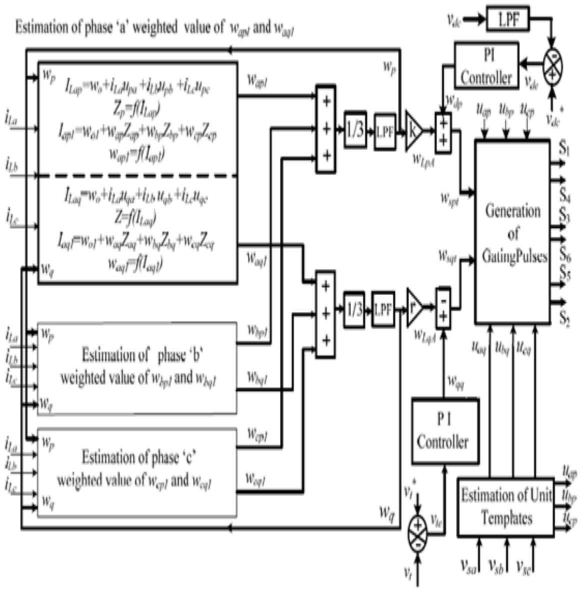


Fig.Estimation of reference currents using BP control algorithm

Extracted values of *ILap*, *ILbp* and *ILcp* are passed through sigmoid function as a activation function and output signals (*Zap*, *Zbp* and *Zcp*) of feed forward section are expressed as

$$Z_{ap}=f(I_{Lap})= 1/(1+e^{-I_{Lap}})$$
$$Z_{bp}=f(I_{Lbp})= 1/(1+e^{-I_{Lbp}})$$
$$Z_{cp}=f(I_{Lcp})= 1/(1+e^{-I_{Lcp}})$$

Estimated values of *Zap*, *Zbp* and *Zcp* are fed to hidden layer as input signals.Updated weight of phase 'a' active power current componentsof load current *'wap'* at n^{th} sampling instant is expressed as,

$$wap(n)=wp(n)+\mu\{wp(n)-wap1(n)\}\ f'(Iap1)\ zap(n)$$
$$wbp(n)=wp(n)+\mu\{wp(n)-wbp1(n)\}\ f'(Ibp1)\ zbp(n)$$
$$wcp(n)=wp(n)+\mu\{wp(n)-wcp1(n)\}\ f'(Icp1)\ zcp(n)$$

Similarly, for phase 'b' and phase 'c', updated weighted value of active power current components of load current are expressed as,

$$wbp(n)=wp(n)+\mu\{wp(n)-wbp1(n)\}\ f'(Ibp1)\ zbp(n)$$
$$wcp(n)=wp(n)+\mu\{wp(n)-wcp1(n)\}\ f'(Icp1)\ zcp(n)$$

Performance of DSTATCOM inPFC Mode

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The dynamic performance of a VSC based DSTATCOM is studied for PFC mode at nonlinear loads. The performance indices are as phase voltages at PCC (*vs)*, balanced source currents (*is*), load currents (*iLa, iLb, iLc*), compensator currents (*iCa, iCb, iCc*), and dc bus voltage (*vdc*) which are shown in Fig under varying loads (at t=3.7 s to 3.8 s) conditions. The waveforms of phase 'a' voltage at PCC (*vsa*), source current (*isa*) and load current (*iLa*) are shown in Figs.4 (a-c) respectively. Total harmonic distortion (THD) of the phase 'a' at PCC voltage, source current, load current are found 2.86%, 2.94% and 24.82% respectively. It is observed that the DSTATCOM is able to perform the functions of load balancing and harmonic elimination with high precision.

Performance of DSTATCOM in ZVR Mode

In ZVR mode, the amplitude of PCC voltage is regulated to the reference amplitude by injecting extra leading reactive power components. The dynamic performance of DSTATCOM in terms of PCC phase voltages (*vs*), balanced source currents (*is*), load currents (*iLa,iLb,iLc*), compensator currents (*iCa,iCb,iCc*), amplitude of voltages at PCC (*vt*) and dc bus voltage (*vdc*) waveforms are shown under unbalanced load at time(t) =3.7s to 3.8s duration.

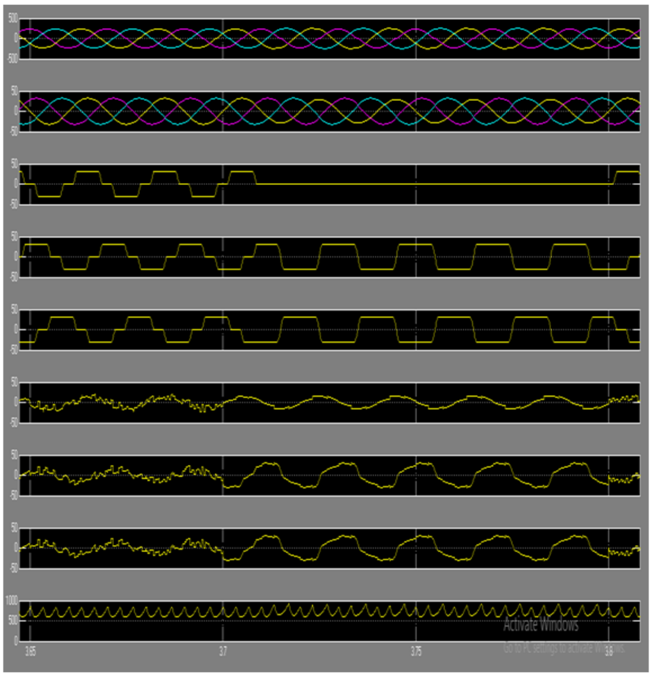
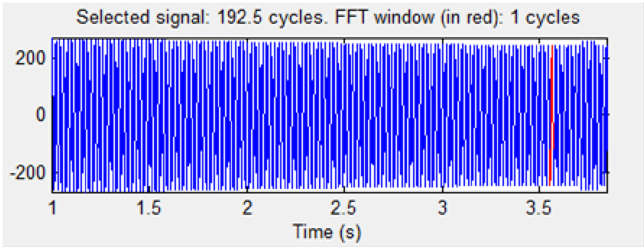
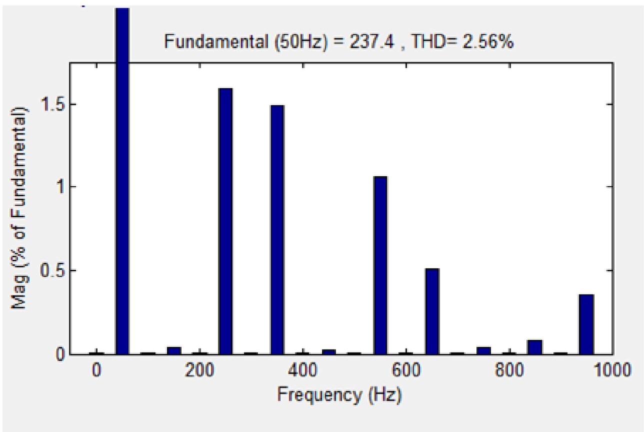
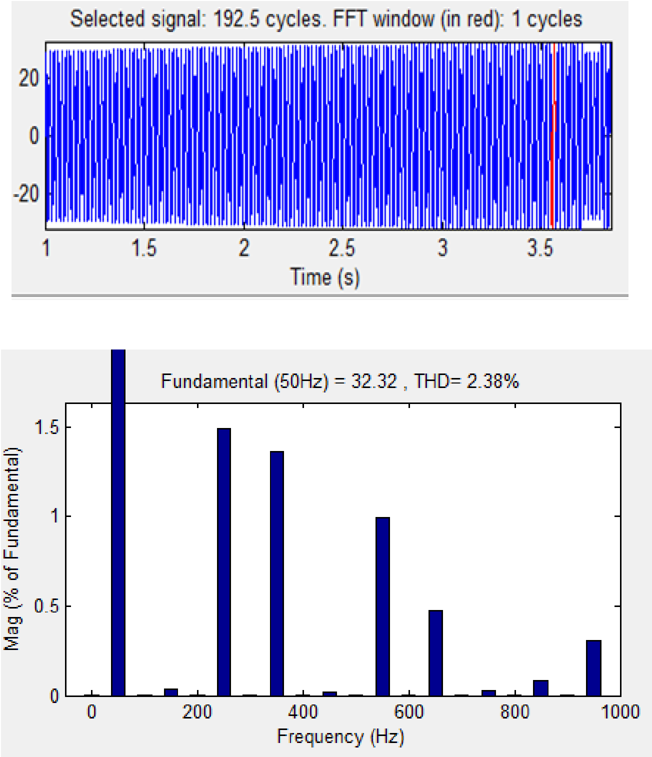


Fig. Dynamic performance of DSTATCM under varying nonlinear loads in PFC mode.

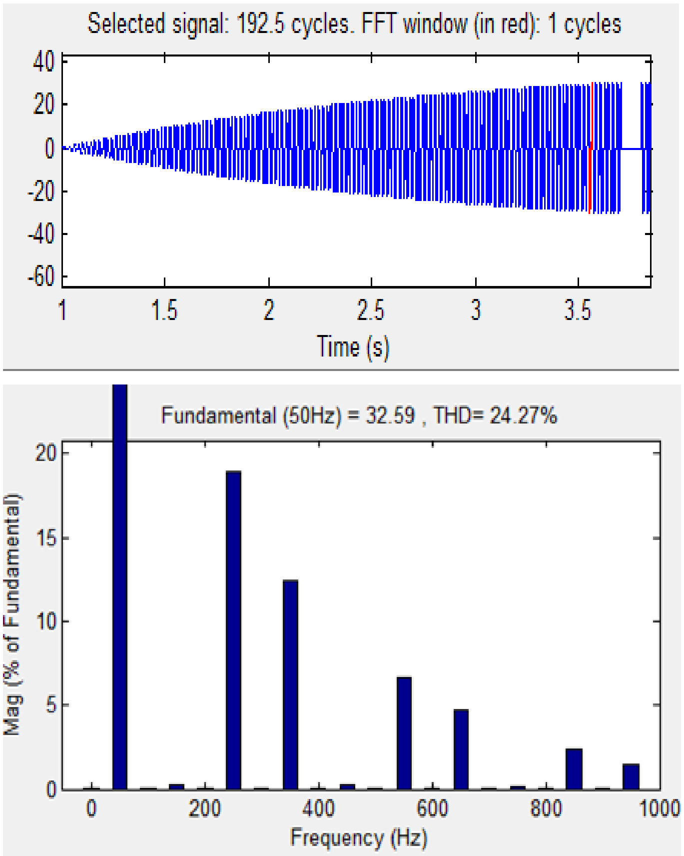




Wave forms & harmonic spectra of (a)PCC voltage of phase'a'



(b)source current of phase'a'



(c) Load current of phase 'a' in pfc mode

Harmonic spectra of phase 'a' voltage at PCC (*vsa*), source current (*isa*) and load current (*iLa*) are shown in Figs4.7.(a-c). 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 shows the summarized simulation results.

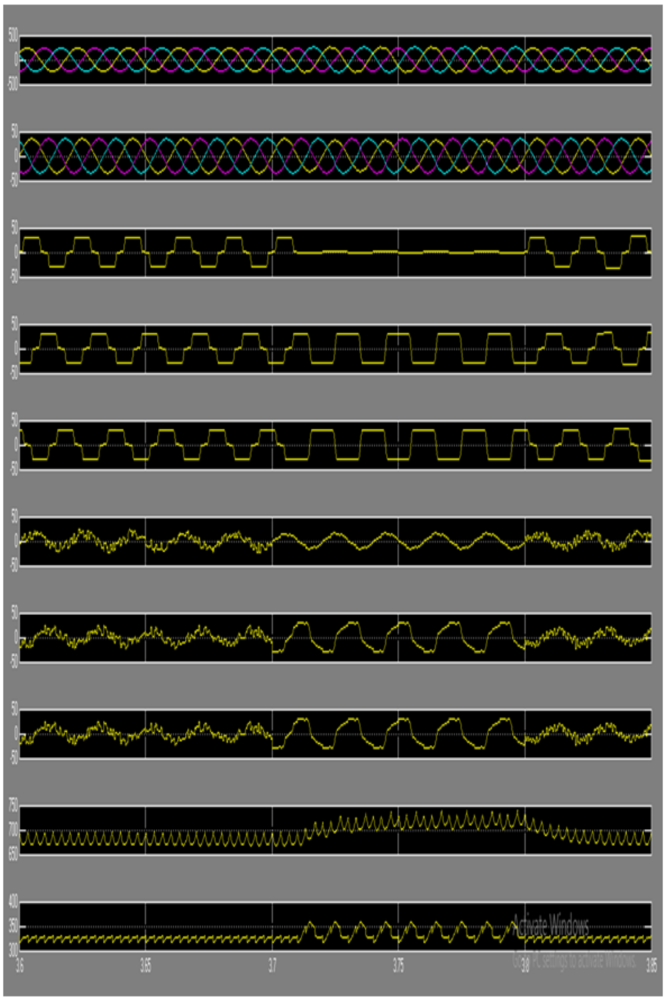
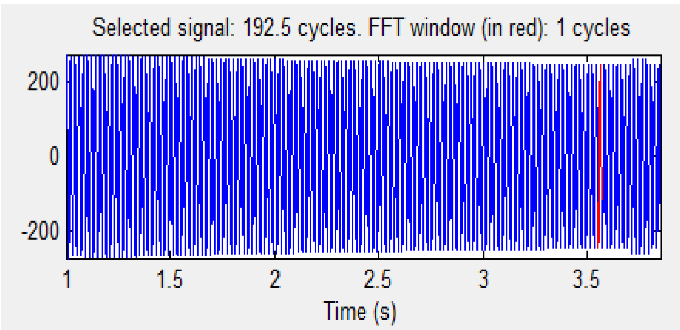


Fig: output results & dynamic performance of DSTATCOM under varying nonlinear in ZVR mode.



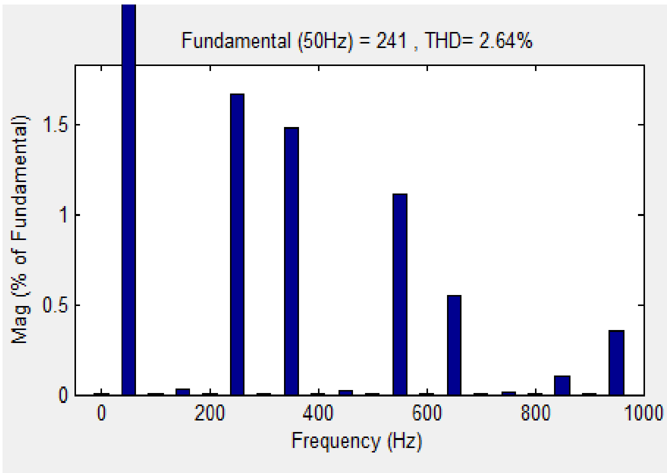
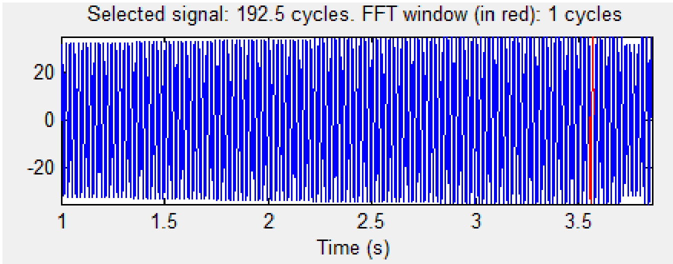
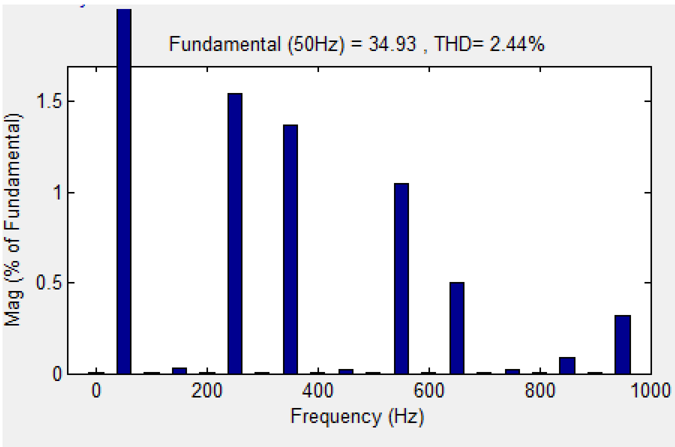
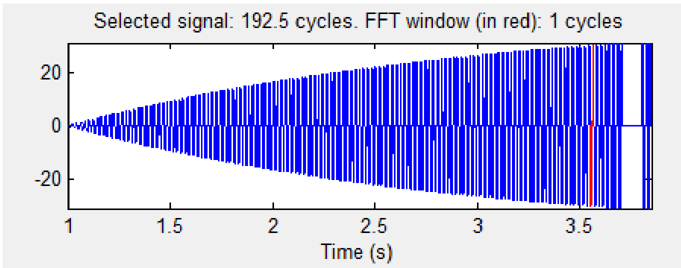


Fig: wave forms & harmonic spectra of (a) pcc voltage of phase 'a'





(b) Source current of phase'a'



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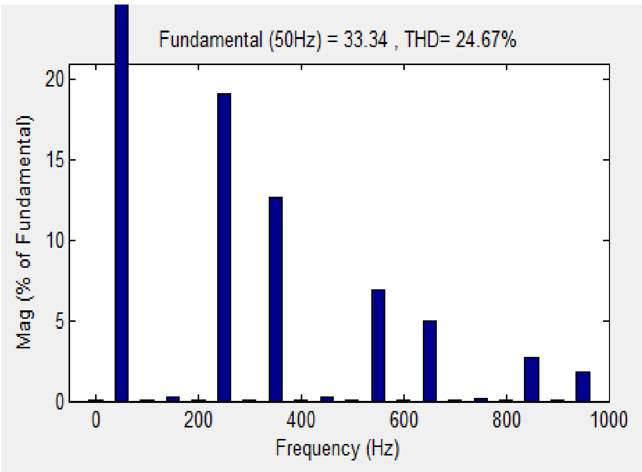


(c) Load current of phase 'a' in ZVR mode.

Extention Based On Adaptive Neuro Fuzzy

Fuzzy logic is a multi-valuedlogic whereas classical logic (prepositional / predicate) is a two valued logic denoting truth and falsity of a statement. •Membership grade in fuzzy set can be interpreted as truth value of the proposition "x is a member of set"•Ultimate goal of fuzzy logic is to provide foundations for approximatereasoning with imprecise propositions using fuzzy set theory as the principle tool.

Fuzzy reasoning is neither exact nor absolutely inexact but only to certain degree of exact or inexact.•Primary focus of Fuzzy logic is on natural language where approximate reasoning with imprecise propositions are rather typical.•Fuzzy logic allows the use of fuzzy predicates such as {old, expensive, young rare, rich, dangerous etc.}Fuzzy quantifiers {many, few, almost all, usually, several, frequently, seldom} Fuzzy truth values {quite true, very true, more or less, fairly true, true, mostly} Fuzzy modifiers {likely, almost impossible extremely unlikely etc.}

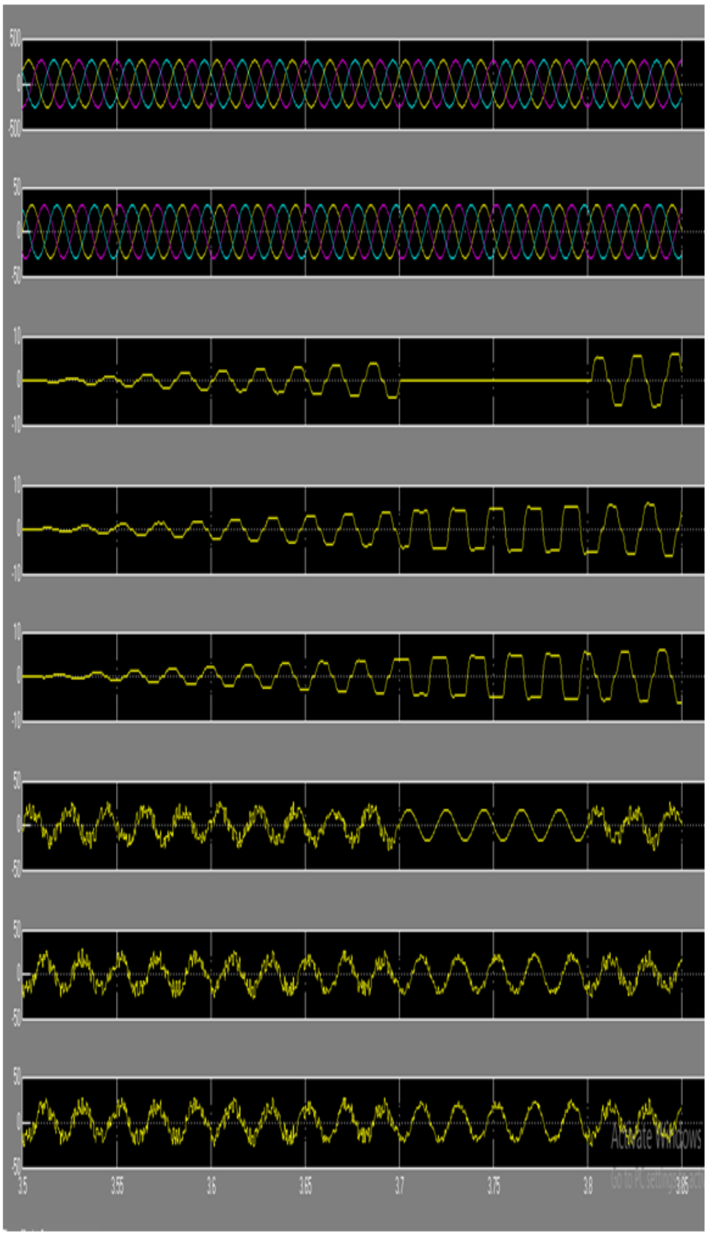
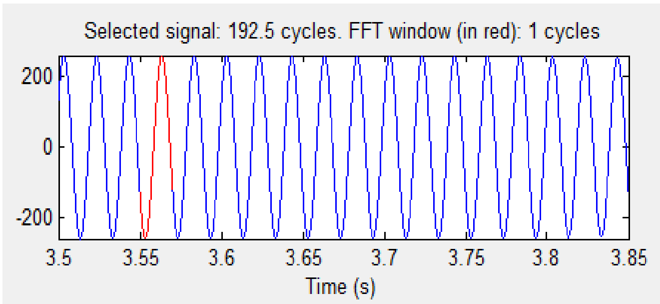


Fig: simulation results for PFC mode.



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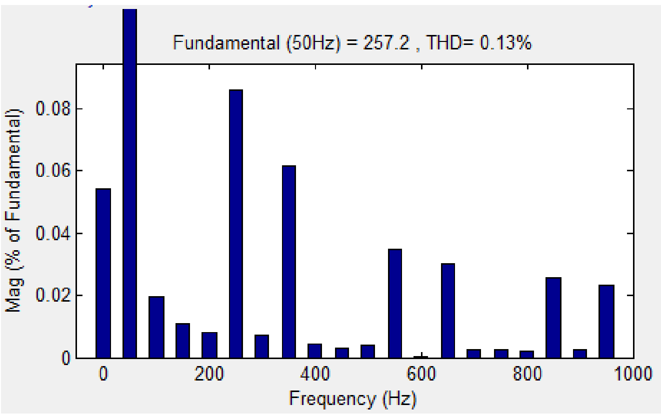
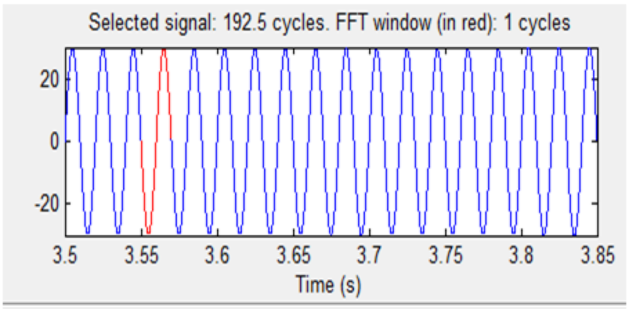


Fig :(a) PCC voltage of phase 'a'



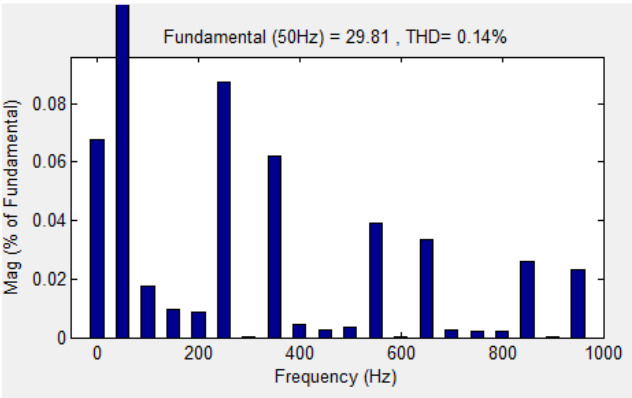
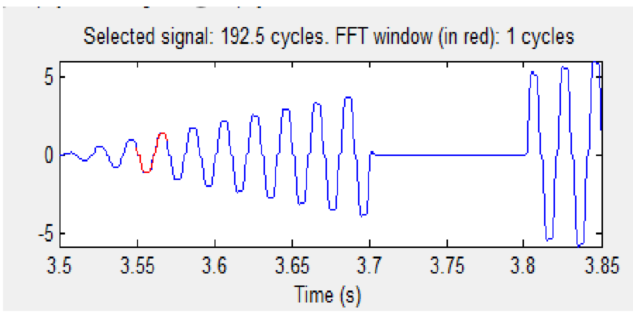


Fig:(b) source current of phase 'a'



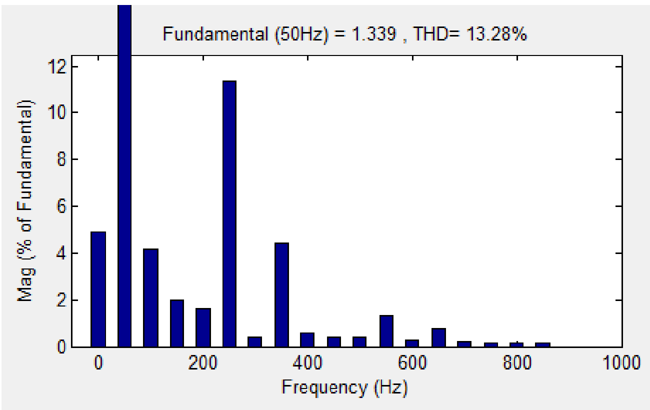


Fig : (c) load current of phase 'a'

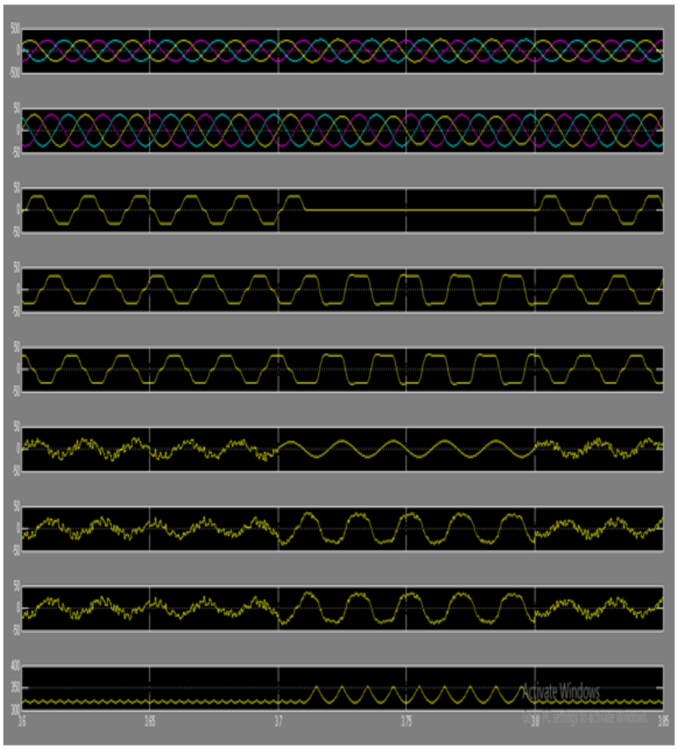
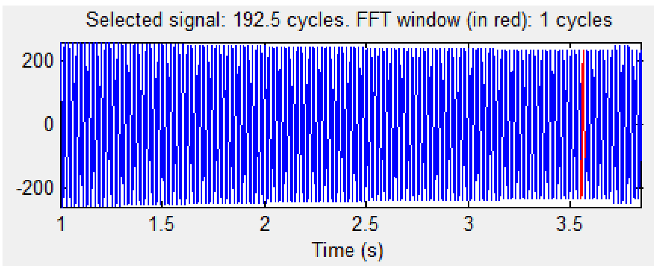


Fig : simulation results during zvr mode



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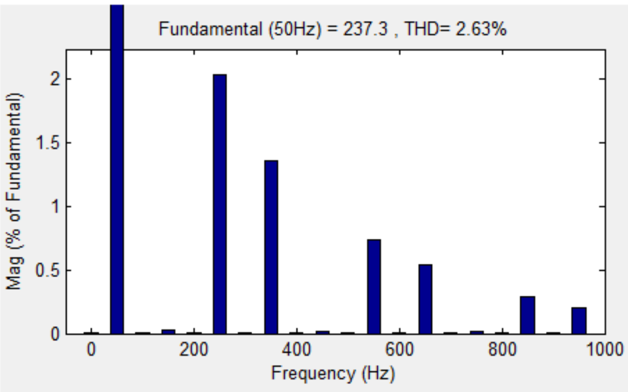


Fig : (a) pcc voltage of phase'a'

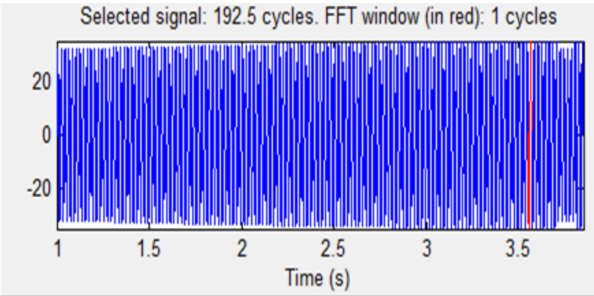


Table1:PERFORMANCE OF DSTATCOM

TOTAL HARMONIC DISTORTATION PARAMETERS	ZVR OPERATING MODE		PFC OPERATING MODE	
	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

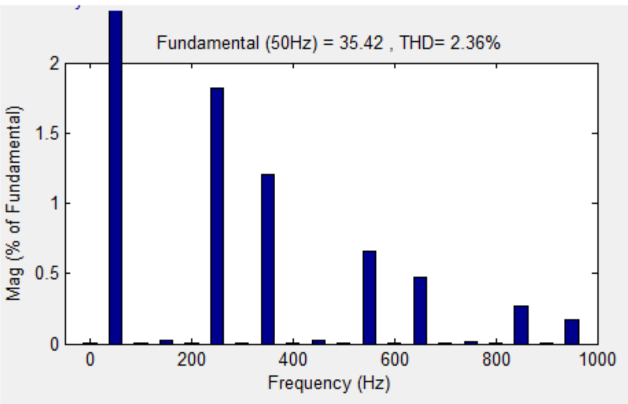
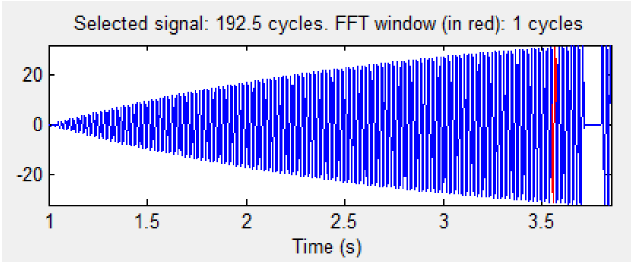


Fig (b) source current of phase'a'



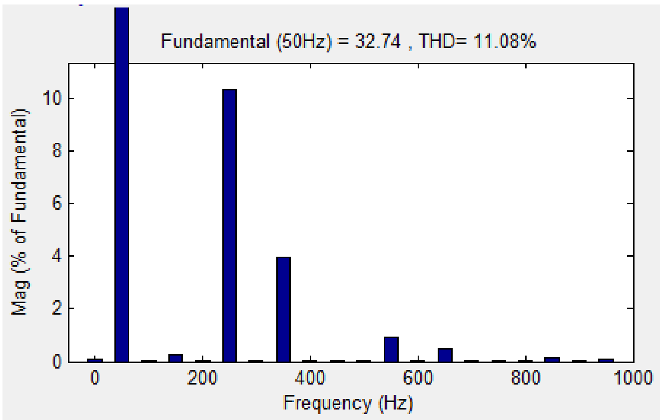


Fig (c) Load current of phase'a'

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 operatingconditions. The performance of ANFIS is foundsatisfactory with proposed control algorithm for various types ofloads. 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 dynamicconditions. 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.

FUTURE SCOPE:

We had performed functions such as harmonic elimination, load balancing and reactive power compensation for power factor correction (PFC) and zero voltage regulation(ZVR).Using Back Propagation control algorithm.It may be performed through Recursive least mean square method and Quantitative feedback theory.

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