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Back – Propagation Control Algorithm for Power Quality Improvement using DSTATCOM

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Abstract:-This paper proposes development fuzzy logic control of DSTATCOM for improvement of power quality. The nonlinear loads make voltage to be deviated and current to be distorted from its sinusoidal waveform quality. Thus load balancing, harmonics elimination and voltage regulation is a heavy task that has to be accomplished to maintain quality of the power. The performance of any device depends on control algorithm used for the reference current estimation and gating pulse generation scheme. Thus the fuzzy logic control based Back Propagation (BP) algorithm has been proposed to generate the triggering pulses for the three phase H bridge inverter (DSTATCOM). These schemes are simulated under MATLAB environment using SIMULINK.

Keywords:-Back Propagation (BP) Control Algorithm, Harmonics, Load Balancing, Power Quality, Fuzzy Logic Control.

I. INTRODUCTION

Power quality in distribution system affects all electrical and electronic equipment that are connected to it. In recent years the use of power converters in power supplies, adjustable speed drives, is continuously increasing. This equipments draw harmonic currents from AC mains and increases the supply demands. The classification of loads includes linear (lag power factor loads), nonlinear (current or voltage source type of harmonics generating loads), mixed and unbalance types of loads. The power quality problems associated with these loads includes voltage variation harmonics, high reactive power burden,load unbalancing,. To overcome those limitations Back Propagation (BP) and improved linear sinusoidal tracer algorithm (ILST) have been proposed in this paper to achieve harmonic compensation. An improved Back Propagation and linear sinusoidal tracer control algorithm is implemented on a DSTATCOM for the extraction of load currents fundamental components in three phase consume loads. Internal parameters of this algorithm have clear physical understanding and easily adjustable to optimal value, which show simplicity of the algorithm. Time and frequency domain characteristics of the ILSTare Not affected due to external environment changes. Speed and detection accuracy of dynamic response can be tuned after adjusting the algorithm internal parameters.

In this algorithm, extracted reference source currents exactly follow the actual source currents during steady-state as well as dynamic conditions. For this reason, three-phase source currents have smooth variation during load perturbations. This algorithm is implemented on the DSTATCOM for compensation of nonlinear and linear loads. In this paper, a back-propagation (BP) algorithm is implemented in 3-phase shunt connected custom power device known as DSTATCOM for extraction of the weighted value of the load reactive power and active power current components in nonlinear loads. The proposed control algorithm is used for load balancing and harmonics suppression with DC voltage regulation of DSTATCOM. In this BP algorithm, training of the weights has three stages. It includes feed forward of input signal training, calculation and back propagation of error signals and upgrading of the training weights. It may have one or more layers. Continuity, non-decreasing monotony, differentiability are the main characteristics of this algorithm. It is based on mathematical formula and does not need any special features of function in the learning process. It also has smooth variation on the weight correction due to batch updating features on the weights. In this training process, it is slow because of more number of learning steps but after training of weights, this algorithm gives very fast trained output response. In this application, proposed control algorithm on a DSTATCOM is implemented for the compensation of the nonlinear loads.

II. SYSTEM CONFIGURATION

A D-STATCOM is a 3-phase, shunt connected power electronic device. It is connected at the load at distribution systems. The major components of DSTATCOM are shown in Fig 1. It consists of a dc capacitor, three-phase converter module, ac filter, coupling transformer and a control strategy. The basic electronic block of the DSTATCOM is the voltage sourced converter that converts an input dc voltage into a three phase output voltage at fundamental frequency. The controller of the D- STATCOM was used to operate inverter in a way that phase angle between the inverter voltage and line voltage was dynamically adjusted so that DSTATCOM generates or absorbs the desired VAR at point of connection.

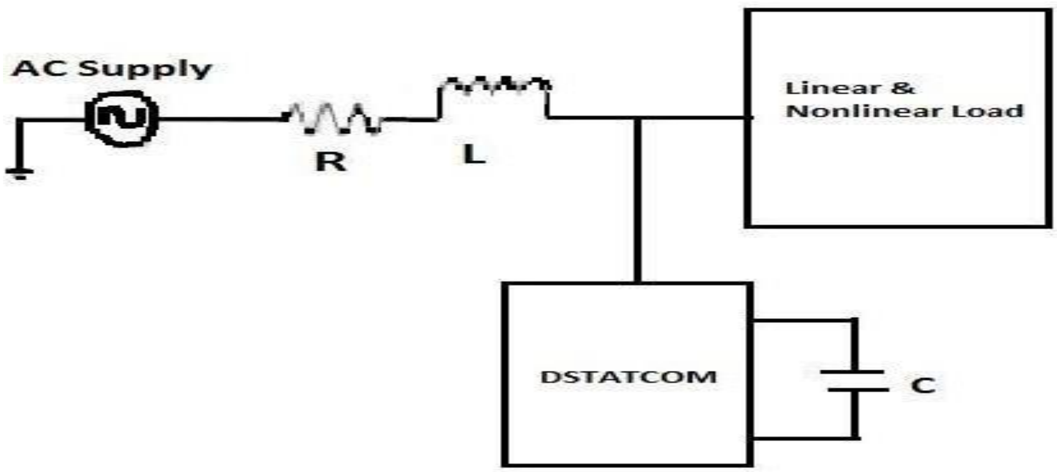

Fig.1. Basic Building Blocks of DSTATCOM.

III. SYSTEM CONFIGURATION AND CONTROL ALGORITHM

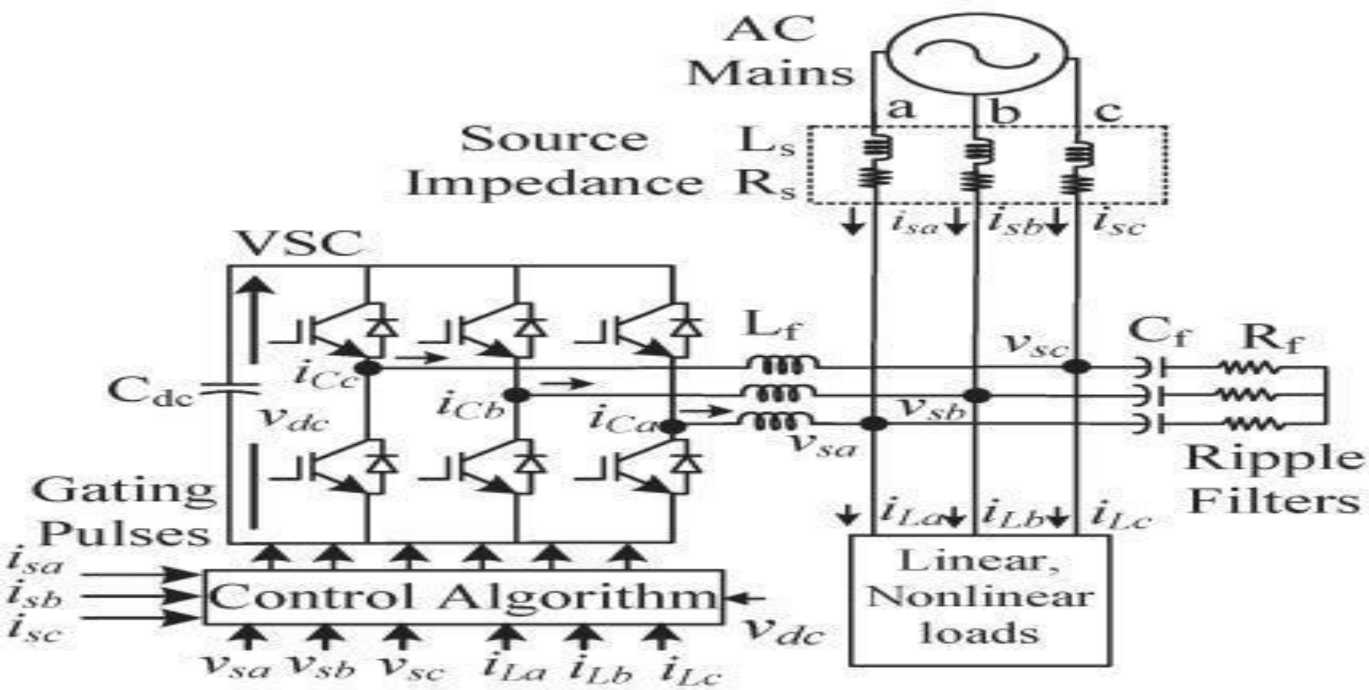

Fig.2. Schematic Diagram of VSC-Based DSTATCOM.

A voltage source converter (VSC)-based DSTATCOM is connected to a 3-phase AC mains feeding 3-phase linear or nonlinear loads with internal grid impedance which is shown in Fig.2. The performance of DSTATCOM depends on accuracy of harmonic current detection. To reduce ripple in compensating currents, tuned values of interfacing inductors (L_f) are connected to the ac output of the VSC. A 3-phase series combination of capacitor (C_f) ,a resistor (R_f) represents shunt passive ripple filter which is connected at the point of common coupling (PCC) for reducing high frequency switching noise of VSC. DSTATCOM currents (iCabc) are injected as required compensating currents to cancel reactive power components and harmonics of load currents so that load due to reactive power component or harmonics is reduced on distribution systems.

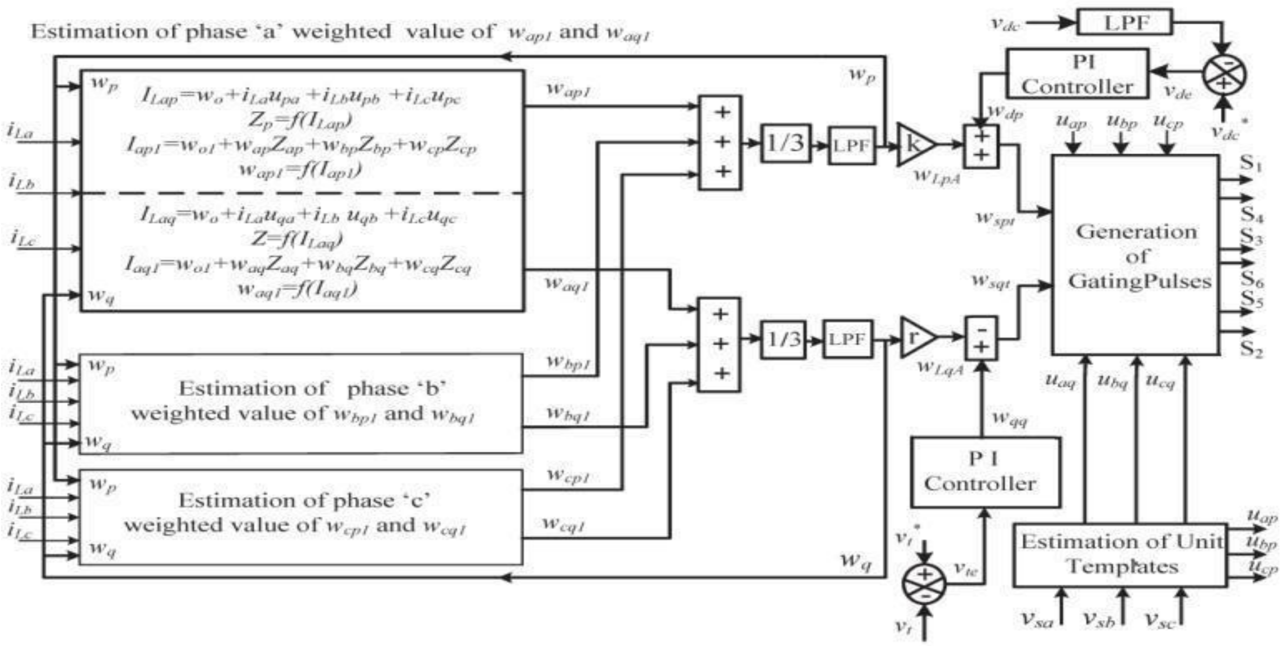

Fig.3. Estimation of Reference Currents using BP Control Algorithm.

Fig3 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. The application of the algorithm for estimation of various control parameters is given below.

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

A BP training algorithm is used to calculate 3-phase weighted values of load active power current components (wap, wbp, and wcp) ,reactive power current components (waq, wbq, and wcq) from polluted load currents using feed forward and supervised principle. In this calculation, input layer for 3 phases (a, b, and c) can be 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 wois selected value of the initial weight and u_{ap}, u_{bp}, and u_{cp} are in-phase unit templates.

In-phase unit templates are calculated using sensed PCC phase voltages (v_{sa}, v_{sb}, and v_{sc}). It is the relation of phase voltage and amplitude of the PCC voltage (vt). The amplitude of sensed PCC voltages calculated as follows

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

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

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

The values of ILap, ILbp, and ILcp 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

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

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

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

Three estimated values of Zap, Zbp, and Zcp are fed to a hidden layeras 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 wo1,wap,wbp,and wcp are selected value so finitial weight in the hidden layer and the updated values of 3-phase weights using the average weighted value (wp) of the active power current component as a feedback signal.

The updated weight of phase "a" active power current components of load current "wap" 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 wp(n) and $w_{ap}(n)$ are average weighted values of active power component of load currents and the updated weighted value of phase "a" at the nth sampling instant, respectively and $w_{ap1}(n)$ and $z_{ap}(n)$ are the phase "a" fundamental weighted amplitudes of active power component of load current, output of feed forward section of the algorithm at the nth instant. Thef(Iap1) ,µ are expressed as derivative of I_{ap1} component, learning rate, respectively.

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

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

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

The values of I_{ap1}, I_{bp1}, and I_{cp1} are passed through a sigmoid function as an activation function to calculate fundamental active components in terms of 3-phase weights w_{ap1}, w_{bp1}, and w_{cp1} as follows:

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

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

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

Average weighted amplitude of fundamental active power component (wp) is calculated using amplitude sum of 3-phase load active power components (wap1, wbp1,and wcp1) divided by 3. It is required to realise load balancing features of a DSTATCOM. It is expressed as

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

First-order low-pass filter is used to separate low frequency components. The "k" denotes the scaled factor of extra cted active power components of current in algorithm which is shown in Fig. 3. After separating low frequency components, scaling to actual value as the output of activation function is between 0 to 1, it is represented as WLpA. Similarly, weight ed amplitudes of reactive power components of load currents(waq, wbq, and wcq) of fundamental load current are calculated as:

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

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

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

Where $w_o$is the selected value of 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

$$u_{aq} = \frac{(-u_{bp} + u_{cp})}{\sqrt{3}}, \quad u_{bq} = \frac{(3u_{ap} + u_{bp} - u_{cp})}{2\sqrt{3}}$$
$$u_{cq} = \frac{(-3u_{ap} + u_{bp} - u_{cp})}{2\sqrt{3}}. \quad (22)$$

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 Zaq, Zbq, and Zcq

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

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

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

The values of Zaq, Zbq, and Zcq fed into hidden layer as input signals. 3-phase output oflayer (Iaq1,Ibq1,and Icq1)before the activation functions represented as

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

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

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

Wherew_{o1}, w_{aq}, w_{bq}, and $w_{cq}$are selected values of the initial weight in hidden layer, updated 3 weights using average weighted value of reactive power components of currents (wq) as feedback signal.

Updated weight phase "a" reactive power components of the load currents "w_{aq}" at nth sampling instant is denoted as

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

wq(n) and waq(n) are the average weighted value of the reactive power components of load currents and updated weight in nth sampling instant and waq1(n)and zaq (n) are the phase "a" weighted amplitude of the reactive power current component of load currents, output of the feed forward section of algorithm at nth instant. f(Iaq1),µ are presented derivative of Iaq1 components and learning rate.

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

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

The extracted values of I_{aq1}, I_{bq1}, and I_{cq1} are passed through an activation function to the estimation of the

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fundamental reactive component in terms of three phase weights $w_{aq}1$, $w_{bq}1$,and $w_{cq}1$ as

$$w_{aq1} = f(I_{aq1}) = 1/(1+e^{-Iaq1}) \quad (31)$$

$$w_{bq1} = f(I_{bq1}) = 1/(1+e^{-Ibq1}) \quad (32)$$

$$w_{cq1} = f(I_{cq1}) = 1/(1+e^{-Icq1}) \quad (33)$$

The average weight of amplitudes of the fundamental reactive power current components (wq) is calculated using the amplitude sum of the 3-phase load reactive power components of the load current (w_{aq1}, w_{bq1}, and w_{cq1}) divided by three and mathematically, it is represented as

$$w_q = (w_{aq1} + w_{bq1} + w_{cq1})/3. \quad (34)$$

First-order low-pass filters used to separate low frequency component. "r" denotes the scaled factor of extracted reactive power components in algorithm which is shown in Fig.3. After separating low-frequency components and scaling to actual value because output of activation function is between 0and1,itis represented as w_{LqA}.

IV. FUZZY LOGICCONTROL

Fuzzy set theory widely used in the control area with application to power system[5]. A fuzzy logic control is built up by group of rules based on human knowledge of system behavior. Matlab or Simulink simulation model is built to study dynamic behavior of converter as shown in Fig.4. Further, design of fuzzy logic controller can provide desirable small and large signal dynamic performance at same time, which is not possible with linear control technique. Thus, fuzzy logic controller has potential ability to improve robustness of compensator.

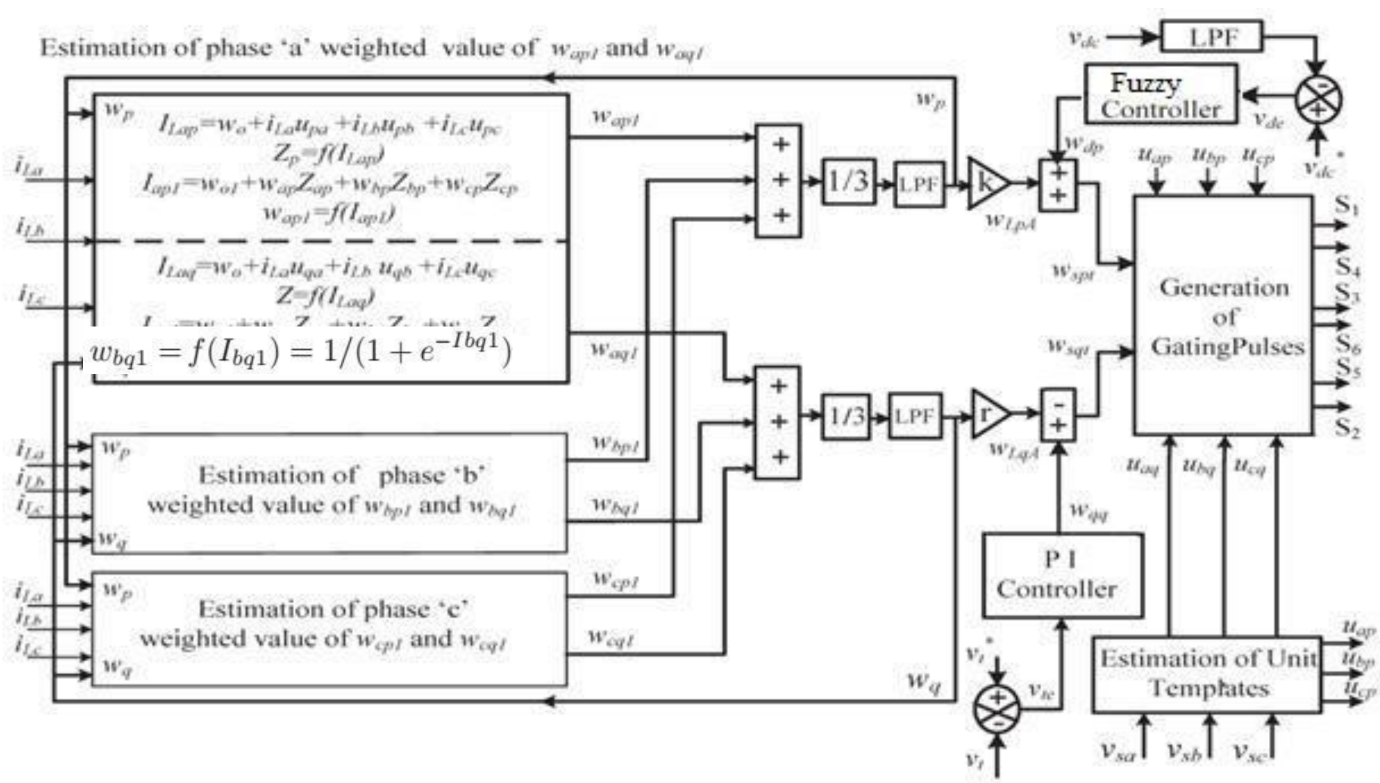

Fig. 4.Estimation of Reference Currents using BP Control Algorithm with the Fuzzy Logic Control.

Basic scheme of fuzzy logic controller is showed in Fig.5 and has 4 principal components such as: fuzzyfication interface, that converts input data to suitable linguistic value; the knowledge base, that consists of a data base with necessary linguistic definitions and control rule set; the decision making logic which simulating a human decision process, infer fuzzy control action from knowledge of control rules and linguistic variable definitions; a de-fuzzification interface that yields non fuzzy control action from a inferred fuzzy control action[10].

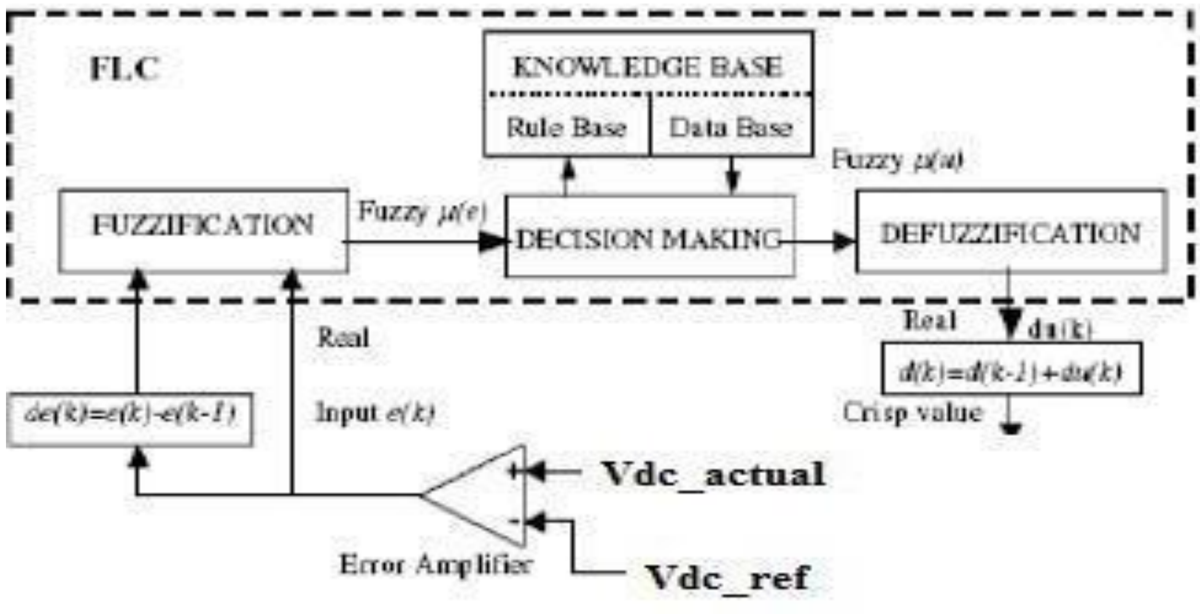

Fig.5. Block Diagram of Fuzzy Logic Controller(FLC) for proposed converter.

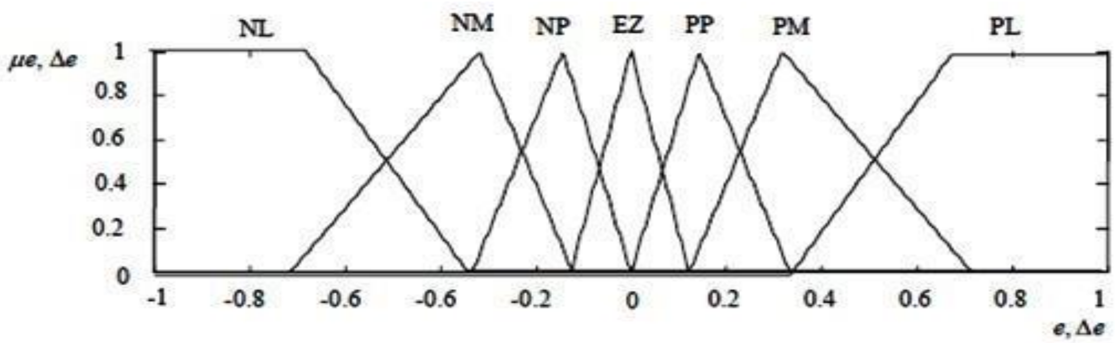

Fig.6. Membership functions for Input, Change in input, Output.

Rule Base: the elements of this rule base table are determined based on the theory that in the transient state, large errors need coarse control, which requires coarse in- put/output variables; in the steady state, small errors need fine control, which requires fine input/output variables as shown in Fig.6. Based on this the elements of the rule table are obtained as shown in Table, with „Vdc" and „Vdc-ref" as inputs.

e / Δe	NL	NM	NS	EZ	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	EZ
NM	NL	NL	NL	NM	NS	EZ	PS
NS	NL	NL	NM	NS	EZ	PS	PM
EZ	NL	NM	NS	EZ	PS	PM	PL
PS	NM	NS	EZ	PS	PM	PL	PL
PM	NS	EZ	PS	PM	PL	PL	PL
PL	NL	NM	NS	EZ	PS	PM	PL

Table 1: Fuzzy Rules Table

V. MATLAB/SIMULINK RESULTS

Simulation results of this Paper is as shown in bellow Figs.7 to 15.

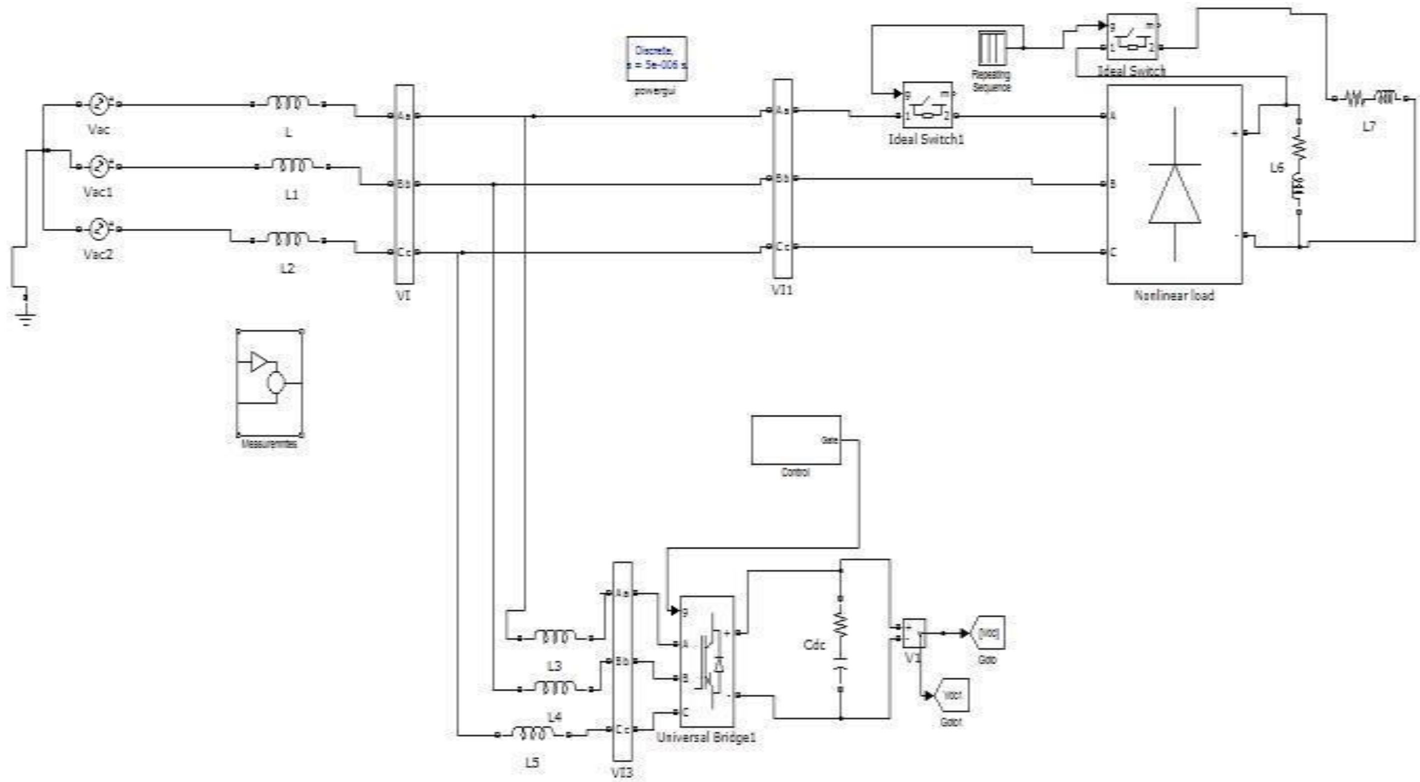

Fig.7.Matlab or Simulink Model Diagram of VSC-Based DSTATCOM.

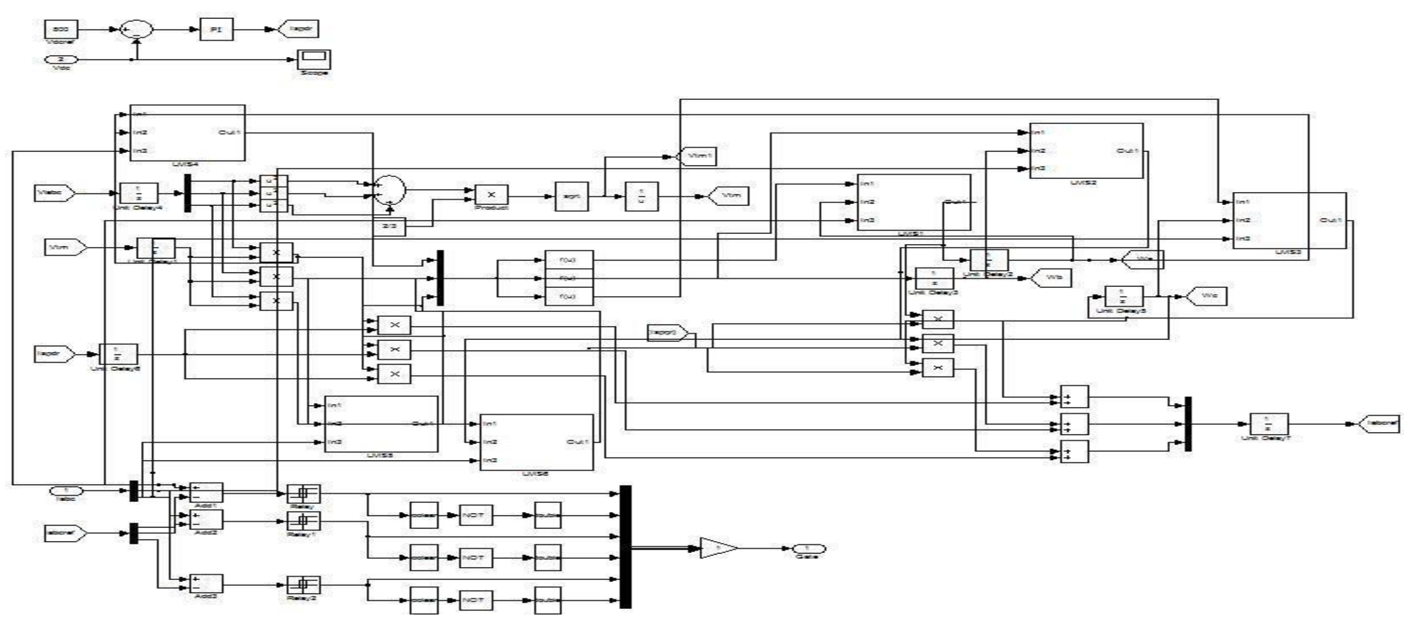

Fig.8. PI Control of Diagram of VSC-Based DSTATCOM.

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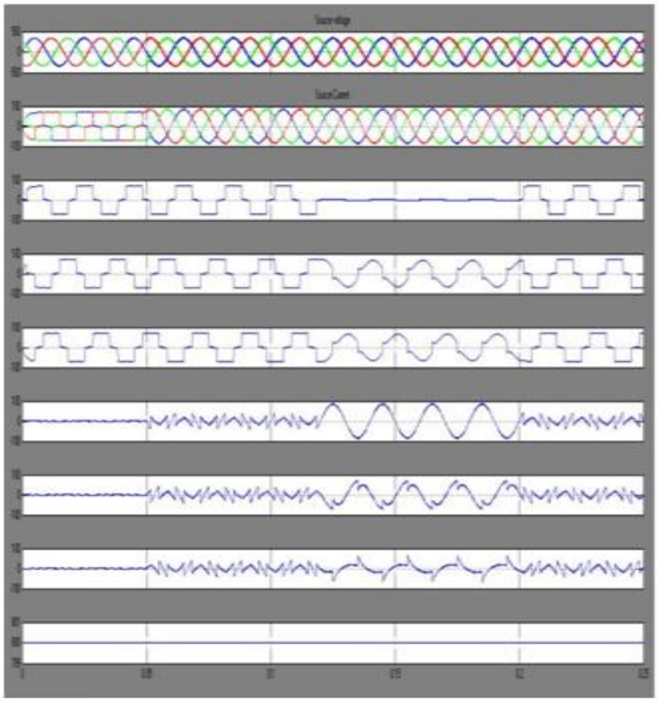

Fig. 9.This wave form shows Vs,Is,iLa,iLb,iLc,iCa,iCb,iCc and Vdc respectively under Dynamic performance of DSTATCOM under varying nonlinear loadsin PFC mode.

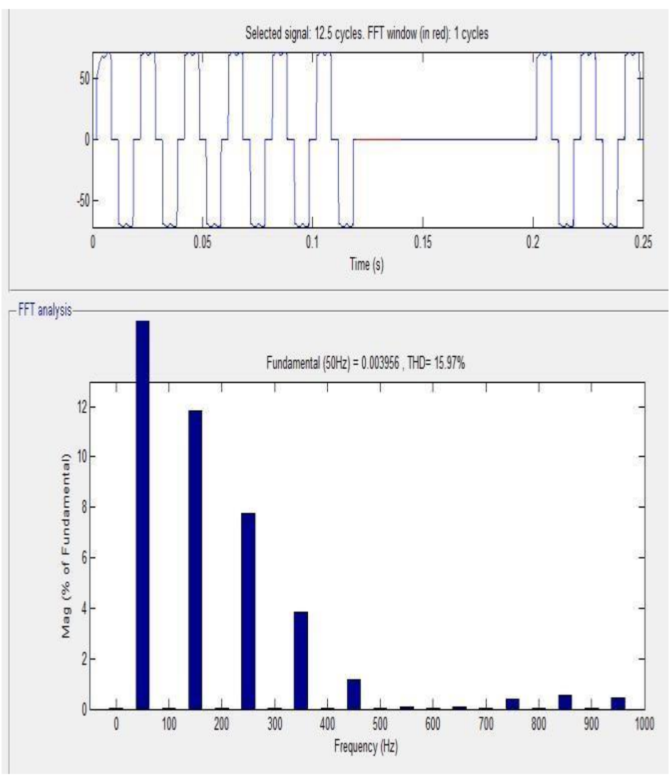

Fig.10. Waveforms and Harmonic Spectra of Load Current of phase "a" in PFC mode with PI controller.

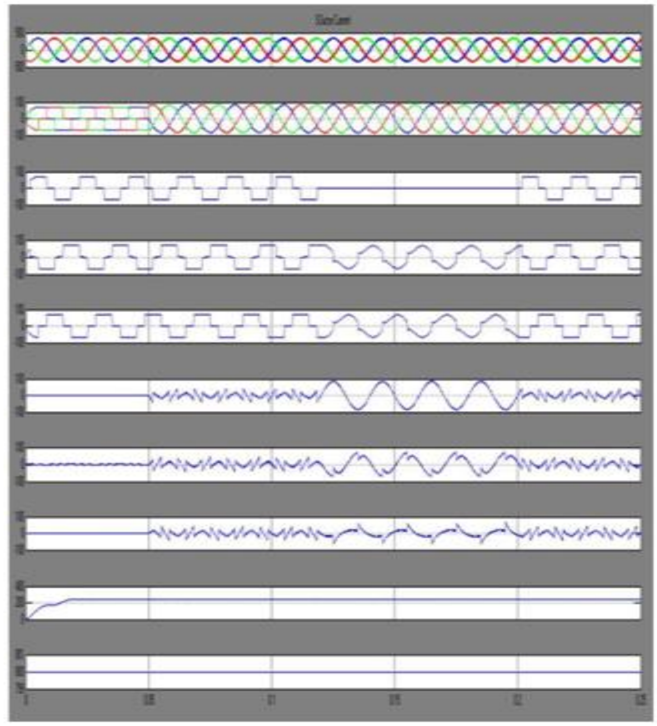

Fig. 11.This wave form shows Vs,Is,iLa,iLb,iLc,iCa,iCb,iCc ,Vt and Vdc respectively under Dynamic performance of DSTATCOM under varying nonlinear loads in ZVRmode.

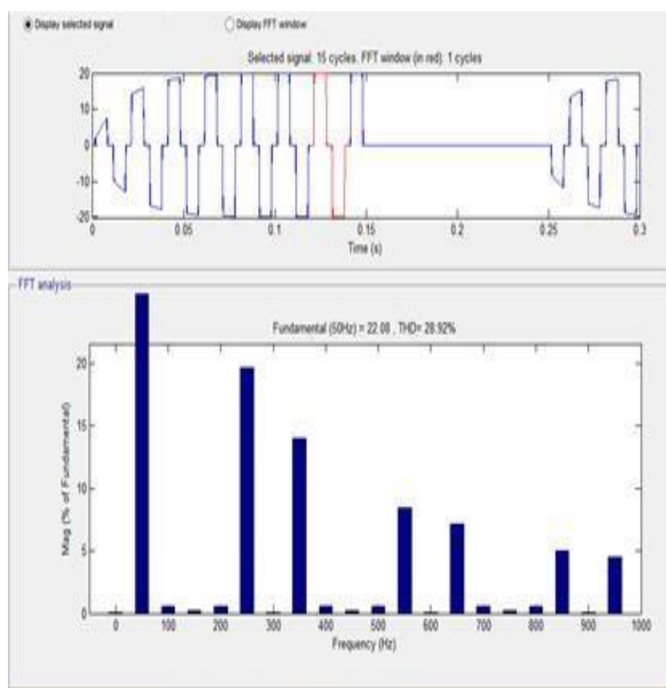

Fig.12.Waveforms and harmonic spectra of load current of phase "a" in ZVR mode with PI controller.

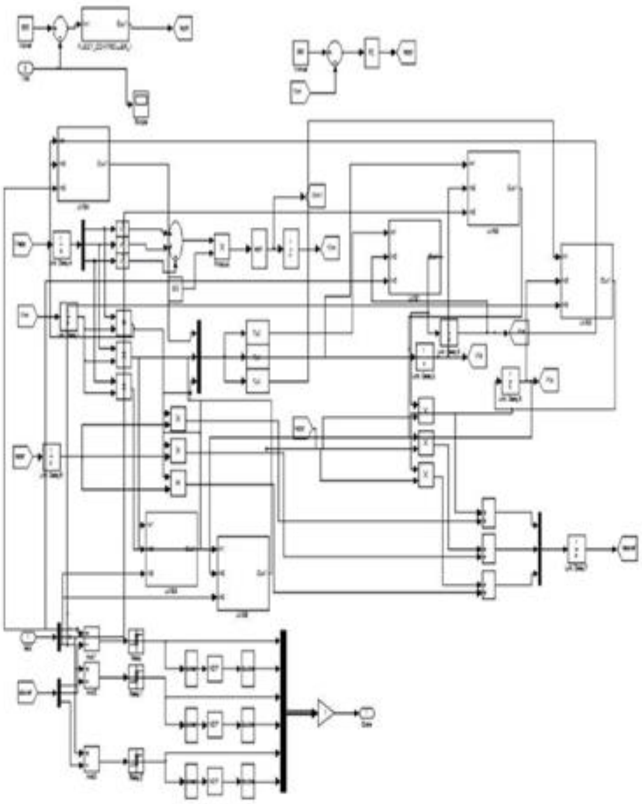

Fig.13. Fuzzy Logic Control of Diagram of VSC-based DSTATCOM.

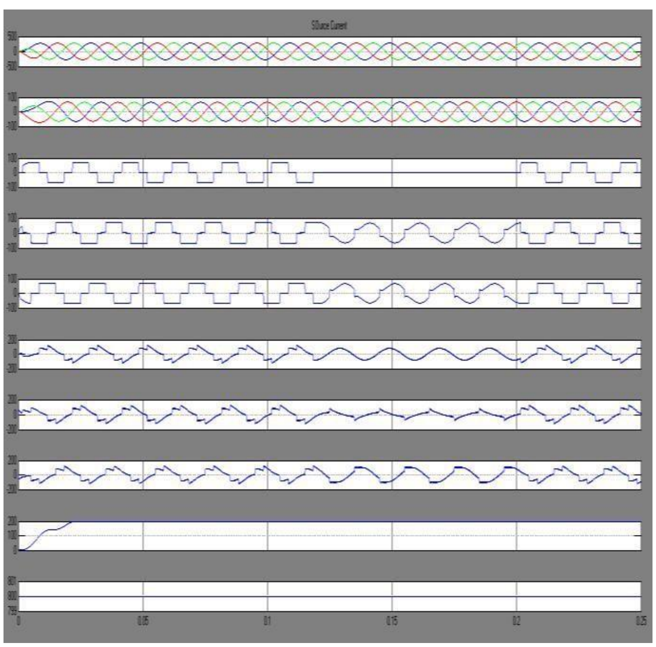

Fig.14.This wave form shows Vs, Is, iLa, iLb, iLc, iCa, iCb, iCc,Vtand Vdc respectively under Dynamic performance of DSTATCOM under varying nonlinear loads in PFC mode with fuzzy logic controller.

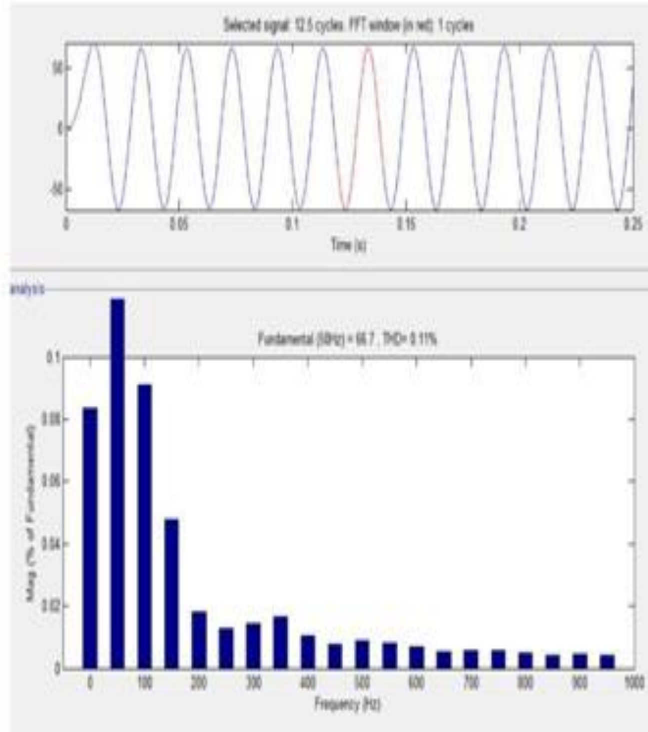

Fig.15. Waveforms and Harmonic Spectra of Load Current of phase “a” in non linear mode with fuzzy logic controller.

VI. CONCLUSION

The DSTATCOM which is based on VSC has been the most preferred solution for improvement of power quality as PFC and to maintain rated PCC voltage. The 3-phase DSTATCOM has been used for the compensation of non-linear loads which uses BPT control algorithm to verify its efficiency and effectiveness. The BPT control algorithm which is proposed has been used for extraction of reference source currents to generate switching pulses for IGBT’s of the VSC of DSTATCOM. Several functions of DSTATCOM like elimination of harmonics and load balancing have been demonstrated in ZVR and PFC modes with DC voltage regulation of DSTATCOM is also regulated to rated value without any undershoot or overshoot during variation of load. The disadvantage of this algorithm is large training time in application of complex system and selection of no.of hidden layer in system. The proposed BPT algorithm has been used for extraction of reference source currents to generate the switching pulses for IGBT’s of the VSC of DSTATCOM by introducing fuzzy controller THD reduced and better performance is obtained.

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