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Improved Power Quality by Using Fuzzy Logic Controller Based D-Statcom in Distribution System

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Abstract: *Power Quality pollution at the Load end is in the form of Voltage/Current waveform distortion, long/short duration voltage variations and poor load power factor. Amongst the various distribution FACTS controllers, Distribution Static Compensator (D-STATCOM) is important shunt compensator which has the potential to solve any power quality problem faced by distribution system. It provides effective compensation to unbalanced and non-linear loads by injecting appropriate reactive power at the Point of common coupling (PCC). In this paper we have designed Fuzzy Logic controller based D-STATCOM to mitigate the harmonics due to non-linear loads. The proposed system is designed in MATLAB/simulink software and the performance of the system is analized.*

Key words:D-STATCOM (Distributed Static Synchronous Compensator); Voltage Sag; Power quality.

I. INTRODUCTION

The power electronic devices, due to their inherent non-linearity draw harmonics and reactive power from the power supply. In three phase systems, they sometimes also cause unbalance and draw excessive neutral currents. The injected harmonics, reactive power burden, unbalance and excessive neutral currents lead to low system efficiency and poor power factor. In addition to this, the power system is subjected to various transients like voltage sags, swell, flickers etc [1]. These transients would affect the voltage at distribution levels. Excessive reactive power of loads would increase the generating capacity of generating stations and increase the transmission losses in lines [2]. Hence supply of reactive power at the load ends becomes essential. Power quality has become an important issue since many loads at various distribution ends like adjustable speed drives, process industries, printers, domestic utilities, computers, microprocessors based equipments etc. have become intolerant to voltage fluctuations, harmonic content and interruptions [3-5]. Power quality mainly deals with issues like maintaining a fixed voltage at the point of common coupling for various distribution voltage levels irrespective of voltage fluctuations, maintaining near unity power factor power draw from the supply, blocking and current unbalance from passing upwards from various distribution levels, reduction of voltage and current harmonics in the system and suppression of excessive supply neutral current [6].

At present, a wide range of flexible AC controller which is capitalized on newly available power electronic components is emerging for custom power application. FACTS components have been found as the most efficient and economical way to control the power transfer in interconnected AC transmission systems [7]. Among these distributions static compensator is used in the present work. The fast response of DSTATCOM makes it efficient solution s for improving the power quality in distribution system [8-10].

One useful option is to use DSTATCOM in shunt configuration with the main system so that the full capacity of generating sets is efficiently utilized .DSTATCOM employs a voltage source converter (VSC) and generates capacitive and inductive reactive power internally [11]. Its control is very fast and has the capability to provide adequate reactive compensation to the system. DSTATCOM can be effectively utilized to regulate voltage for one large rating motor or for a series of small induction motors starting simultaneously. Induction motor loads draw large starting currents (5-6times) of the full rated current and may affect working of sensitive loads [12][13].

II. POWER QUALITY

Power quality is defined as the concept of powering and grounding sensitive. Equipment in a matter that is suitable to the operation of that equipment.
Power quality deals with maintaining a pure sinusoidal waveform of voltage and frequency. Voltage quality concern with deviation of voltage from ideal voltage (sinusoidal) it isa single frequency sine wave at rated magnitude and frequency with no harmonics. Current quality is a complimentary term of voltage quality concern with a deviation from the ideal current. Current should be in phase with the voltage.

Equipment produces more current disturbances than it used to do both low and high power equipment is more and more powered by simple power electronic converters which produce a broad spectrum of distortion there are indications that the harmonics distortion in the power system is rising, but no conclusive results are obtained due to the lack of large scale surveys. Also energy efficient equipment is a source of power quality

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disturbance adjustable speed drives and energy saving lamps are both important sources of waveform distortion and are also sensitive to certain type of power quality disturbances.
According to IEEE standard 1100, "power quality is the concept of powering and grounding sensitive equipment in amanner that is suitable to the operation of that equipment".

a) Power quality problems

There are so many problems related with quality of power. Here the main concern with the poor power quality with nonlinear loads. Non-linear loads can cause voltage and current distortion. That is it changes its shape other than sinusoidal.

b) Harmonic Distortion

Harmonic components are those waveforms which have the frequency as an integer multiple of the fundamental. Any periodic waveform which is non-sinusoidal can be divided into fundamental and non fundamental components. Everynth harmonic will have a frequency n times that of fundamental frequency.

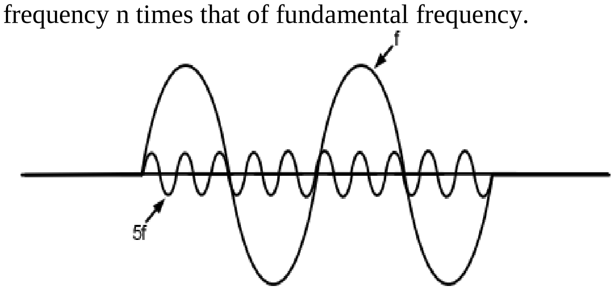

Figure.1: Fundamental component and 5th harmonic component

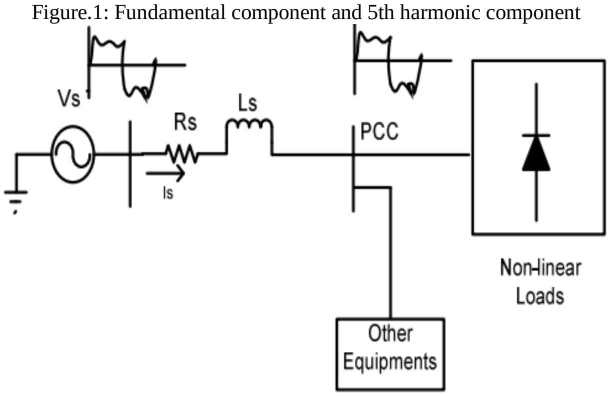

Figure.2: Power System with non-linear loads

Voltage at point of common coupling

$$V_{pcc} = V_s - L_{s1}\left(\frac{di_s}{dt}\right) \tag{1}$$

$$i_s = i_{s1} + \Sigma i_{sh} \tag{2}$$

$$V_{pcc} = \left(V_{sh} - L_{s1}\left(\frac{di_{s1}}{dt}\right)\right) - \left(L_{s1} - \left(\frac{di_{sh}}{dt}\right)\right) \tag{3}$$

$$V_{pcc} = V_{pcc1} - V_{pcc(distortion)} \tag{4}$$

Where

$$V_{pcc1} = \left(V_{sh} - L_{s1}\left(\frac{di_{s1}}{dt}\right)\right)$$

$$V_{pcc(distortion)} = \left(L_{s1} - \left(\frac{di_{sh}}{dt}\right)\right)$$

Non-linear loads draw reactive power. So input power factoris also get poor.
Line current and Total Harmonic Distortion (THD)

$$v_s = \sqrt{2}V_s \sin \omega t \tag{5}$$

$$i_s = \sqrt{2}I_{s1}\sin(\omega_1 t - \phi_1) + \Sigma\sqrt{2}I_{sh}\sin(\omega_n t - \phi_h) \tag{6}$$

$$i_s = i_{s1}(t) + \Sigma i_{sh}(t) \tag{7}$$

$$I_s = (I_{s1}^2 + \Sigma i_{sh}^2) \tag{8}$$

If we remove fundamental, then only ripple will be left

$$i_{distortion} = (i_s^2 - i_{s1}^2)^{\frac{1}{2}} = (\Sigma i_{sh}^2)^{\frac{1}{2}} \tag{9}$$

$$\%THD = I_{distortion} * \frac{100}{I_{sh}} \tag{10}$$

$$\%THD = \sqrt{I_s^2 - I_{s1}^2} * \frac{100}{I_{s1}} \tag{11}$$

III. PRINCIPLE OF D-STATCOM

It is shunt connected at the distribution side of the power systems. A D-STATCOM is a controlled reactive source,which includes a Voltage Source Converter (VSC) and a DClink capacitor connected in shunt, capable of generating and/or absorbing reactive power. The operating principles ofa D-STATCOM 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 3. The DC side of the converter is connected to capacitor, which carries the input ripple current of the converter and reactive energy storage element. This capacitor could be charged by voltage source or inverter. When AC output voltage of inverter is equal to terminal voltage, then there is no reactive power exchange. It there difference between these voltages the only reactive power exchange occurs. The control strategies studied in this paper are applied with a view to studying the performance of a D-STATCOM for reactive power compensation and harmonic mitigation.

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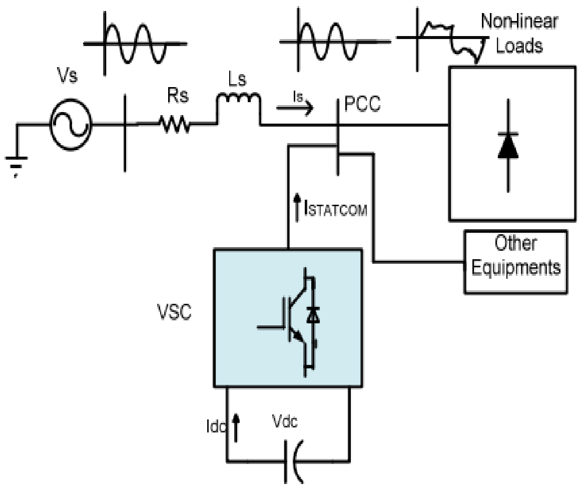

Figure.3: Power system with D-STATCOM

Configuration and operation of DSTATCOMD-STATCOM has 3-phase voltage source converter, capacitor at DC side of inverter is connected with the electrical system at the PCC. The instantaneous controllable3-phase output voltage is generated from DC voltage at fundamental frequency. The pulse is generated by the hysteresis current controllers which takes the difference of reference current and actual source current and minimizes the error and controls the current and generate 3-phase output voltage and injects capacitive or inductive current according to the nature of load.

IV. MATHEMATICAL EXPRESSION FOR SYSTEM

Total instantaneous power delivery drawn by non-linear load

$$P_L(t) = P_{s1}(t) + P_r(t) + P_{sh}(t) \quad (12)$$

Real power supplied by source-

$$P_s = P_{s1} \quad (13)$$

Reactive power supplied by source-

$$Q_s = 0 \quad (14)$$

Real power drawn by the load-

$$P_L = P_{s1} + P_{sh} \quad (15)$$

Reactive power drawn by the load-

$$Q_L = Q_{s1} + Q_{sh} \quad (16)$$

Real power supplied by the D-STATCOM-

$$P_{STATCOM} = P_{sh} - P_{loss} \quad (17)$$

Reactive power supplied by D-STATCOM-

$$Q_{STATCOM} = Q_{s1} + Q_{sh} \quad (18)$$

Where P_{loss}component of STATCOM
From the single line diagram Figure 2

$$i_s(t) = i_L(t) + i_{STATCOM}(t) \quad (19)$$

When the phase of $V_{STATCOM}$ is in quadrature with $I_{STATCOM}$ without injecting real power the D-STATCOM canachieve the voltage sag mitigation. The shunt injecting current$I_{STATCOM}$ and 5 in Figure 3 can be expressed as equation (20and 21)

$$I_{STATCOM} = I_L - I_s = I_L - \left(\frac{V_{th} - V_L}{Z_{th}}\right) \quad (20)$$

$$V_L = V_{th} + (I_{STATCOM} - I_L)Z_{th} \quad (21)$$

$$I_s = (V_{th} - V_L)/Z_{th} \quad (22)$$

Where

V. CONTROL STRATEGY

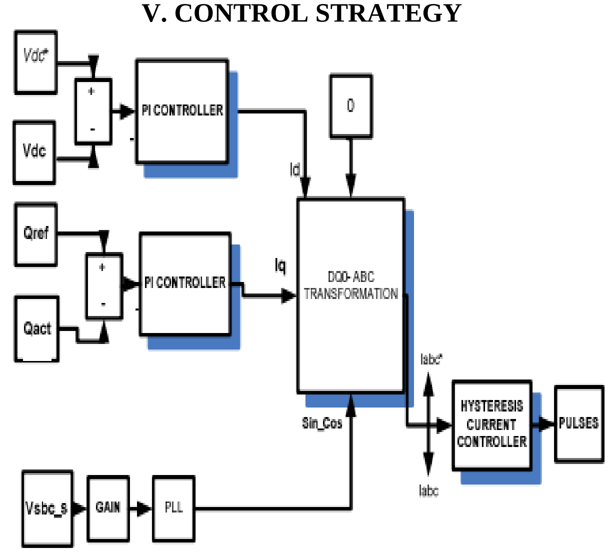

Figure.4: Control Strategy to generate pulses

VI. MATHEMATICAL MODELING

The direct and quadrature axis component of current are:

$$I_d = \left(K_p + \frac{Ki}{s}\right) * (V_{DC}^* - V_{DC}) \quad (23)$$

$$I_q = \left(K_p + \frac{Ki}{s}\right) * (Q_{grid}^* - Q_{grid}) \quad (24)$$

a) d-q-0 to a-b-c transformation

$$x_{abc} = K^{-1} x_{dq0}$$

$$= \sqrt{\frac{2}{3}} * \begin{bmatrix} \cos(\theta) & -\sin(\theta) & \frac{1}{\sqrt{2}} \\ \cos\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{2\pi}{3}\right) & \frac{1}{\sqrt{2}} \\ \cos\left(\theta + \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} x_d \\ x_q \\ x_0 \end{bmatrix} \quad (25)$$

b) Hysteresis Current Controller

In conventional hysteresis band (HB) current control, the switching signal is sent to the IGBT at the same arm (T1 andT4). The output of the HBC is directly connected

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to the transistor T1 and reverse is connected to the T4, therefore the transistor in the same leg is not simultaneously ON or OFF.IGBT are self commutated. Hysteresis Current Controller compares the actual and reference current and generates pulses for the inverter.

If

$$i \leq (i^* - HB), \text{ then T1 in ON} \tag{26}$$

If

$$i \geq (i^* + HB), \text{ then T4 is ON} \tag{27}$$

VII INTRODUCTION TO FUZZY LOGIC CONTROLLER

L. A. Zadeh presented the first paper on fuzzy set theory in 1965. Since then, a new language was developed to describe the fuzzy properties of reality, which are very difficult and sometime even impossible to be described using conventional methods. Fuzzy set theory has been widely used in the control area with some application to dc-to-dc converter system. A simple fuzzy logic control is built up by a group of rules based on the human knowledge of system behavior. Matlab/Simulink simulation model is built to study the dynamic behavior of dc-to-dc converter and performance of proposed controllers. Furthermore, design of fuzzy logic controller can provide desirable both small signal and large signal dynamic performance at same time, which is not possible with linear control technique. Thus, fuzzy logic controller has been potential ability to improve the robustness of dc-to-dc converters. The basic scheme of a fuzzy logic controller is shown in Fig 5 and consists of four principal components such as: a fuzzification interface, which converts input data into suitable linguistic values; a knowledge base, which consists of a data base with the necessary linguistic definitions and the control rule set; a decision-making logic which, simulating a human decision process, infer the fuzzy control action from the knowledge of the control rules and linguistic variable definitions; a de-fuzzification interface which yields non fuzzy control action from an inferred fuzzy control action [10].

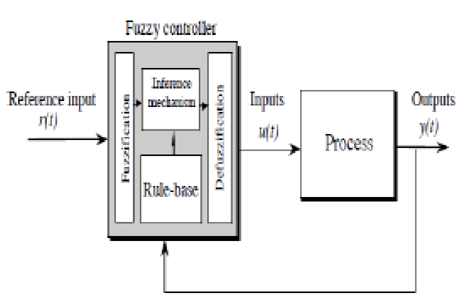

Fig.5. General Structure of the fuzzy logic controller on closed-loop system

The fuzzy control systems are based on expert knowledge that converts the human linguistic concepts into an automatic control strategy without any complicated mathematical model [10]. Simulation is performed in buck converter to verify the proposed fuzzy logic controllers.

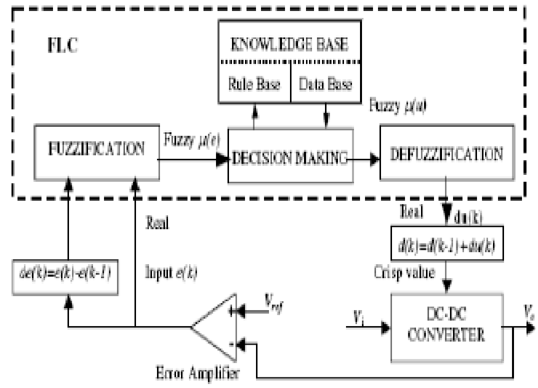

Fig.6. Block diagram of the Fuzzy Logic Controller (FLC) for dc-dc converters

A. Fuzzy Logic Membership Functions:

The dc-dc converter is a nonlinear function of the duty cycle because of the small signal model and its control method was applied to the control of boost converters. Fuzzy controllers do not require an exact mathematical model. Instead, they are designed based on general knowledge of the plant. Fuzzy controllers are designed to adapt to varying operating points. Fuzzy Logic Controller is designed to control the output of boost dc-dc converter using Mamdani style fuzzy inference system. Two input variables, error (e) and change of error (de) are used in this fuzzy logic system. The single output variable (u) is duty cycle of PWM output.

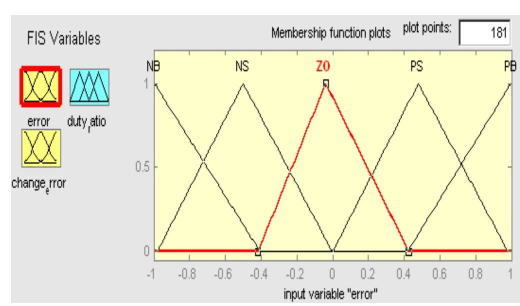

Fig. 7.The Membership Function plots of error

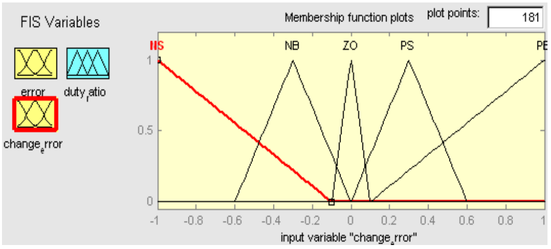

Fig.8. The Membership Function plots of change error

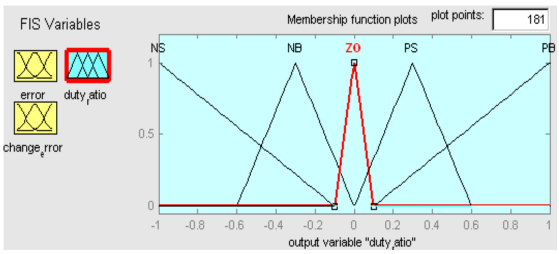

Fig.9. the Membership Function plots of duty ratio

B. Fuzzy Logic Rules:

The objective of this dissertation is to control the output voltage of the boost converter. The error and change of error of the output voltage will be the inputs of fuzzy logic controller. These 2 inputs are divided into five groups; NB: Negative Big, NS: Negative Small, ZO: Zero Area, PS: Positive small and PB: Positive Big and its parameter [10]. These fuzzy control rules for error and change of error can be referred in the table that is shown in Table I as per below:

Table I

Table rules for error and change of error

(de) \ (e)	NB	NS	ZO	PS	PB
NB	NB	NB	NB	NS	ZO
NS	NB	NB	NS	ZO	PS
ZO	NB	NS	ZO	PS	PB
PS	NS	ZO	PS	PB	PB
PB	ZO	PS	PB	PB	PB

VIII. MATLAB/SIMULATION RESULTS

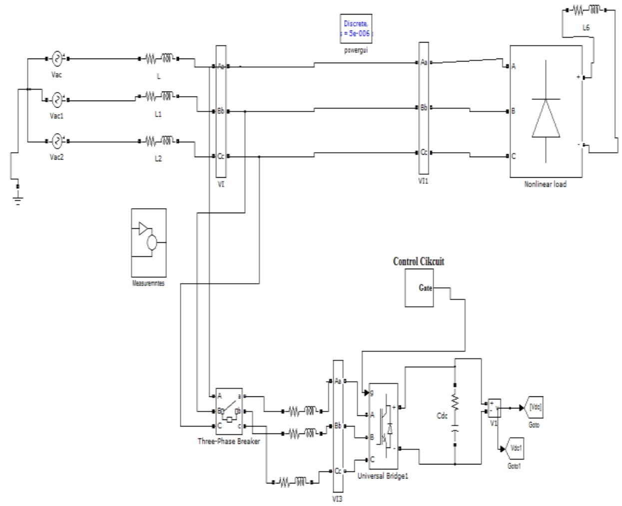

Fig.10. Matlab/Simulink circuit for Power system with D-STATCOM

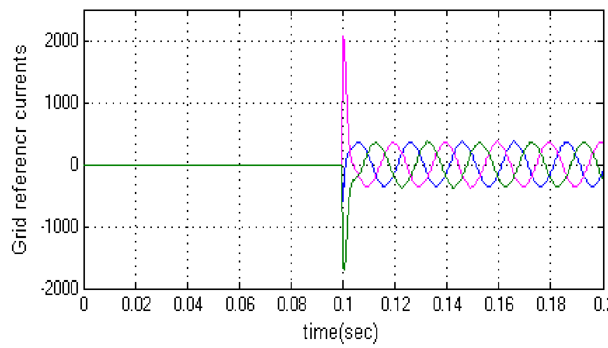

Fig.11. Simulation waveform for Grid reference current

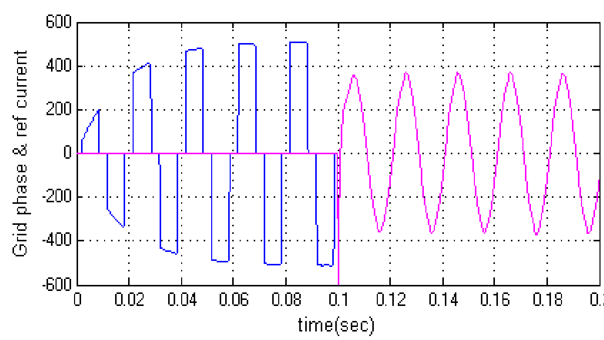

Fig.12. Simulation waveform for Grid phase and reference currents

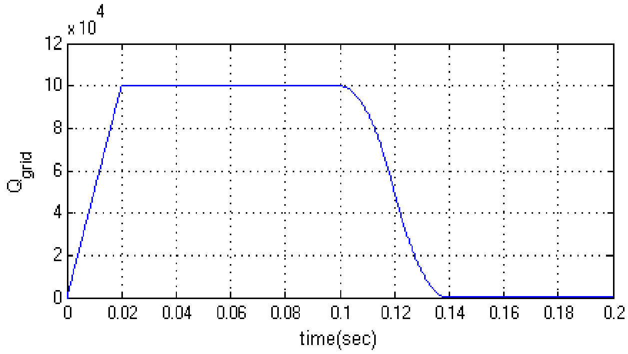

Fig.13. Reactive power generated by Grid

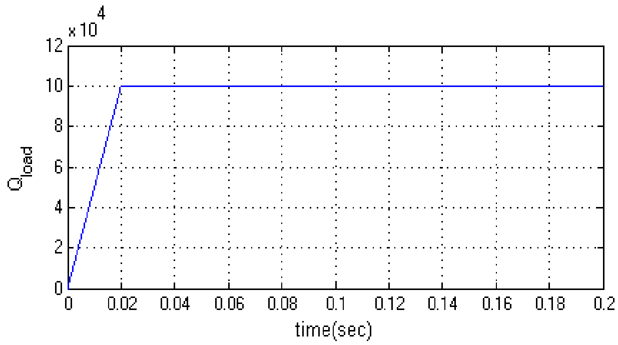

Fig.14. Reactive power demanded by load

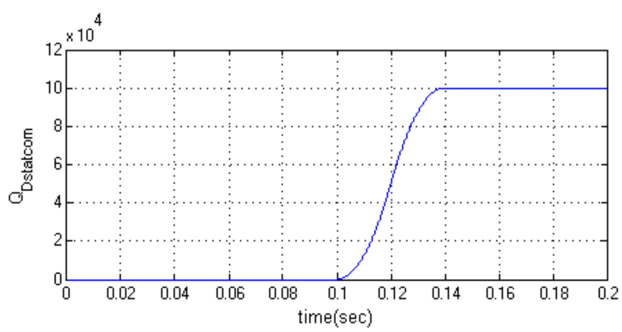

Fig.15. Reactive power supplied by D-STATCOM

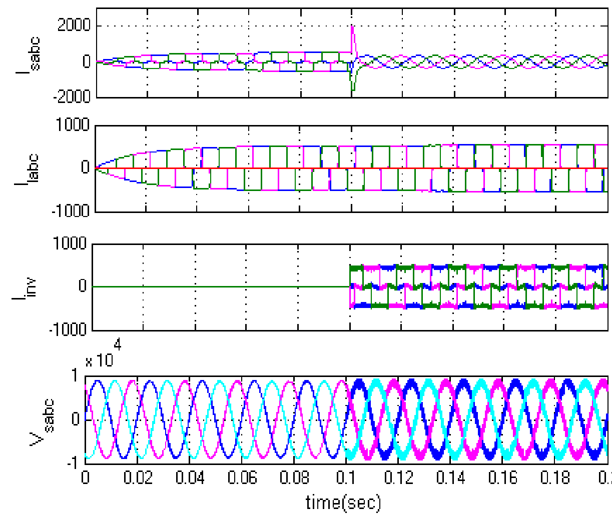

Fig.16. Source current, Load current, D-STATCOM injected harmonic current and Source voltage

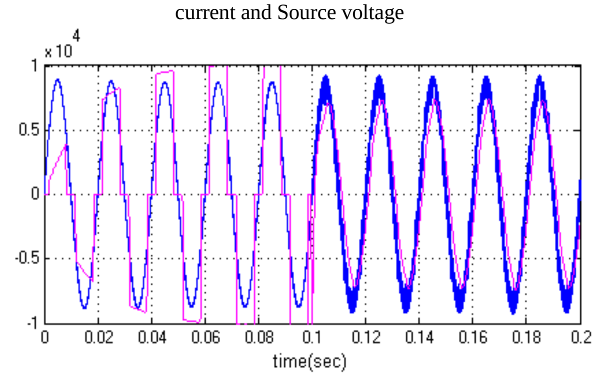

Fig.17. Power factor angle between source voltage and current

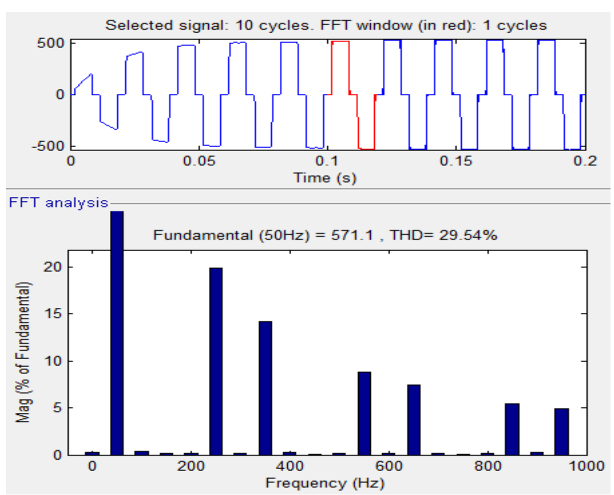

Fig.18. Load current THD

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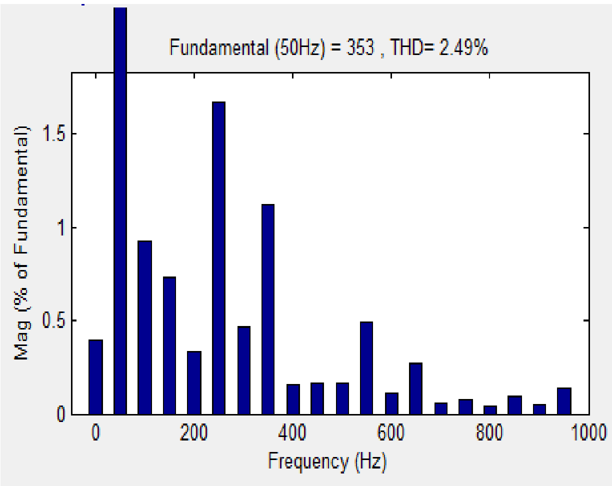

Fig.19. Source current THD

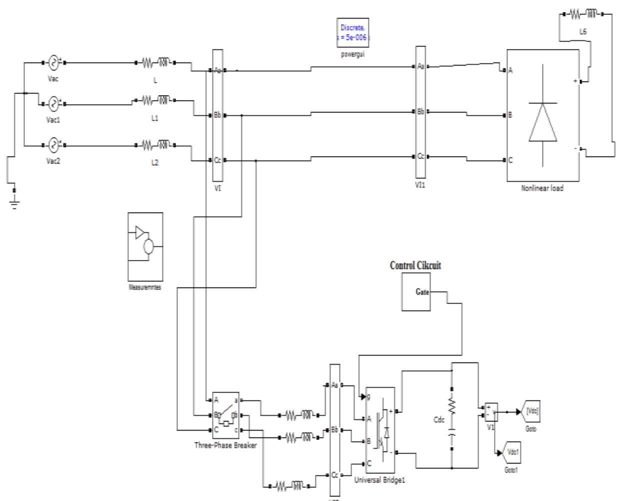

Fig.20. Matlab/Simulink circuit for Power system with D-STATCOM with Fuzzy Logic Control

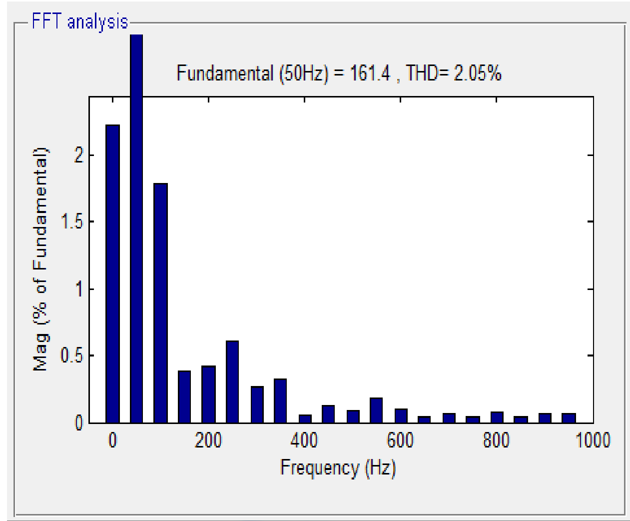

Fig.21.Source Current THD with Fuzzy Logic Control

IX. CONCLUSION

In this paper the performance of D-STATCOM to mitigate reactive power and to improve the power quality in distribution network with non-linear load is studied. In this work the investigation is composed of power system distribution system with and without D-STATCOM .Total Harmonic Distortion Comparision with PI and Fuzzy logic controller on Source and load side. So it can be concluded that D-STATCOM effectively improves the power quality in distribution network with non-linear loads. The simulation results show that the performance of the D-STATCOM system has been found to be satisfactory for improving the power quality at the consumer premises.

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