www.ijemr.net ISSN (ONLINE): 2250-0758, ISSN (PRINT): 2394-6962

Volume-5, Issue-6, December-2015

International Journal of Engineering and Management Research

Page Number: 281-288

Fuzzy Logic Control Algorithm of Distribution Static Compensator for Power Quality Improvement

N. Santhi kumari[1], S. Narmadha[2], M. Vamsi krishna[3]

Department of EEE, Brahmaiah College of Engineering, Northraju Palem, SPSR, Nellore, AP, INDIA

ABSTRACT

This paper is proposed to control a three-phase, four-wire distribution static compensator (D-STATCOM) based on Fuzzy logic control technique for peak detection of load currents for power quality improvement under linear/non-linear loads. This control algorithm is accurate and simple to implement for real time applications in grid. In the proposed control algorithm using fuzzy logic based input and error in input are taken into consideration for required output with that estimation of active and reactive power components of load currents using low-pass filter and the voltage unit vector has achieved for power quality improvements. A four-wire D-STATCOM is analyzed for the compensation of linear and non-linear loads using MATLAB/SIMULINK model design. The Performance of DSTATCOM is found quite satisfactory under balanced and unbalanced loads in three-phase, four-wire distribution system.

***Keywords*—** Fuzzy, D-statcom, Power quality, linear/Non-linear load.

I. INTRODUCTION

Modern day power systems are complicated networks with hundreds of generating stations and load centers being interconnected through various power transmission lines. An electric power system has three separate components power generation power transmission and power distribution. As per reliability consideration in power system, generation unit must generate adequate amount of power, transmission unit should supply maximum power over long distances without overloading and distribution system must deliver electric power to each consumer's premises form bulk power systems. Distribution system is located at the end of electric power system and is directly to the consumer, so the power quality depends upon the state of distribution system. The reason for this is that failure in the electric distribution network accounts for about 91% of the average consumer's interruptions. Earlier, power system reliability focused on generation and transmission system due to capital investment in these. But today, distribution system is receiving more attention as reliability is concerned.

The term electric power quality (PQ) is generally used to assess and to maintain the good quality of power at the level of generation, transmission, distribution, and utilization of AC electrical power. Since the pollution of electric power supply systems is much severe at the utilization level, it is important to study at the terminals of end users in distribution systems. There are a number of reasons for the pollution of the AC supply systems, including natural ones such as lightening, flashover, equipment failure, and faults (around 60%) and forced ones such as voltage distortions and notches (about 40%). A number of customer's equipment also pollute the supply system as they draw non-sinusoidal current and behave as nonlinear loads. Therefore, power quality is quantified in terms of voltage, current, or frequency deviation of the supply system, which may result in failure or mal-operation of customer's equipment. Typically, some power quality problems related to the voltage at the point of common coupling (PCC) where various loads are connected are the presence of voltage harmonics, surge, spikes, notches, sag/dip, swell, unbalance, fluctuations, glitches, flickers, outages, and so on. These problems are present in the supply system due to various disturbances in the system or due to the presence of various nonlinear loads such as furnaces, uninterruptible power supplies (UPSs), and adjustable speed drives (ASDs). However, some power quality problems related to the current drawn from the AC mains are poor power factor, reactive power burden, harmonic currents, unbalanced currents, and an excessive neutral current in poly-phase systems due to unbalancing and harmonic currents generated by some nonlinear loads.

Because of these problems, power quality has become an important area of study in electrical engineering, especially in electric distribution and utilization systems. It has created a great challenge to both the electric utilities and the manufacturers. Utilities must supply consumers with good quality power for operating their equipment satisfactorily, and manufacturers must develop their electric equipment either to be immune to such disturbances or to override them. A number of techniques have evolved for the mitigation of these problems either in existing systems or in equipment to be developed in the near future. It has resulted in a new direction of research and development (R&D) activities for the design and development engineers working in the fields of power electronics, power systems, electric drives, digital signal processing, and sensors. It has changed the scenario of power electronics as most of the equipment using power converters at the front end need modifications in view of these newly visualized requirements. Moreover, some of the well-developed converters are becoming obsolete and better substitutes are required. It has created the need for evolving a large number of circuit configurations of front-end converters for very specific and particular applications. Apart from these issues, a number of standards and benchmarks are developed by various organizations such as IEEE (Institute of Electrical and Electronics Engineers) and IEC (International Electro technical Commission), which are enforced on the customers, utilities, and manufacturers to minimize or to eliminate the power quality problems.

The techniques employed for power quality improvements in exiting systems facing power quality problems are classified in a different manner from those used in newly designed and developed equipment. These mitigation techniques are further sub classified for the electrical loads and supply systems, since both of them have somewhat different kinds of power quality problems. In existing nonlinear loads, having the power quality problems of poor power factor, harmonic currents, unbalanced currents, and an excessive neutral current, a series of power filters of various types such as passive, active, and hybrid in shunt, series, or a combination of both configurations are used externally depending upon the nature of loads such as voltage-fed loads, current-fed loads, or a combination of both to mitigate these problems. However, in many situations, the power quality problems may be other than those of harmonics such as in distribution systems, and the custom power devices such as distribution static compensators (DSTATCOMs), dynamic voltage restorers (DVRs), and unified power quality conditioners (UPQCs) are used for mitigating the current, voltage, or both types of power quality problems. Power quality improvement techniques used in newly designed and developed systems are based on the modification of the input stage of these systems with power factor corrected (PFC) converters, also known as improved power quality AC–DC converters (IPQCs), multi pulse AC–DC converters, matrix converters for AC–DC or AC–AC conversion, and so on, which inherently mitigate some of the power quality problems in them and in the supply system by drawing clean power from the utility.

In this paper, a modified fuzzy logic based simple peak detection control algorithm is implemented for load balancing, reactive power compensation and harmonics elimination with self-supporting DC bus of VSC in a three-phase four-wire distribution system. It is also extended for zero voltage regulation at PCC. A zig-zag connected transformer is used for compensation of neutral current because it has advantage of low rating as well as enhanced the capability of VSC for load balancing. It has equal distribution of neutral currents among all three phases. Simple structure and fast extraction of reference supply currents are the advantages of this control algorithm. Direct estimation of reference supply currents from load currents without use of any reference frame is the main characteristics of this algorithm. It is based on mathematical formulation using basic theory. As the simple structure of the control algorithm, uncertainty in response is drastically reduced. This algorithm requires only few components in real time implementation so its practical implementation is easy.

II. PRINCIPLES OF D-STATCOM

This is a shunt device and does not require passive elements like inductors and capacitors. The schematic diagram of a single machine infinite bus (SMIB) power system that is compensated by a shunt compensator is shown in figure. The STATCOM is built around a voltage source inverter, which is supplied by a DC capacitor. The inverter consists of GTO switches which are turned on and off through a gate driver circuit.

The output of the voltage source inverter is connected to that ac system through a coupling transformer. The inverter produces a quasi sine wave voltage V_o at the fundamental frequency. Let us assume that the losses in the inverter and the coupling transformer are negligible. The inverter is then gated such that the output voltage of the inverter V_o is in phase with the local bus voltage Vm. In this situation two ac voltages that are in phase are connected together through a reactor, which is the leakage reactance of the coupling transformer. Therefore the current i_q is a purely reactive. If the magnitude of the voltage V_m is more than that of the voltage V_o , the reactive current i_q flows from the bus to the inverter.

Then the inverter will consume reactive power. If on the other hand, the magnitude of V_o is greater than that of Vm, then the inverter feeds reactive power to the system. Therefore through this arrangement the STATCOM can generate or absorb reactive power. In practice however the losses are not negligible and must be drawn from the ac system. This is accomplished by slightly shifting the phase angle of the voltage V_o through a feedback mechanism such that the DC capacitor voltage is held constant.

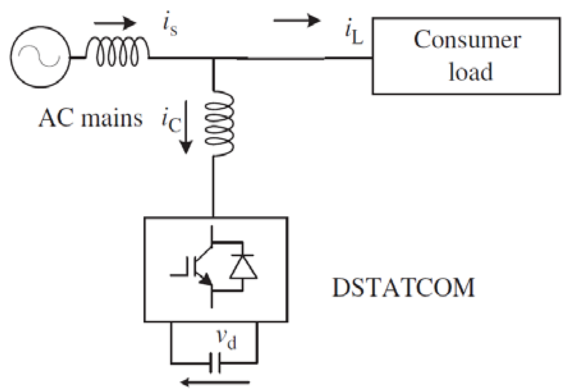


Fig 2.2STATCOM connected to a distribution network

2.1 Load compensation using DSTATCOM

The schematic diagram of a distribution system compensated by an ideal shunt compensator (DSTATCOM) is shown in Figure 1.4 In this it is assumed that the DSTATCOM is operating in current control mode. Therefore its ideal behavior is represented by the current source i_f it is assumed that Load-2 is reactive, nonlinear and unbalanced. In the absence of the compensator, the current *J*, flowing through the feeder will also be unbalanced and distorted and, as a consequence, so will be Bus-I voltage.

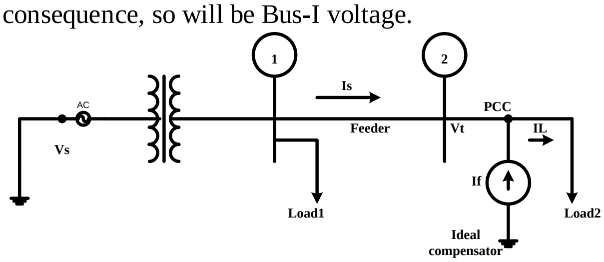


Fig 2.3 Schematic diagram of ideal load compensation

To alleviate this problem, the compensator must inject current such that the current i_s becomes fundamental and positive sequence. In addition, the compensator can also force the current is to be in phase with the Bus-2 voltage. This fashion of operating the DSTATCOM is also called load compensation since in this connection the DSTATCOM is compensating the load current. From the utility point of view, it will look as if the compensated load is drawing a unity power factor, fundamental and strictly positive sequence current.

The point at which the compensator is connected is called the utility customer point of common coupling (PCC). Denoting the load current i_l by the KCL at the PCC yields

$$i_s + i_f = i_l \qquad i_s = i_l - i_f$$

The desired performance from the compensator is that it generates a current i_f such that it cancels the reactive component, harmonic component and unbalance of the load current

III. ANALYSIS OF PROPOSED TOPOLOGY

A simple peak detection control algorithm is implemented for load balancing, reactive power compensation and harmonics elimination with self-supporting DC bus of VSC in a three-phase four-wire distribution system. It is also extended for zero voltage regulation at Point of common coupling (PCC). A four leg voltage source converter used as DSTATCOM for neutral current compensation. It has equal distribution of neutral currents among all three phases. Simple structure and fast extraction of reference supply currents are the advantages of this control algorithm. Direct estimation of reference supply currents from load currents without use of any reference frame is the main characteristics of this algorithm. It is based on mathematical formulation using basic theory. As the simple structure of the control algorithm, uncertainty in response is drastically reduced.

3.1 Configuration of DSTATCOM

Fig3.1 shows the schematic diagram of a DSTATCOM connected to AC mains feeding the four-wire linear/ non-linear loads. Three-phase loads may be an unbalanced load, a lagging power factor load, non-linear load or combination of them. Non-linear loads are represented by a three-phase rectifier with a resistive load and an inductive filter. The VSC performs an inverter operation and generates three-phase AC output PWM voltages for required compensation. For reducing ripple in compensating currents, interfacing inductors (L_f) are used at AC side of the VSC. A small series connected capacitor (C_f) and a resistor (R_f) represent a ripple filter and it is connected at PCC to filter the high frequency switching noise of the PCC voltage. The rating of the IGBT (insulated gate bipolar transistor) switches of VSC is based on the voltage and current rating of VSC for necessary compensation. A four leg DSTATCOM is used to compensate the load neutral current, which provides a path for load neutral currents.

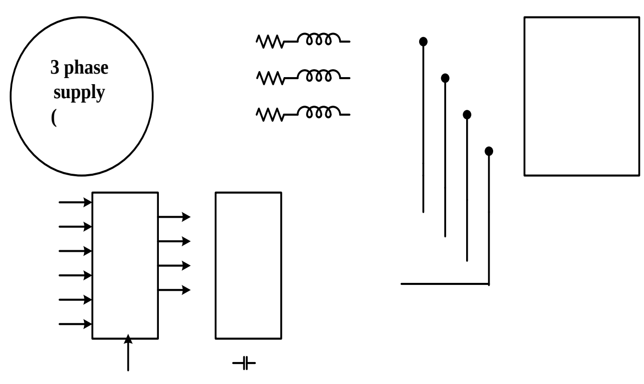


Fig 3.1 Block diagram 3 phase supply system with VSC

3.2 *Control algorithm*

Various functions of DSTATCOM depend upon the control algorithm for accurate and fast detection of non linear quality/disturbances. Generally DSTATCOM is based on VSC and it is controlled as a current source by use of PWM switching. Fig shows the block diagram of a peak detection control algorithm for extraction of reference supply currents which is based on mathematical formulation. Basic equations of this control algorithm for the estimation of various control signals are given as follows.

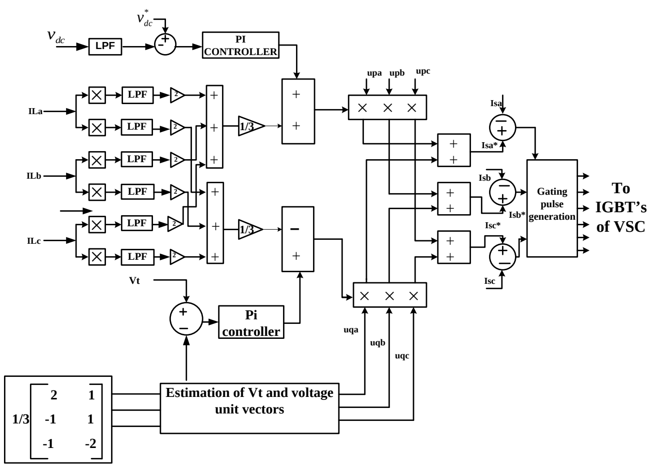


Fig3.2 Peak detection based control algorithm for extraction of reference supply currents.

Sensed PCC line voltages V_{ab} *and* V_{bc} are converted to three phase PCC voltages V_{sa}, V_{sb} *and* V_{sc} as follows

$$v_{sa} = \frac{2v_{ab} + v_{bc}}{3} \quad (3.1)$$

$$v_{sb} = \frac{-v_{ab} + v_{bc}}{3} \quad (3.2)$$

$$v_{sc} = \frac{-v_{ab} - 2v_{bc}}{3} \quad (3.3)$$

The amplitude of PCC voltages (V_t) and in phase unit vectors are computed as

$$V_t = \sqrt[2]{\frac{2*(v_{sa}^2 + v_{sb}^2 + v_{sc}^2)}{3}} \quad (3.4)$$

Where Vsa, Vsb, Vsc are three phase voltages at PCC.

In phase unit vectors of three phase PCC voltages (U_{pa}, U_{pb} and U_{pc}) are estimated after dividing respective phase voltage with amplitude of three phase PCC voltage (V_t) as

$$u_{pa} = \frac{v_{sa}}{V_t} \qquad u_{pb} = \frac{v_{sb}}{V_t}$$

$$u_{pc} = \frac{v_{sc}}{V_t} \quad (3.5)$$

The quadrature unit vectors are estimated as

$$u_{qa} = \frac{(-u_{bp} + u_{cp})}{\sqrt{3}} \quad (3.6)$$

$$u_{qb} = \frac{(3u_{pa} + u_{pb} - u_{pc})}{\sqrt{3}} \quad (3.7)$$

$$u_{qc} = \frac{(-3u_{pa} + u_{pb} - u_{pc})}{2\sqrt{3}} \quad (3.8)$$

3.2.1 *Estimation of fundamental active and reactive power components of load currents*

Generally the load current is lagging and distorted because of application of reactive and non linear loads. As these components, load current $i_{La}(t)$ can be expressed as

$$i_{La}(t) = I_0 + I_{Lpa}(t) + I_{Lqa}(t) + I_h(t) \quad (3.9)$$

Where I_0 is the DC component which amplitude is very low because of the half wave symmetry

The term $I_{Lpa}(t)$ is the fundamental active power component of load current for phase 'a'.

The term $I_{Lqa}(t)$ is the fundamental reactive power component of load current for phase 'a'

The term $I_h(t)$ is the harmonics present in load current $i_{La}(t)$.

$$i_{La}(t) = I_0 + I_{Lpa}\sin\omega t + I_{Lqa}\cos\omega t + I_h(t) \quad (3.10)$$

In order to extract the peak amplitude of fundamental active power component of the load current for phase 'a' (I_{Lpa}), the in phase vector $U_{pa}(\sin\omega t)$ is multiplied with the $i_{La}(t)$ given in eq3.10 for phase 'a' and it results in following expressions

$$i_{Lpa} = i_{La}(t) * u_{pa} = i_{La}(t)\sin\omega t \quad (3.11)$$

$$= I_o\sin\omega t + \left[\left(\frac{I_{Lpa}}{2}\right)(1-\cos 2\omega t)\right] + \left[\left(\frac{I_{Lqa}}{2}\right)(\sin 2\omega t)\right] + \sum_{m=1}^{\infty}\frac{I_{2m}}{2}[\cos(\{2m-1\}\omega t + \phi_{2m}) - \cos(\{2m+1\}\omega t + \phi_{2m})] + \sum_{n=1}^{\infty}\frac{I_{2n+1}}{2}[\cos(\{2n\omega t + \phi_{2n+1}\}) - \cos(\{2n+2\}\omega t + \phi_{2n+1})] \quad (3.12)$$

After product of phase 'a' load current (i_{La}) and in phase unit vector (u_{pa}), DC and oscillatory components are presented in eq3.12. It is proportional to (i_{Lpa}) with the factor of 1/2. The amplitude of fundamental active power component of the load current (i'_{Lpa}) is extracted using a low-pass filter with a cut off frequency (15 Hz) less than supply frequency. An amplification factor of 2 as a gain is used to determine (I'_{Lpa}). The amplitude of fundamental active power component (I'_{Lpb}) (I'_{Lpc}) of the load currents for phases 'b' and 'c' are extracted using same procedure. The average amplitude of fundamental active power component of load currents (I_{LpA}) (I_{LpA}) is calculated as

$$I_{LpA} = \left(\frac{I'_{Lpa} + I'_{Lpb} + I'_{Lpc}}{3} \right) \quad (3.13)$$

The amplitude fundamental reactive power component of load current (i_{Lqa}) for phase 'a' is extracted by multiplying (3.10) with quadrature unit vector $u_{qa}(\cos \omega t)$ as follows

$$i_{Lqa}(t) = i_{la}(t) * u_{qa} = i_{la}(t) \cos \omega t \quad (3.14)$$

$$= I_o \cos \omega t + \left[\left(\frac{I_{Lqa}}{2} \right) (1 + \cos 2\omega t) \right] + \left[\left(\frac{I_{Lpa}}{2} \right) \sin 2\omega t \right] + \sum_{m=1}^{\infty} \frac{I_{2n+1}}{2} [\sin(\{2m+1\}\omega t + \phi_{2m}) + \sin(\{2m-1\}\omega t + \phi_{2m})] + \sum_{n=1}^{\infty} \frac{I_{2n+1}}{2} [\sin(2n+2)\omega t + \phi_{2n+1} \sin(2n\omega t + \phi_{2n+1})] \quad (3.15)$$

After multiplication of phase 'a' load current (I_{La}) with quadrature phase unit vector (u_{qa}), DC and oscillatory components are presented in (eq3.15). It is proportional to $\mathbf{I_{Lqa}}$ with a factor of 1/2. The amplitude of fundamental reactive power component of the load current (I'_{Lqa}) is extracted using a low-pass filter with a cut off frequency (15 Hz) less than supply frequency. An amplification factor of 2 as a gain is used to determine I'_{Lqa}.This control algorithm belongs in the category of classical control based on the strong mathematical expression. The fundamental reactive power component of the load currents for phases 'b' and 'c', I'_{Lqb} I'_{Lqc} are extracted in the same manner. The average amplitude of load reactive power component of currents (I_{LqA}) is calculated as

$$I_{LqA} = \frac{I'_{LqA} + I'_{LqB} + I'_{LqC}}{3} \quad (3.16)$$

3.2.2 Extraction of active power components of reference supply currents

The active power component of supply currents (I_{tsp}) is an addition of fundamental active power component of load current (I_{LpA}) and a current required for self supporting DC bus of DSTATCOM (I_{cp}). The control DC bus voltage of DSTATCOM is achieved by adjusting a small amount of active power flowing into the DC capacitor of VSC. A current required for self supporting DC bus of VSC is extracted using PI controller over the DC bus voltage which is used to eliminate the steady state error in the DC voltage of VSC of DSTATCOM. At nth instant it is expressed as

$$I_{cp}(n) = I_{cp}(n-1) + K_{dp}(v_e(n) - v_e(n-1)) + K_{di} v_e(n) \quad (3.17)$$

Where $V_e = V^*_{dc} - V_{dc}$ is the error in the DC bus voltage. V^*_{dc}, V_{dc} are the reference voltage and sensed filtered voltage of DC bus of DSTATCOM, respectively. K_{dp} *and* K_{di} are the proportional and integral gain constants of the DC bus PI voltage controller.

Total value of active power component of reference supply current (I_{tsp}) is as

$$I_{tsp} = I_{LpA} + I_{cp} \quad (3.18)$$

3.2.3 Extraction of reactive power components of reference supply currents

The DSTATCOM can be operated in either power factor correction (PFC) mode or zero voltage regulation (ZVR) modes. The ZVR mode is used when PCC voltage is not rated value. The PCC voltage may reduce because of loading. In case of ZVR, the PCC voltage is regulated by supplying extra reactive power locally. For regulating PCC voltages, the VSC has to supply extra reactive power of the load as well as to compensate the drop because of supply impedance. The reactive power component of load current is estimated from load currents. A voltage PI controller is used to estimate total reactive power component for ZVR to be supplied by DSTATCOM. The output of PCC voltage PI controller includes the extra reactive power component of supply current required for ZVR. The reactive power component of load current is subtracted from output of PCC voltage PI controller as shown in fig3.2 to estimate net reactive power component of reference supply current. This reactive power component of supply current (I_{cq})is to regulate the amplitude of the PCC voltage at nth sampling instant is expressed as

$$I_{cq}(n) = I_{cq}(n-1) + k_{qp}\{V_{te}(n) - V_{te}(n-1)\} + k_{qi}V_{te}$$
(3.19)

Where $V_{te} = V_t^* - V_t$ is the error in the PCC voltage. V_t^*, V_t are the amplitude of PCC reference voltage and amplitude of PCC voltage and amplitude of PCC voltage, respectively. $K_{qp} and K_{qi}$ are the proportional and integral gain constants of the PCC voltage bus PI voltage controller.

The value of reactive power components of reference supply current (I_{tsq}) is as

$$I_{tsq} = I_{cq} - I_{Lqa} \quad (3.20)$$

3.3 Estimation of reference supply currents and generation of devices gating pulses

Three phase reference active power components of supply currents are estimated using its amplitude (I_{tsp}) and in phase unit voltage vectors (u_{pa}, u_{pb}, u_{pc}) as

$$i_{sap} = I_{tsp}u_{pa};\ i_{sbp} = I_{tsp}u_{pb};\ i_{scp} = I_{tsp}u_{pc} \quad (3.21)$$

Similarly, reference reactive power components of supply currents are estimated using its amplitude (I_{tsq}) and in phase unit voltage vectors (u_{qa}, u_{qb}, u_{qc}) as

$$i_{saq} = I_{tsq}u_{qa};\ i_{sbq} = I_{tsq}u_{qb};\ i_{scq} = I_{tsq}u_{qc}$$
(3.22)

Total reference supply currents are obtained after addition of reference active and reactive powers components of supply currents as

$$i_{sa}^* = i_{sap} + i_{saq} \qquad i_{sb}^* = i_{sbp} + i_{sbq}$$
$$i_{sc}^* = i_{scp} + i_{scq} \quad (3.23)$$

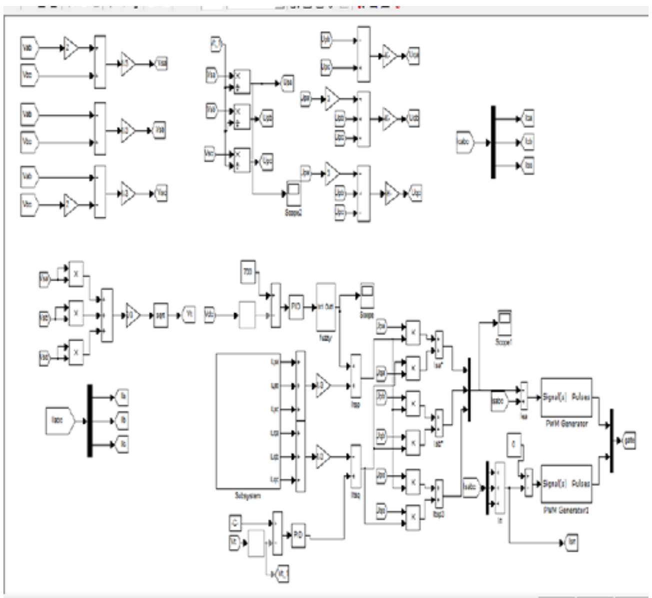
These three phase reference supply currents ($i_{sa}^*, i_{sb}^*, i_{sc}^*$) are compared with sensed supply currents (i_{sa}, i_{sb}, i_{sc}) to estimated current errors. These current errors (i_{ea}, i_{eb} and i_{ec}) are amplified using PI controllers and output of the PI controllers is used in the PWM controller to generate gating pulses of IGBTs of VSC used as DSTATCOM

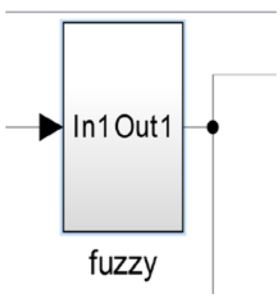
IV. RESULTS AND DISCUSSION

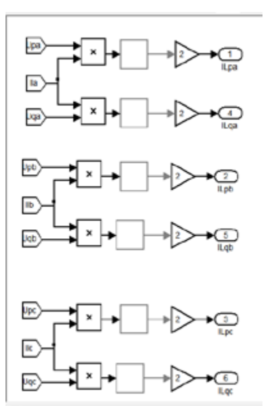
The performance of DSTATCOM using proposed peak detection control algorithm is simulated using MATLAB model for PFC and ZVR modes of operation under linear and non-linear loads. The performance of DSTATCOM is presented for linear and non-linear loads as follows:

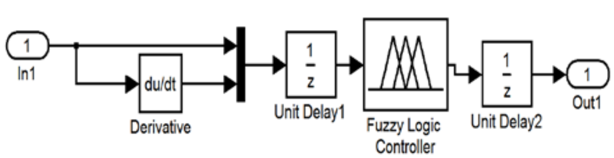
Fig. shows the response of DSTATCOM for reactive power compensation under lagging power factor in PFC mode. The performance of DSTATCOM is shown as phase voltages at PCC (v_s), balanced supply currents (i_s), load currents (i_{la}, i_{lb} and i_{lc}), compensator currents (i_{ca}, i_{cb} and i_{cc}) and DC bus voltage (v_{dc}), load neutral current (i_{Ln}), supply neutral current (i_{sn}), at the time of load removal on phase 'a' load at t = 2s. It shows the unity power factor after compensation of load reactive power demand through DSTATCOM and balanced supply currents during load unbalancing.

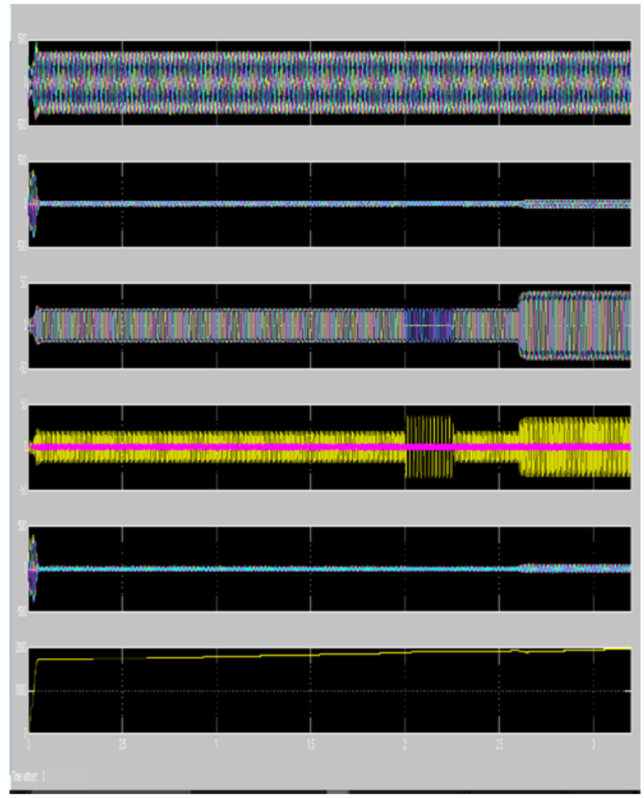
S.NO	ELEMENTS
1	Ac mains: 415V (L-L), 50 HZ.
2	Source impedance $R_s = .07\Omega$ $L_s = 2mH$
3	Load: 1) Linear: 10KVA 0.8 power factor.
4	2) Nonlinear three phase full bridge uncontrolled rectifier with $R_L = 15\Omega L_L = 100mH$.
6	Ripple filter $R_f = 5\Omega$ R_f=5Ω, $C_f = 10\mu F$.
7	Dc bus capacitance: 7500µF.
8	Reference DC bus voltage: 700V.
9	Frequency of low pass filter used in DC bus=12HZ.
10	Frequency of low pass filter used in AC bus=12HZ.
11	Interfacing inductor (L_f) =3.5mH.

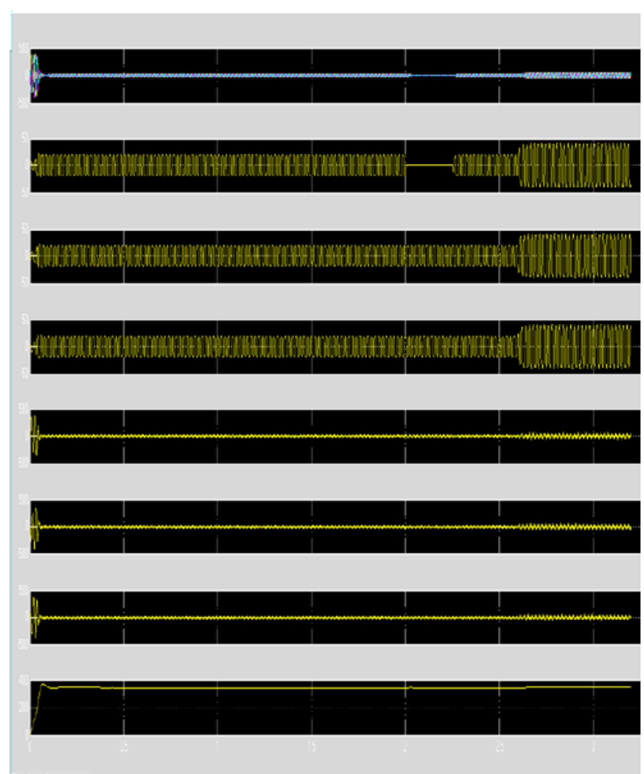


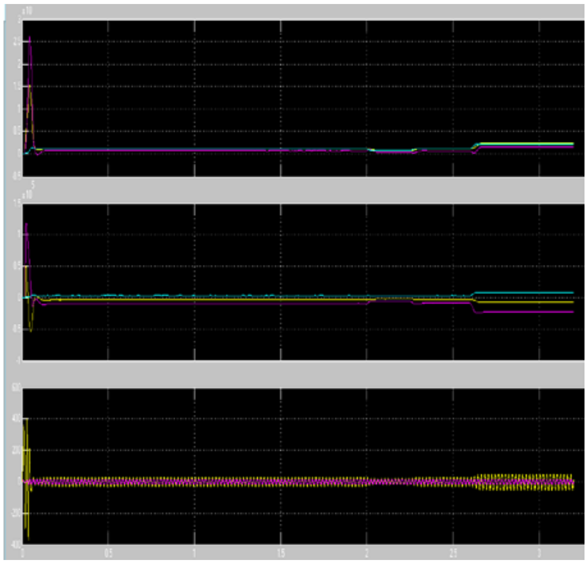

In1 Out1
fuzzy




1
In1
du/dt
Derivative
1
z
Unit Delay1
Fuzzy Logic
Controller
1
z
Unit Delay2
1
Out1







V. CONCLUSION

These instructions give you guidelines for preparing papers for IJEMR online JOURNALS. Use this document as a template. Use this document as an instruction set. The electronic file of your paper will be formatted further at IJEMR. Define all symbols used in the abstract. These instructions give you guidelines for preparing papers for IJEMR online JOURNALS. Use this document as a template. Use this document as an instruction set. The electronic file of your paper will be formatted further at IJEMR. Define all symbols used in the abstract. These instructions give you guidelines for preparing papers for IJEMR online JOURNALS. Use this document as a template. Use this document as an instruction set. The electronic file of your paper will be formatted further at IJEMR. Define all symbols used in the abstract. These instructions give you guidelines for preparing papers for IJEMR online JOURNALS. Use this document as a template. Use this document as an instruction set. The electronic file of your paper will be formatted further at IJEMR.

REFERENCES

[1] Singh, B., Chandra, A., Al-Haddad, K.: ‘Computer-aided modeling and simulation of active power filters’, J. Electr. Mach. Power Syst., 1999,27, pp. 1227–1241

[2] Singh, B., Jayaprakash, P., Kothari, D.P.: ‘A three-phase four-wire DSTATCOM for power quality improvement’, J. Power Electron. 2008, 8, (3), pp. 259–26

[3] IEEE Recommended Practices and Requirement for Harmonic Control on Electric Power System, IEEE Std.519, 1992

[4] Limits For Harmonic Current Emissions: International Electro technical Commission IEC-61000-3-2, 2000.

[5] El-Habrouk, M., Darwish, M.K., Mehta, P.: ‘Active power filters: a review’, IEE Proc., Electr. Power Appl., 2000, 147, (5), pp. 403–413

[6] Khan, M.M., Feng, J.F., Chen, C., Zhiming, W.: ‘Single-phase dynamically decoupled active power filter for system-integrated application’, IEE Proc. Electr. Power Appl., 2006, 153, (5), pp. 625–631

[7] Routimo, M., Salo, M., Tuusa, H.: ‘Comparison of voltage source and current source shunt active power filters’, IEEE Trans. Power Electron., 2007, 22, (2), pp. 636–643.

