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SIMULATION BASED PERFORMANCE AND ANALYSIS OF GRID CONNECTED IRP CONTROL THEORY STATCOM WITH VARIATION OF DC LINK VOLTAGE

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ABSTRACT: *The STATCOM (Static synchronous compensator) is a shunt connected voltage source converter using self-commutating device and can be effectively used for reactive power control. This paper describes the modeling of STATCOM in which linear controller of current and voltage is replaced by IRP (Instantaneous reactive power) controller. The IRP p-q theory is based on the Clarke transformation.IRP theory consumes time of operation, it reduces harmonic distortion and improves power factor. The IRP theory for the control of the VSC (Voltage Source Converter) in the STATCOM. It takes a feed back of the grid voltage and source current for the compensation of the lagging power factor. The static device used is ultra capacitor with controlled DC link voltage VSC. IRP controller allows an increase in transfer of apparent power through a transmission line and much better stability by the adjustment of parameters that govern the power system. The designed controller with variation of DC link voltage has been applied to the STATCOM and suitable DC link voltage has been selected on basis of spike and overshoot of response. The total design and analysis is carried out in MATLAB Simulink Software with complete graphical representation.*

KEYWORDS: *STATCOM, IRP, Controller Design, PI Controller, MATLAB*

I. INTRODUCTION

In recent year's power systems have become very complex with interconnected long distance transmission lines. The interconnected grids tend to become unstable as the heavy loads vary dynamically in their magnitude and phase angle and hence power factor. Commissioning new transmission systems are extremely expensive and take considerable amount of time to build up. Therefore, in order to meet increasing power demands, utilities must rely on power export/import arrangements through the existing transmission systems. The capacitor banks are used to improve power factor but having a number of disadvantages. One of the main components to form a major part is the reactive power in the system. It is required to maintain the voltage to deliver the active power through the lines. To improve the performance of ac power systems, we need to manage this reactive power in an efficient way and this is known as reactive power compensation. Two types of compensation can be used: series and shunt compensation. The FACTS (Flexible AC Transmission Systems) devices, such as STATCOM has been introduced more recently which employs a VSI with a fixed DC link capacitor as a static replacement of the synchronous condenser. In a traditional synchronous condenser, the field current of the synchronous motor controls the amount of VAR absorbed/injected and hence in a similar way, the firing instant of the 3-phase inverter controls the VAR flow into or out of the STATCOM. This paper describes the modelling of STATCOM in which linear controller of current and voltage is replaced by IRP (Instantaneous reactive power) controller. The Instantaneous Reactive Power (IRP) p-q Theory is based on the Clarke Transform of voltages and currents in three-phase systems into α and β orthogonal coordinates. The IRP controller allows an increase in transfer of apparent power through a transmission line and much better stability by the adjustment of parameters that govern the power system. The static device used is a ultra capacitor with controlled DC link voltage through VSC. The total design and analysis is carried out in MATLAB Simulink software with complete graphical representations and THD FFT analysis.

II. MODELING OF THE STATCOM AND ANALYSIS

2.1 Operating principle

The operating principles of the STATCOM can be explained by considering the per-phase fundamental equivalent circuit of the STATCOM system as shown in Fig. 1a. An equivalent voltage source is connected to the ac mains through a reactor L_s having a resistance R_s representing the total losses in the inductor, including the converter. If the fundamental component of the output voltage of the STATCOM is in-phase with the supply voltage then the current flowing out or towards the STATCOM is always 90_ lagging or leading to the supply voltage as given in Fig. 1b. The STATCOM can also operate, when terminal voltage (fundamental) of the STATCOM is greater than the supply and lagging (and then current will lead the supply voltage). The STATCOM will then operate in fully capacitive mode supplying reactive power of the system. In case STATCOM current lags the system voltage, the STATCOM will operate in inductive mode injecting reactive VARs into the system. This is shown in Fig. 1c. By controlling the phase angle a of the STATCOM terminal voltage with respect to the phase of the source voltage, the dc-link capacitor voltage can be changed and hence the amplitude (of the fundamental component) of the STATCOM terminal voltage can be controlled. In other words, the reactive power either generated or absorbed by the phase angle between the STATCOM output voltage and the supply voltage. STATCOM can be controlled only by one parameter—the phase angle between the STATCOM output voltage and the supply voltage.

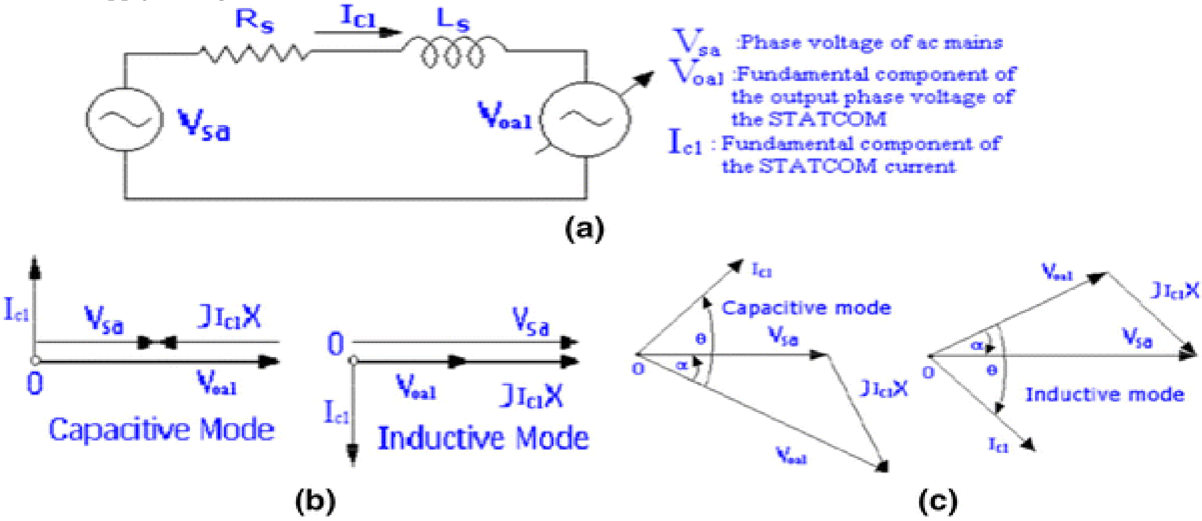

Fig. 1 a) Per-phase fundamental equivalent circuit, b) phasor diagram for operation of STATCOM in both modes in-phase and c) capacitive mode

2.2 System Modelling

The schematic diagram of STATCOM is shown in Fig. 2. The primary modelling of the STATCOM has been presented by the authors using (d-q) transformation. However, for easy reference, the modelling of the above is briefly revisited here. The 3-phase grid voltage, $v_{s;abc}$ lagging with the phase angle difference 'a' to the STATCOM converter terminal voltages $v_{o;abc}$ can be expressed as

$$v_{s,abc}=\begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} = \sqrt{\frac{2}{3}}\, v_s \begin{bmatrix} sin(\omega t-\alpha) \\ sin\left(\omega t-\alpha-\frac{2\pi}{3}\right) \\ sin\left(\omega t-\alpha+\frac{2\pi}{3}\right) \end{bmatrix} \quad (1)$$

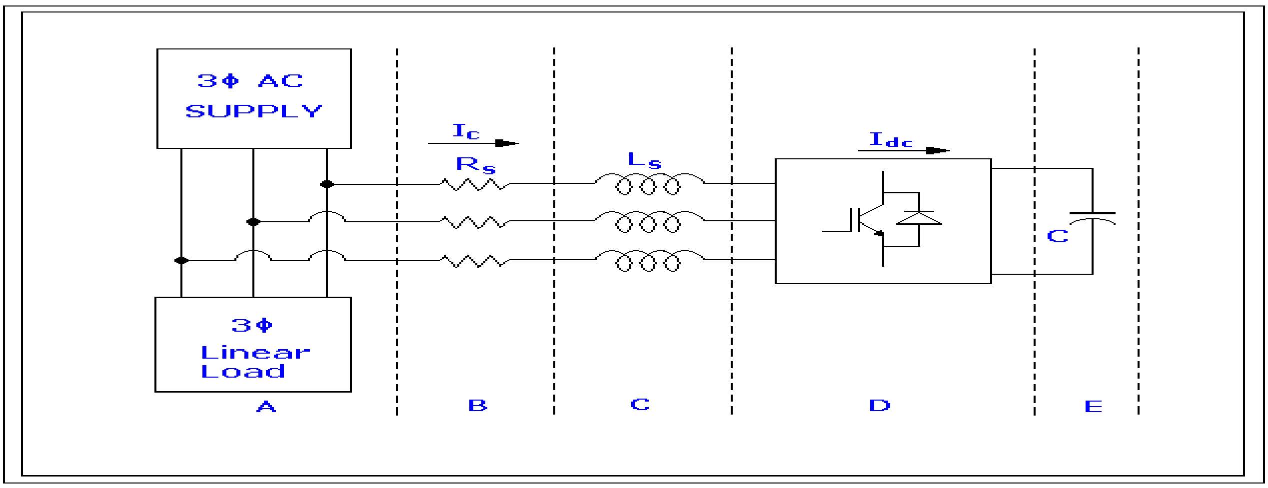

Fig. 2 Simplified main circuit diagram of the STATCOM

$L_s \frac{d}{dt}(i_{c,abc}) = -R_c i_{c,abc} + v_{s,abc} - v_{o,abc}$ -υ_{oabc} (2)

where, υ_s,□□,Rs and Ls have their usual connotations. The above voltages and currents are transformed into *dq* frame,

$$L_s \frac{d}{dt}(i_{cq}) = -R_c i_{cq} - wL_s i_{cd} + V_{sq} - V_{oq} \quad (3a)$$

$$L_s \frac{d}{dt}(i_{cq}) = -R_c i_{cq} - wL_s i_{cd} + V_{sq} - V_{oq} \quad (3b)$$

The switching function *S* of the STATCOM can be defined as follows

$$S=\begin{bmatrix} Sa \\ Sb \\ Sc \end{bmatrix} = \sqrt{\frac{2}{3}} m \begin{bmatrix} Sin(\omega t) \\ Sin\left(\omega t - \frac{2\pi}{3}\right) \\ Sin\left(\omega t + \frac{2\pi}{3}\right) \end{bmatrix} \quad (4)$$

$$MI = \frac{v0, peak}{Vdc} = \sqrt{\frac{2}{3}} \quad (5)$$

The STATCOM output voltages in *dq* transformation amd The dc side current in the capacitor in *dq* transformation are

υ_0,qd$_0$= $m[0\ 1\ 0]^T$ υ_{dc}

$i_{dc=}$ m $[0\ 1\ \ 0][icq\ \ icd\ ico]^T$

The voltage and current related in the dc side is given by

$$\frac{d\upsilon\ dc}{dt} = \frac{m}{C} i_{cd} \quad (6)$$

The complete mathematical model of the STATCOM in *dq* frame is obtained as given in (8),

$$\frac{d}{dt}\begin{bmatrix} icq \\ icd \\ \upsilon cd \end{bmatrix} = \begin{bmatrix} \frac{Rs}{Ls} & -w & 0 \\ w & -\frac{Rs}{Ls} & -\frac{m}{Ls} \end{bmatrix} \begin{bmatrix} icq \\ icd \\ \upsilon cd \end{bmatrix} + \frac{Vs}{Ls}\begin{bmatrix} -sin\alpha \\ Cos\alpha \\ 0 \end{bmatrix} \quad (7)$$

III. INSTANTANEOUS REACTIVE POWER CONTROLLER

This theory is very efficient and flexible in designing controllers for power coordinaters based on power electronic devices(Proposed by Akagi in 1983)The Instantaneous Reactive Power **(**IRP**)** p-q Theory is based on the Clarke Transform of voltages and currents in three-phase systems into α and β orthogonal coordinates. Power properties of three-phase systems are described by the IRP p-q Theory in two orthogonal α and β coordinates in terms of two, p and q instantaneous powers.

3.1 Instantaneous P-Q Theory

The p-q theory uses a -b - 0 transformations and various definitions of active and reactive powers. The transformation of 3-Phase quantities (a-b-c) of stationary reference frame into 2-Phase quantities (a -b - 0) stationary reference frame is achieved by applying Clark's transformation and the calculation of instantaneous active and reactive power in this frame. ea, eb and ec, iLa, iLb and iLc are fed to the controller, and these quantities are processed to generate reference currents. The switching signals for the STATCOM is generated by comparing source current and reference current

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (8)$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (9)$$

Let the instantaneous real, imaginary and zero sequence power denoted by p, q and p0 respectively. Then the three phase instantaneous power is given by

$$P_{3\emptyset}=vaia+vbib+vcic \quad (10)$$

Using the transformation

$$P_{3\emptyset}\, P_{3\emptyset}\,(t) = va\ ia + vb\ ib + v0\ i0$$

$$P_{3\emptyset}P_{3\emptyset}\,(t)=p(t)+\ p_0\,(t) \quad (11)$$

$$q=v_\alpha i_\beta - v_\beta i_\alpha = \frac{1}{\sqrt{3}}\{i_a(v_c-v_b)+i_b(v_a-v_c)+i_c(v_b-v_a)\} \quad (12)$$

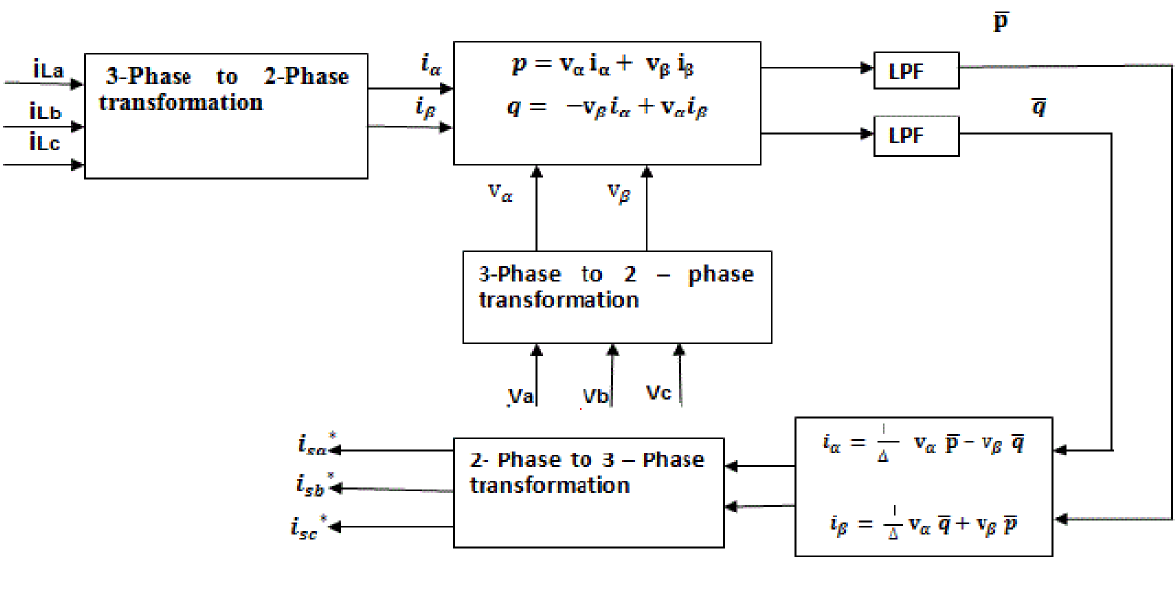

Fig.3 Block diagram of IRPT control algorithm

It represents an energy that may be constant or not and that is being exchanged between the phases of the system. This implies that q does not contribute to the energy transfer between the source and the load at any time. From Eq. (8)-(9), we write p and q as following

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{pmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{pmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (13)$$

The instantaneous active and reactive powers p and q can be decomposed into an average and an oscillatory component.

P=P- +P~

q=q- +q~

P~ = Mean value of the instantaneous real power. It corresponds to the energy per time unity that is transferred from the power source to the load, in a balanced way, through the a-b-c coordinates (it is, indeed, the only desired power component to be supplied by the power source).

P~ = Alternating value of the instantaneous real power. It is the energy per time unity that is exchanged between the power source and the load, through the a-b-c co- ordinates. Since p" does not involve any energy transference from the power source to load, it must be compensated.

Therefore the reference source currents i sα and i sβ in α-β coordinate are expressed as:

The instantaneous currents on the $\alpha - \beta$ coordinates, i_α and i_β are divided into two kinds of instantaneous current components respectively. Finally, through $\alpha - \beta - 0$ inverse transformation we compute the filter reference currents in a –b-c phase system

$$\begin{bmatrix} i^{*fa} \\ i^{*fb} \\ i^{*fc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} -i_0 \\ i^{*f\alpha} \\ i^{*f\beta} \end{bmatrix} \quad (14)$$

Where io is the zero sequence component which is zero in 3- phase 3-wire system. The extracted current components are followed by hysteresis based PWM current controller to generate switching pluses and these signals are applied to STATCOM .The p-q theory has the following limitations: The source voltages are unbalanced and non-sinusoidal. It needs a large number of transducers of measurements and intensive computation. It tends to make the system operation complex.

IV. SIMULINK MODEL

4.1 Simulation model without STATCOM Compensator

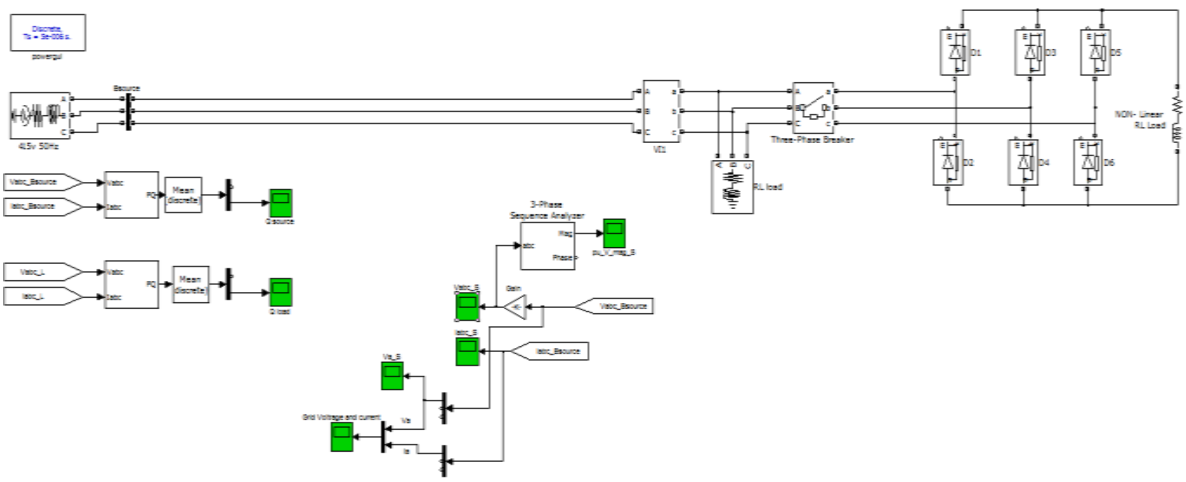

Fig.4 Simulink model of three phase grid system without compensator

The power system consists of a three phase source of 415V, 50Hz which supplies real and reactive power to a combination of RL Nonlinear loads connected to linear load with the help of circuit breaker. The nonlinear load is switched on at time 0.4 sec. In this condition, source (grid) is responsible for handling the total real power and reactive power demands of the load. Nonlinear loads connected to linear load with the help of circuit breaker. The nonlinear load is switched on at time 4 sec. The waveform is distorted after 4 sec.

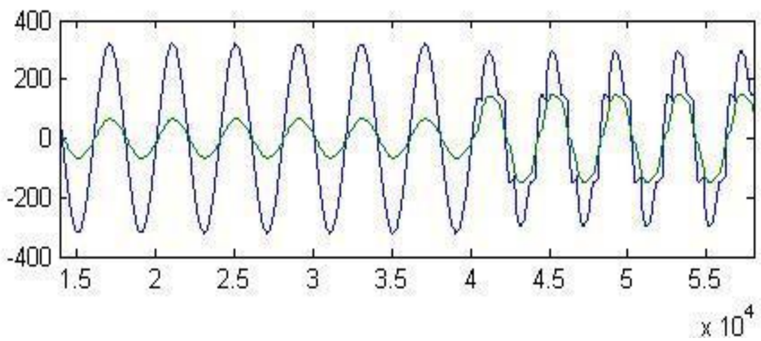

Fig.5 Shows Grid Voltage and Current waveform

4.2 Simulation model of Linear Controller STATCOM

The control scheme for controlling DC link voltage as well as *d* and *q* axes current of STATCOM simultaneously as shown in Fig. 6 is implemented with MATLAB SIMULINK with the parameters given in Table. I. The PI controller is applied at DC link voltage and reference current for controlling *q* axis current of STATCOM is generated from the *q* axis of the linear load currents. The generated reference output voltages of *d* and *q* -axes are transformed to α and β axis and then *abc* axes. All the relevant outputs are shown below. The sub system1 shows 3Φ to dq transformation as in fig.The waveforms shows that at time 0.4sec circuit breaker operates and statcom is connected to the nonlinear load which is RL load.

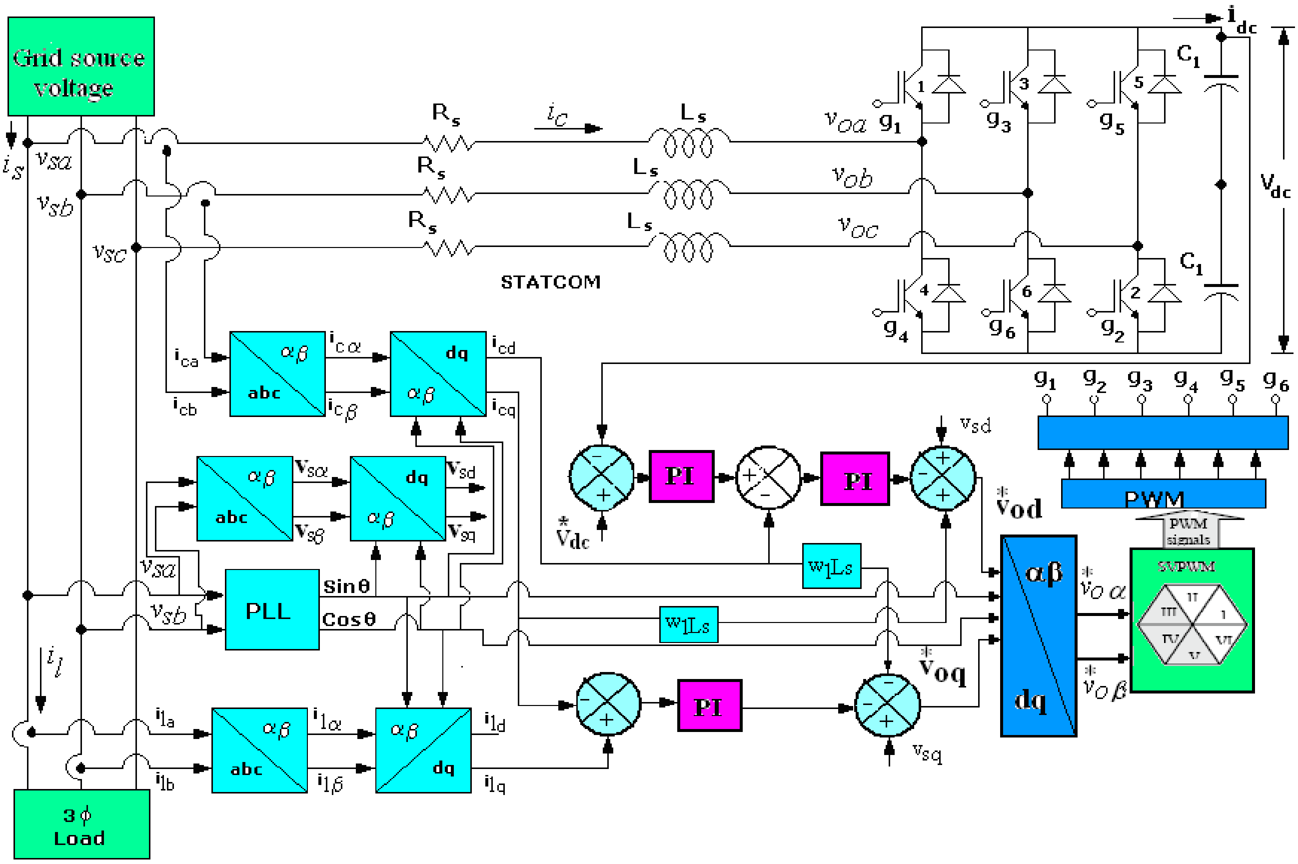

Fig.6 Implementing scheme of STATCOM

Table No.1. MATLAB SIMULINK Parameters

Sr.No.	Parameters	Symbol	Values
1	Frequency	*F*	50 Hz
2	Angular Frequency	*W*	314 rad/sec
3	RMS line-to-line Voltage	Vs	230V
4	Coupling Resistance	*Rs*	1.0 Ω
5	Coupling Inductance	*Ls*	5.0mH
6	DC link capacitor	C	500µ*F*
7	Modulation Index	M	0.979
8	Phase angle	A	± 5°
9	Load Resistance	R_L	52Ω
10	Load Inductance	L_L	126*mH*
11	Load Power factor	Φ	0.79

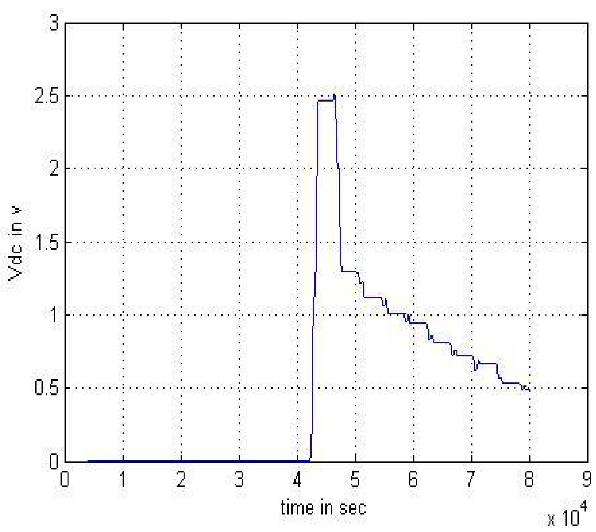

Fig.7. Shows Dc link Voltage Waveforms

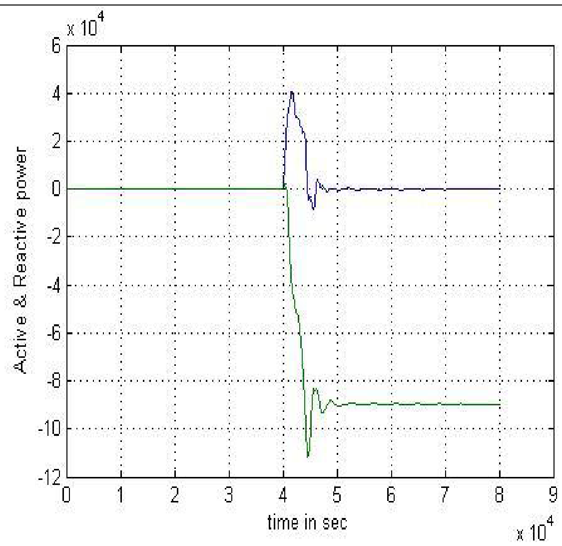

Fig.8. Active and Reactive Power Waveforms

4.3 Simulation model of IRP Controller STATCOM

The simulink model of the STATCOM with instantaneous reactive power theory control is shown in Fig.9.

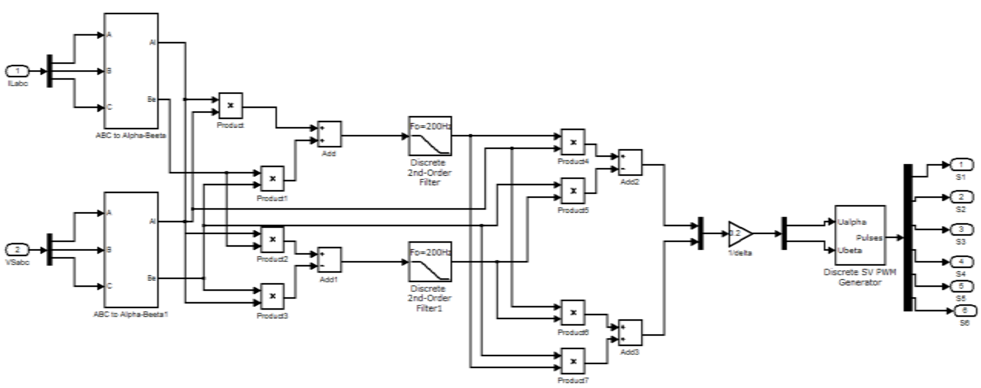

Fig.9. Simulink model instantaneous reactive power theory

Fig.10. are the voltage and current wave forms of the three phase system, taken at the source(grid)side.Fig.11. shows active and reactive power waveforms and Fig.12. shows a Dc link voltage waveforms. The dynamics and unbalance conditions are simulated as per the previous case. The delay in compensation can be seen from source current waveforms. This delay is due to the low pass filter (LPF) used for filtering power signals. Moreover, p-q theory uses voltage signals to compute instantaneous active and reactive powers, any distortion and unbalance in voltage will lead to inaccurate calculation of reference source currents which should contain only real fundamental frequency component of load current. Fundamental frequency(50Hz)=403.5 and THD is 1.16% .

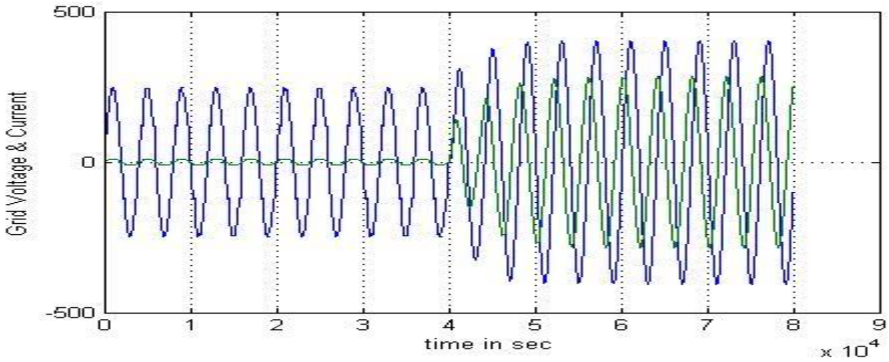

Fig.10. Grid Voltage and Current Waveform

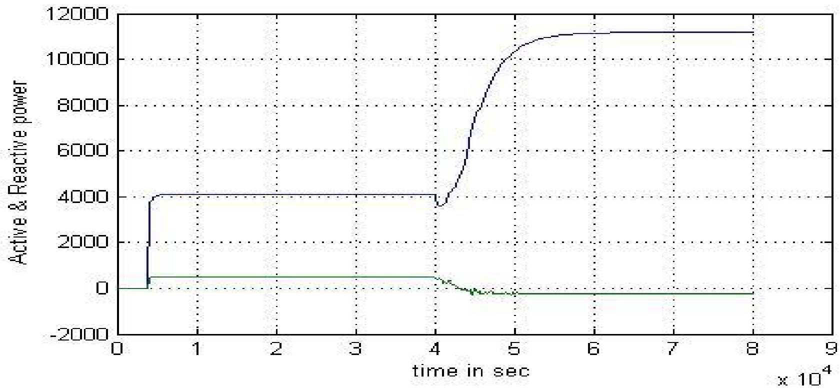

Fig.11. Shows Active and Reactive Power Waveforms

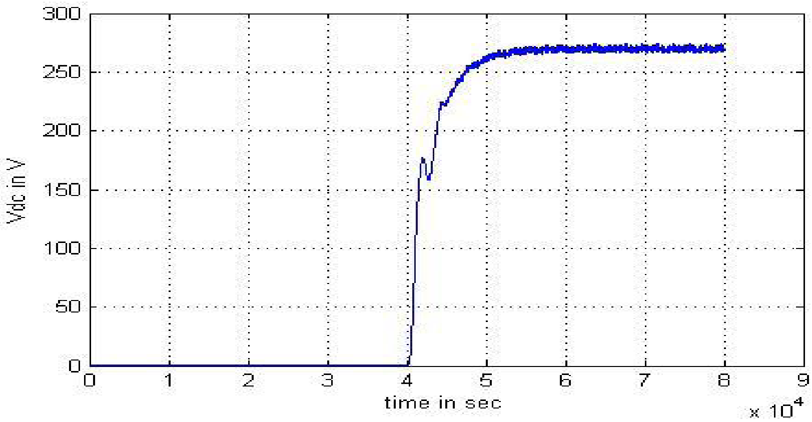

Fig.12. Shows Dc link Voltage Waveforms

A comparison between PI controller and IRP theory control algorithm for generating control pulses for the STATCOM are done based on their performance parameters. STATCOM unit with IRPT control pulses provide better source voltage THD with better power factor.

Table No 1. Comparison of STATCOM With or Without IRP

	Source current THD (%)	Input power factor	Real and Reactive power	Source voltage THD(%)
With STATCOM compensator	23.2	0.667	P=2816Var Q=23.65w	26.97
STATCOM with Instantaneous Reactive Power Theory Algorithm	5.658	0.8815	P=1867Var Q = 1000w	6.67

V. CONCLUSION

In this paper, complete analysis of PI controller and IRPT controls algorithm of statcom application are presented. The controllers design on basis of parameters of the statcom shown in Table 1. The controllable reactive power allows for a rapid control of bus voltage and power factor at the system or at the load end. To compensate for the distorted current drawn by the rectifiers from the utility grid, the STATCOM and its current controller must have the capability to track source PWM (Pulse Width Modulation) converters. The present paper suggests the design of a linear current controller and voltage controller on the basis of gain and time constant adjustment along with the parameter of the coupling inductor and storage capacitor. The settling time of the system by using the PI controller is faster than other controllers. A comparative study has been done for the control algorithms to achieve above objectives. From the study it is clear that IRP theory control algorithm is better than PI controllers. PI controller is complicated because it uses Parks transformation. IRP theory consumes time of operation, it reduces harmonic distortion and provide better performance with input power factor of 0.8815 and source voltage and current THD of 6.67, 5.658 respectively.

VI. FUTURE SCOPE

To improve performance of power system, the future scope for this dissertation work is as follows;

-Here performance of the system is verified using STATCOM.

-This work also can also be extended using any FACTS Devices hence the performance of power system can be verified by using FACTS Devices.

-Here, IRP theory used to control Statcom .The Adaline based control technique can be used to control Statcom.

IRP theory can also be used for DSTATOM (Distribution Statcom).

REFERENCE

[1] C.L.Wadhwa, “Electrical Power Systems”, Wiley Eastern Ltd, New Delhi

[2] N. G. Hingorani, and L. Gyugyi, "Understanding FACTS, Concepts and Technology of Flexible AC Transmission Systems", IEEE Press book,2000.

[3] P.Kundur, “Power System Stability and Control”, EPRI, Power Engineering Series, 1994.

[4] S.K.Sethy and J.K.Moharana" Design, Analysis and Simulation of Linear Controller of a STATCOM for Reactive Power Compensation on Variation of DC link Voltage" IEEE TRANSACTIONS ON POWER ENERGYAND CONTROL, Volume:28 , Issue: 1, FEB 2013.

[5] Mr.CH. Venkata Krishna Reddy, DR. K.Krishna Veni, Dr.G.Tulsiram Das AND DR. Sampath.Pulla "Performance analysis of d-statcom compensator using control techniques for load compensation" International Journal of Electrical and Electronics Engineering Research (IJEEER) Vol.1, Issue 2 Dec 2011 149-171.

[6] Dayananda. B, Velappagari Sekha, Dr. Ramesh Babu" Implementation of Linear Controller of a STATCOM Design in DC Link Voltage" International Journal of Emerging Technology and Advanced Engineering (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 4, Issue 9, September 2014)

[7] Leszek S. Czarnecki" Instantaneous Reactive Power p-q Theory and Power Properties of Three-Phase Systems" IEEE Transactions on Power Delivery, Vol. 21, No.1, Jan. 2006, pp. 362-367.

[8] A. Albakkar, Student O.P. Malik, LFIEEE W. Rosehart, MIEEE,"ADALINE Network Based Adaptive Controller for STATCOM,"IEEE Press book,2006.

[9] Anu Raveendran, Beena M Varghese, Smitha Paulose " Power Quality Improvement using STATCOM with Different Control Algorithms " International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering " Vol. 3, Special Issue 5, December 2014

[10] Akagi, Y. Kanazawa and A. Nabae, "Generalized theory of the instantaneous reactive power in three-phase circuits," in Proc. of IEEE IPEC, 1983, pp. 821-827.