Hysteresis Band Current Controller for Voltage Regulation and Harmonic Mitigation using DSTATCOM

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Abstract- *This paper presents, Distribution Static Compensator (DSTATCOM) used for voltage regulation and harmonic mitigation in the three phase distribution system. Six pulse voltage source converter (VSC) is used as DSTATCOM with DC bus capacitor. Instantaneous Reactive Power Theory (IRP) and Synchronously Rotating Reference Frame Theory (SRF) is used for controlling the DSTATCOM. Using MATLAB and Sim Power System toolboxes (SPS), Simulink model of DSTATCOM is presented. Results of simulation of IRP and SRF theories are studied when linear as well as nonlinear loads are connected to the 3 phase distribution system. Experimental results are discussed and compared for both the theories used in this paper.*

Keywords-DSTATCOM, Voltage Source Converter (VSC), Voltage Regulation, Harmonic mitigation, IRP Theory, SRF Theory.

I. INTROUCTION

In the present age reactive power is largely consumed by the inductive loads such as motors, pumps, and compressors etc. which are mainly installed at the distribution side. These inductive loads consume large reactive power. To have the proper operation of electrical power supply system, frequency as well as voltage should remain at the standard level throughout the process and voltage control problems are greatly dependent upon the reactive power [1]. It is challenging to maintain standard voltage all the time, because electrical distribution system experiencing local voltage collapses. A capacitive load delivers reactive power and improves voltage level in the contrary inductive loads absorbs reactive power and reduces voltage level across load at distribution system [2].

At the time of system stress large amount of current flows through the load and there is a reactive power absorption which reduces the voltage level. At present age voltage regulationcan be achieved with the help of under load tap changers(ULTC) used in regulating transformers, and shunt capacitors, shunt reactors, synchronous condensers, Static VAR Compensators(SVC) which provides reactive power etc.[1-5].

With the use of non-linear loads and power electronic converters in the industries, the power system voltage and current waveform gets deteriorated. The main reason for interfacing problems in the communication systems,large power losses in the distribution system are due to the presence of harmonicsin the waveforms. To compensate these problems passive elements have been used, but they have several disadvantage such as they only filter the frequencies they were previously tuned for. So to cope with this problem, concentration is made on active elements.

In the present distribution system reactive power is compensated using DSTATCOM.Instantaneous Reactive Power (IRP) Theory,Synchronously Rotating Reference Frame (SRF) Theory, Instantaneous Symmetric Component Theory, Current Component using DC Bus Voltage Regulation[7-10] are the theories used for generating reference currents for controlling the DSTATCOM. This paper states the controlling of DSTATCOM taken place through IRP and SRF theory for the compensating the reactive power at the distribution system.

This paper shows that, Distribution Static Compensator (DSTATCOM) is employed with the help of 3 limb Voltage Source Inverter (VSI), with a capacitor providing DC source [6]. By sensing Point of Common Coupling (PCC) voltage and DC bus voltage the reference currents are generated to create gate pulses to the inverter. Two Proportional andIntegral (PI) controllers are employed one for DC bus capacitor voltage regulation and other for AC bus voltage regulation at the distribution end. Using MatLab simulation model of DSTATCOM is employed.MATLAB simulation results are studied for voltage regulation as well as for harmonic mitigation during transient as well as steady state operation.

II. SYSTEM STRUCTURE

In Fig.1.basicbuilding block of DSTATCOM is shown. Here inductive loadsas well as nonlinear loads are connected to three phase three wire distribution system. Star connected resistance and inductance is used to realize linear loadand nonlinear load is connected as Diode Bridge with resistance and inductance. DSTATCOM is connected as a shunt compensator which is configured with three phase Insulated Gate Bipolar Transistor (IGBT) based three limb, 6 pulse Voltage Source Converter (VSC) Bridge, with the input DC bus capacitor. Output AC voltage is given to Distribution system through coupling inductors. Control techniques are used to control gate pulses given to voltage source converter DSTATCOM. Actual DC voltage at DC bus capacitor is sensed by PI controller I and maintains DC bus voltage constant. AC bus voltage at PCC is maintained constant using PI controller II. Using MatLab simulation model of DSTATCOM is employed.

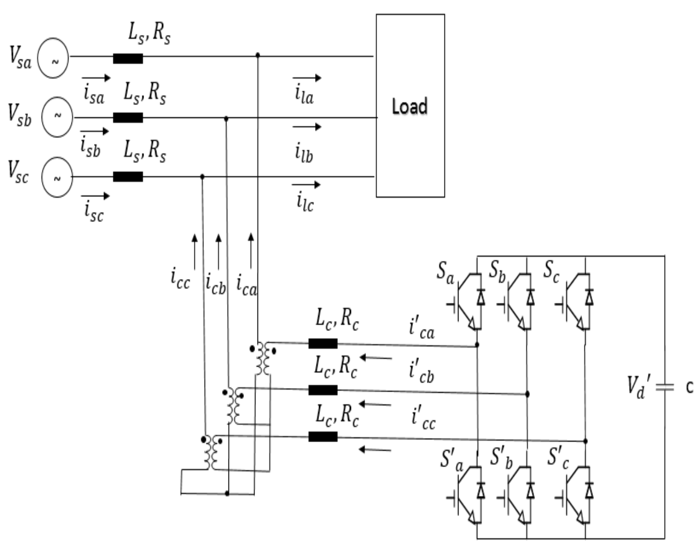


Fig. 1. Basic building block of DSTATCOM system

III. CONTROL SCHEME

Reference currents which are generated using IRP and SRF theories, has fundamental frequency component of load current. Here by controlling DSTATCOM, reactive power required by load is provided and hence voltage regulation at the load end is achieved and also the harmonic contents in the source currents are eliminated. In addition to IRP and SRF theories, PI controllers are used forcapacitor bus voltage regulation as well as other is for AC bus voltage control at the PCC.

A. Instantaneous Reactive Power Theory

IRP theory was initially recommended by Akagi [7]. In IRP theory 3-ph AC quantities are converted into 2-ph stationary reference frame quantities, using Clark's Transformation. Using 2-ph voltage and current quantities instant active and reactive powers are generated [7-8].In fig. 2. the basic building block of IRP theory is shown, where 3-ph source voltages (V_{sa}, V_{sb}, V_{sc}) and 3-ph load currents (I_{la}, I_{lb}, I_{lc}) are taken as input, after that 3-ph reference currents(I_{sar}, I_{sbr}, I_{scr}) are generated which are then given to Hysteresis Band Current Controller [11] to produce gate pulses of DSTATCOM.

Clarks Transformation for source voltages and load current is,

$$\begin{bmatrix} V_{s\alpha} \\ V_{s\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \sqrt{\frac{3}{2}} & -\sqrt{\frac{3}{2}} \end{bmatrix} \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} I_{l\alpha} \\ I_{l\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \sqrt{\frac{3}{2}} & -\sqrt{\frac{3}{2}} \end{bmatrix} \begin{bmatrix} I_{la} \\ I_{lb} \\ I_{lc} \end{bmatrix} \quad (2)$$

α-βaxes are orthogonal coordinate. And from these voltages and currents instantaneous activepower and reactive poweris calculated as follows,

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} V_{s\alpha} & V_{s\beta} \\ -V_{s\beta} & V_{s\alpha} \end{bmatrix} \begin{bmatrix} I_{l\alpha} \\ I_{l\beta} \end{bmatrix} \quad (3)$$

Fig. 2 shows 2 PI controllers, I is used for compensation of loss component of active power which is due to losses occurring due switching of the inverter which is given by,

$$P(n) = P(n-1) + K_p\{V_{dc}(n) - V_{dc}(n-1)\} + K_i\{V_{dc}(n)\} \quad (4)$$

Where, $V_{dc}(n) = V_{dcref}(n) - V_{dcact}(n)$ is error between actual capacitor voltage V_{dcact} and reference capacitor voltage V_{dcref},$K_p$and $K_i$are proportional and integral PI controller gains, of DC bus voltage.

PI controller II is used for AC voltage regulation where reference AC voltageis compared with actual AC voltage at the Point Of Common Coupling and error is given to PI controller, which calculates the reactive power needed by the load. AC voltage magnitude is calculated as,

$$V_{pcc} = (2/3)^{1/2} (V_{sa}^2 + V_{sb}^2 + V_{sc}^2)^{1/2} \quad (5)$$

PI controller gives output voltage as,

$$Q(n) = Q(n-1) + K_p\{V_{ac}(n) - V_{ac}(n-1)\} + K_i\{V_{ac}(n)\} \quad (6)$$

Where $V_{ac}(n) = V_{pccr} - V_{pcc}(n)$, is linear error between actual voltage $V_{pcc}$and reference voltage V_{pccr}.$K_{pq}$and K_{iq} are proportional and integralPI controller gains.

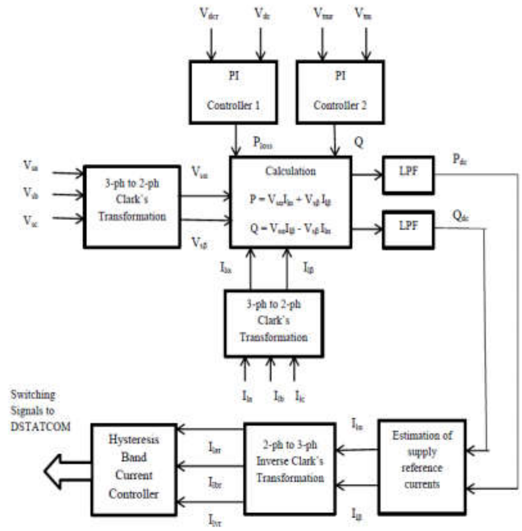


Fig. 2 .Basic building block ofIRP theory

Active and reactive power obtained from equation (4) and (6) are added to equation (3) and by taking inverse of equation (3) we get,

$$\begin{bmatrix} I_{l\alpha r} \\ I_{l\beta r} \end{bmatrix} = \frac{1}{V_{s\alpha}^2 + V_{s\beta}^2} \begin{bmatrix} V_{s\alpha} & -V_{s\beta} \\ V_{s\beta} & V_{s\alpha} \end{bmatrix} \begin{bmatrix} P \\ Q \end{bmatrix} \quad (7)$$

And then by taking Inverse Clarks Transformation, three phase reference currents are generated,

$$\begin{bmatrix} I_{lar} \\ I_{lbr} \\ I_{lcr} \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3/2} \\ -1/2 & -\sqrt{3/2} \end{bmatrix} \begin{bmatrix} I_{l\alpha r} \\ I_{l\beta r} \end{bmatrix} \quad (8)$$

And finally, these reference currents are provided to Hysteresis Band Current Controller [11] to generate gate pulses of DSTATCOM.

B. Synchronously Rotating Reference Frame Theory

Synchronously Rotating Reference Frame (SRF) Theory uses conversion of 3 phase a-b-c quantities to 2 d-q phase synchronously rotating reference frame quantities [9-10]. Fig. 3 shows the basic building block of SRF theory. As shown in the Fig. 3, 3- phase load currents (I_{la}, I_{lb} , I_{lc}), are given to the Parks Transformation which gives 2- phase synchronously rotating reference frame currents (I_{ld},I_{lq}).

Park's Transformation is given below,

$$\begin{bmatrix} I_{ld} \\ I_{lq} \\ I_{l0} \end{bmatrix} = 2/3 \begin{bmatrix} \cos wt & -\sin wt & 1/2 \\ \cos(wt - \frac{2\pi}{3}) & -\sin(wt - \frac{2\pi}{3}) & 1/2 \\ \cos(wt + \frac{2\pi}{3}) & \sin(wt + \frac{2\pi}{3}) & 1/2 \end{bmatrix} \begin{bmatrix} I_{la} \\ I_{lb} \\ I_{lc} \end{bmatrix} \quad (9)$$

Where wt=θ which is transformation angle, calculated by using Phase Locked Loop (PLL) [12] circuit. Inputs to the PLL is three phase AC voltages V_{sa},,V_{ab}, V_{sc} as shown in the Fig. 3.

Similar to the IRP theory, as shown in fig.3 two PI controllers are used one for DC bus capacitor voltage regulation and other for AC bus voltage regulation.

2-phase synchronously rotating reference frame currents $I_{ld}$and I_{lq}has oscillatory as well as DC component, so that the Low Pass Filters (LPF) are used to separate them and only DC components are passed further.

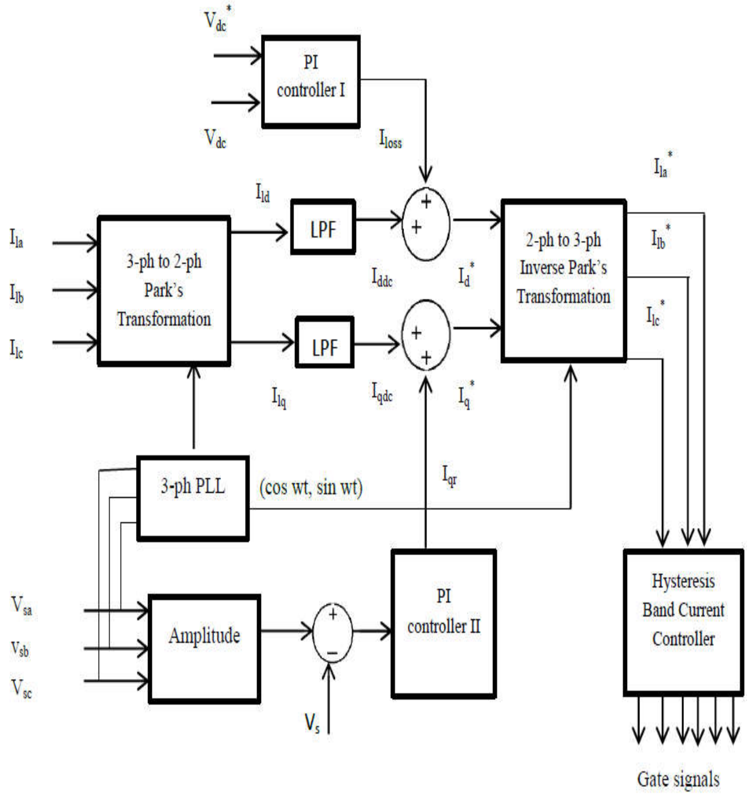


Fig.3. Basic building blockSRF theory

Again by using Inverse Park's Transformation, d-q reference frame currents are converted to a-b-c reference frame currents as shown below,

$$\begin{bmatrix} I_{la}^* \\ I_{lb}^* \\ I_{lc}^* \end{bmatrix} = 2/3 \begin{bmatrix} \cos wt & \cos\,(wt - \frac{2\pi}{3}) & \cos(wt + \frac{2\pi}{3}) \\ -sinwt & -\sin(wt - \frac{2\pi}{3}) & \sin(wt + \frac{2\pi}{3}) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} I_{ld} \\ I_{lq} \\ I_{l0} \end{bmatrix} (10)$$

And similar to IRP theory these 3-phase currents are supplied to Hysteresis Band Current Controller [11] to create gate pulses to DSTATCOM.

IV. DSTATCOM MODELLING IN MATLAB

Fig. 4.Shows the 3-phase 3-wire distribution system, where 3-phase source, 3-phase load is connected. DSTATCOM as a shunt compensator is connected at the load end. Linear load of resistance and inductance is connected as well as nonlinear load of diode rectifier with R-L load is present.Simulation of this DSTATCOM model isprepared with the above described IRP and SRF theories. Fig.5(a),(b) shows Simulink models of IRP and SRF theories shown in fig. 2. andfig. 3.

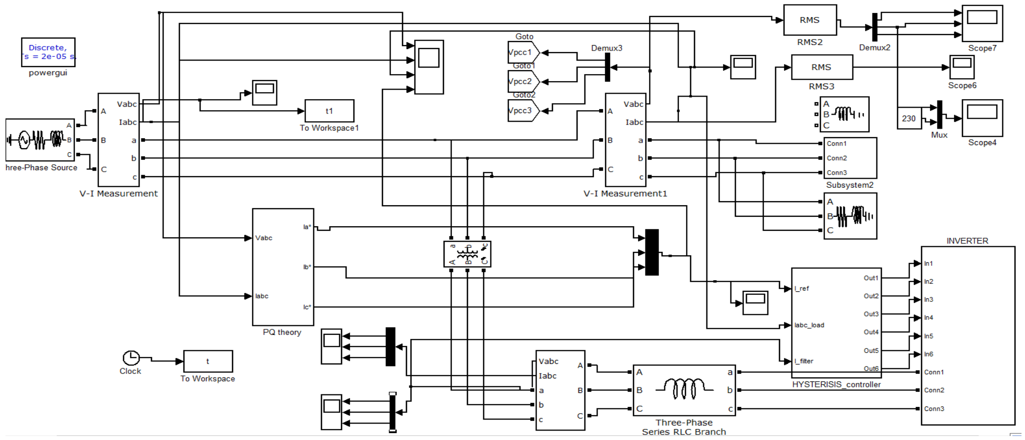


Fig. 4.DSTATCOM model in MATLAB simulation

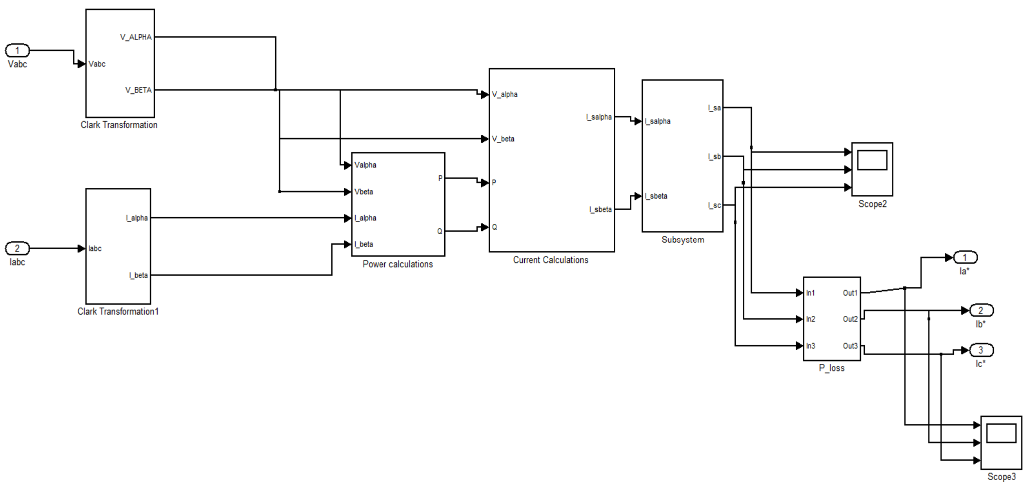


Fig. 5(a).Reference current generation using IRP theory in MATLAB simulation

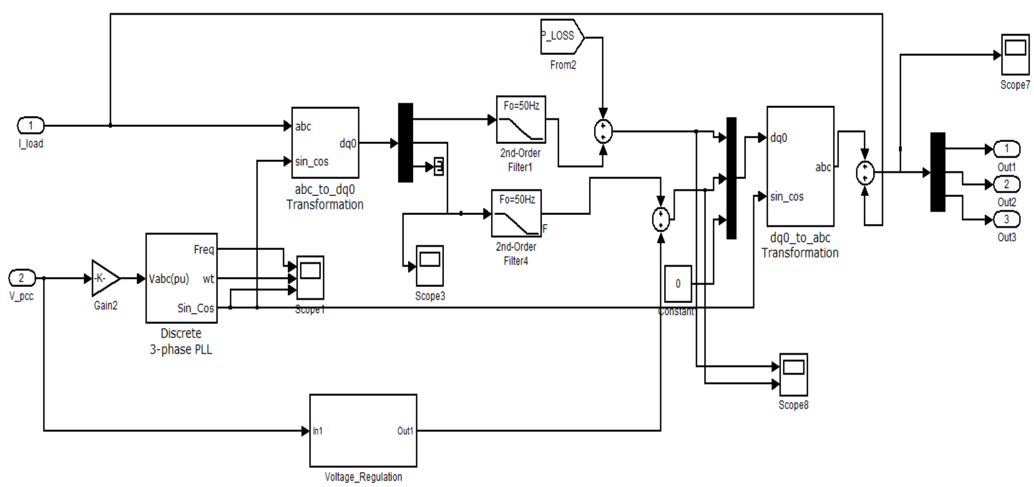


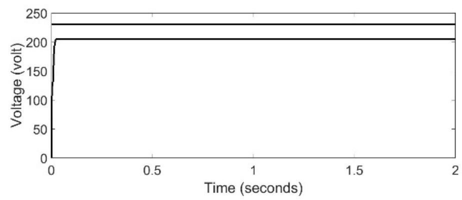
Fig. 5(b). Reference current generation using SRF theory in MATLAB simulation

V. SIMULATION RESULTS

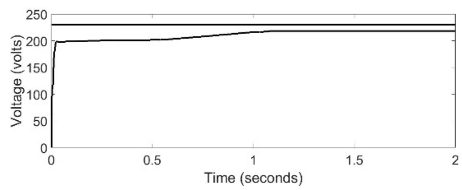
The performance of DSTATCOM is studied under the IRP and SRF theories and following results are observed. In this paper voltage regulation at load end and harmonic mitigation at source current is observed.

A. DSTATCOM control using IRP theory

Fig. 6. Shows voltage at the load end at the PCC, without compensation and then with compensation under the linear load of 23KW and 25 KVAR as well as nonlinear load of Diode rectifier with R-L load of 25Ω and 2e-5 henry. As shown in the fig 6(a) without compensation PCC voltage is 205v, and after compensation fig 6(b) it grows up to 222v. DC bus voltage maintained nearly to the reference value.



(a) Without compensation



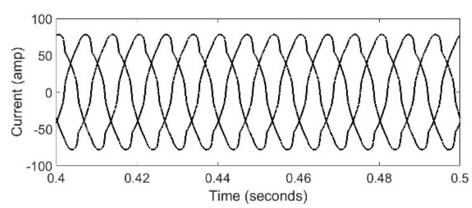
(b) With compensation

Fig.6.Voltage at the load end

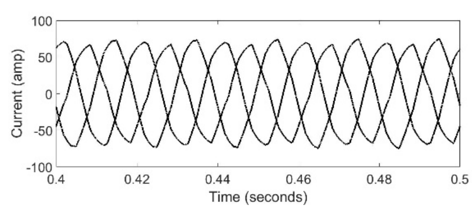
Fig. 7.Shows the harmonic elimination at source current. Because of nonlinear load source current contain harmonics fig.9(a) and due to compensating current fig 9(b) of DSTATCOM, which is injected to the circuit source current fig 9(c) become distortion free.

Table I: Voltage regulation and harmonic compensation using IRP theory

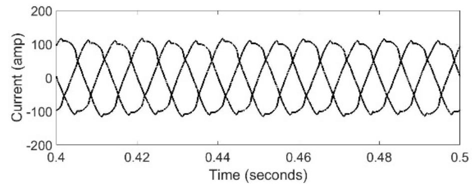
	Voltage at PCC (volts)	%THD at source current
Without compensation	205	8
With compensation	222	4



(a) Source current without controller



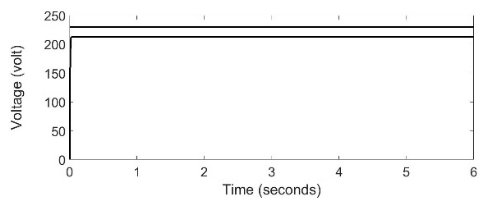
(b) Compensator current



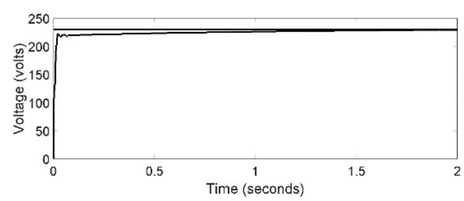
(c) Source current with controller

Fig. 7.Source current compensation

B. Control of DSTATCOM using SRF theory

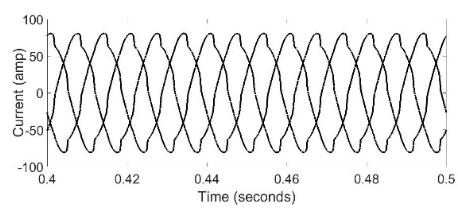


(a) Without compensation

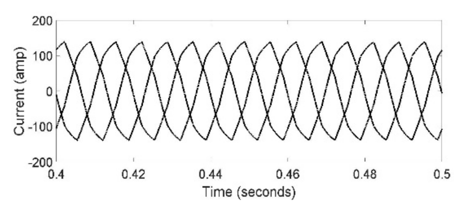


(b) With compensation

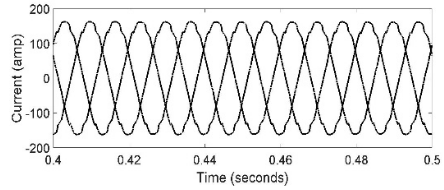
Fig. 8. Voltage at the load end



(a) Source current without controller



(b) Compensator current



(c) Source current with controller

Fig. 8.Source current compensation

Table II. Voltage regulation and harmonic compensation using SRF theory

	Voltage at PCC (volt)	**%THD at source current**
Without compensation	215	8
With compensation	232	2

Table II shows the results of SRF theory, where same linear as well as nonlinear load is connected as for the IRP theory.

VI CONCLUSION

In this paper the performance analysis of IRP and SRF theories for reference current generation under linear as well as nonlinear load based on simulation study is discussed. Comparative analysis shows that Synchronously Rotating Reference Frame Theory gives better results than Instantaneous Reactive Power theory in terms of voltage regulation as well as harmonic compensation at source currents.

REFERENCE

[1] PrabhaKundur, "Power system Stability and Control", McGraw-Hill,1994.

[2] John D. Kueck, D. Tom Rizy, Frangzing(Fran) Li, Yan Xu, Huijuan Li, "Local Dynamic Reactive Power for Correction of System Voltage Problems", OakRidge National Laboratory (ORNL),Oak Ridge,TN,Tech.Rep(ORNL/TM2008/174),Sep2008.

[3] Narain G. Hingoranai Laszlo GYugyi,"Understanding Facts, A JOHN WILEY & SONS", Inc., publication,2000.

[4] Dr D. R. Patil and U. Gudaru, "Firing Angle Range Control For Minimizing Harmonics in TCR Employed in SVC's", World Academy of Science, Engineering and Technology International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering Vol:5, No:8, 2011.

[5] U. GudaruandDr D. R. Patil, "An Innovative Transient Free Adaptive SVC inStepless Mode of Control", World Academy of Science, Engineering and Technology International Journal of Computer, Electrical, Automation, Control and Information Engineering Vol:5, No:5, 2011.

[6] Rahul S.AnkusheArjun Y. Bansode Vishal V. HandeDr.D.R.Patil, "Adaptive Control Schemes for DistributionSystem with DER" 2014 International Conference on Circuit, Power and Computing Technologies [ICCPCT].

[7] H. Akagi , E.H Watanabe, and M Aredes, "Instantaneous Reactive Power Theory and Application to Power Conditioning", Hoboken NJ:Wiley,2007.

[8] Bhim Singh, A.Adya,A.P. Mittal and J.R.P Gupta, "Modelling and Control of DSTATCOM for Three-phase, Four-wire Distribution Systems", IEEE conference 2005.

[9] D.M. Divan, S. Bhattacharya and B. Banerjee, "Synchronous frame harmonic isolator using active series filter",in Proc. Eur. Power Electron.Conf.,1991,pp.3030-3035.

[10] Bhim Singh, P.Jayaprakash, D P Kothari, "Three Single-Phase Voltage Source Converter Based Three-phase four wire DSTATCOM", third international conference in power systems, Kharagpur, India Dec 27-28, 2009.

[11] Murat Kale, Engine Ozdemir, "An adaptive hysteresis band current controller for shunt active power filter", Electrical Power System Research 73 (2005) 113-119.

[12] G.C.Hsieh and J.c.Hung, "Phase Locked Loop techniques. A Survey",IEEE Trans. Ind. Electron.,vol. 43, no. 6,pp.609-615,Dec.1996.