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Voltage Regulation and Harmonic Current Compensation in Three Phase Distribution System using DSTATCOM

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***Abstract*- In this paper, Distribution Static Compensator (DSTATCOM) is proposed for voltage regulation and harmonic elimination in the distribution system feeding commercial and domestic consumers. Three leg voltage source converter (VSC) configurations with a DC bus capacitor is employed as DSTATCOM. Instantaneous Reactive Power Theory and Synchronously Rotating Reference Frame Theory is used for controlling the DSTATCOM. The performance of DSTATCOM is studied under linear as well as non-linear load by simulation using MATLAB with its simulation and Sim Power System (SPS) tool boxes. Simulation and experimental results demonstrate the performance of these schemes for the control of DSTATCOM.**

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

I. INTRODUCTION

In the present distribution system major power consumption has been in reactive loads such as fan, pump etc. These loads take lagging power factor currents and hence there is large reactive power consumption in the distribution system. For the quality of electric power supply both frequency and voltage should remain at a constant level during the operation and voltage control problems are highly depending upon reactive power [1]. It is difficult 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 voltage regulation can be achieved with the help of regulating transformers with under load tap changers(ULTC), reactive power source devices such as, shunt capacitors, shunt reactors, synchronous condensers etc.[1-3].

Power system voltage and current waveforms get deteriorated due to increasing use of power converters and nonlinear loads in the industries. Problems occurring due to harmonics present in the waveforms are large power loss in the distribution system, interfacing problems in the communication systems. 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.

DSTATCOM is used for compensating reactive power in the distribution system. Control of DSTATCOM is done with the help of reference current generation and the techniques used for reference current generation are Instantaneous Reactive Power (IRP) Theory, Synchronously Rotating Reference Frame (SRF) Theory, Instantaneous Symmetric Component Theory, Current Component Using DC Bus Voltage Regulation [4-7]. In this paper, DSTATCOM is controlled using IRP and SRF theory for compensation of reactive power at the distribution system.

In this paper, three leg Voltage Source Converter (VSC), configuration with DC bus capacitor is employed as DSTATCOM. Reference currents are generated from sensing Point Of Common Coupling voltage and DC bus voltage is used as feedback signal. Two Proportional-Integral (PI) controllers are used, one for DC bus voltage regulation and other for AC bus voltage regulation at the distribution end. Model of DSTATCOM is employed in the MATLAB. Simulation results during steady state and transient operation are given. Results are discussed in detail to demonstrate voltage regulation and harmonic elimination capability of DSTATCOM.

II. SYSTEM CONFIGURATION

Fig. 1. Shows the basic circuit diagram of DSTATCOM. Here lagging power factor loads as well as nonlinear loads are connected to three phase three wire distribution system. Linear loads are realized by star connected Resistance and inductance(R-L). Nonlinear load is connected as Diode Bridge with resistance and inductance(R-L) load. DSTATCOM is connected as a shunt compensator which is configured with three phase Insulated Gate Bipolar Transistor (IGBT) based three leg 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 signals given to voltage source converter DSTATCOM. One PI controller is used

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which sensed actual DC voltage across capacitor and maintain it constant. Other PI controller is used which sensed value of AC terminal voltage at the point of common coupling (PCC) for voltage regulation. Dynamic model of DSTATCOM is developed in MATLAB Simulink.

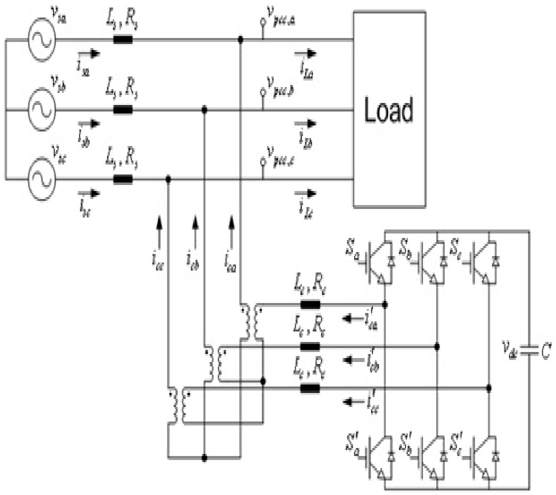

Fig. 1. Basic circuit diagram of DSTATCOM system

III. CONTROL SCHEME

Reference currents used to decide switching of DSTATCOM has real fundamental frequency component of load current, which is drawn with the help of IRP and SRF techniques. Here by controlling DSTATCOM reactive power needed by load is provided by DSTATCOM 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, two PI controllers are used one for DC bus voltage and other is for AC bus voltage control at the PCC.

A. Instantaneous Reactive Power Theory

IRP theory was initially proposed by Akagi [4]. In this theory 3-ph AC quantities are converted into 2-ph stationary reference frame quantities, using Clark's Transformation and from 2-ph quantities instantaneous active and reactive components of power are made [4-5]. Fig. 2. Shows the block diagram of IRP theory, 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 and then 3-ph reference currents(I_{sar}, I_{sbr}, I_{scr}) are generated which are then fed to Hysteresis Band Current Controller to generate gate signals of DSTATCOM.

Clarks Transformation for source voltages and load current is,

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

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

α-β axes are orthogonal coordinate. And from these voltages and currents instantaneous active and reactive powers are calculated as follows,

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

As shown in Fig. 2 PI controller 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,

$$P_{osc(n)} = P_{osc(n-1)} + K_{pd} \{ V_{de(n)} - V_{de(n-1)} \} + K_{id} V_{de(n)} \qquad (4)$$

Where, $V_{de(n)} = V_{dcr} - V_{dca(n)}$ which is error between actual DC voltage V_{dcr} , K_{pd} and K_{id} are proportional and integral gains, of DC bus voltage PI controller.

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

Amplitude of AC terminal voltage is calculated as,

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

Output of PI controller is given by,

$$Q_{(n)} = Q_{(n-1)} + K_{pq} \{V_{ae(n)} - V_{ae(n-1)}\} + K_{iq} V_{ae(n)} \qquad (6)$$

Where $V_{ae(n)} = V_{tmr} - V_{tm(n)}$, is linear error between V_{tm} and reference voltage V_{tmr}. K_{pq} and K_{iq} are proportional and integral gains of second PI controller.

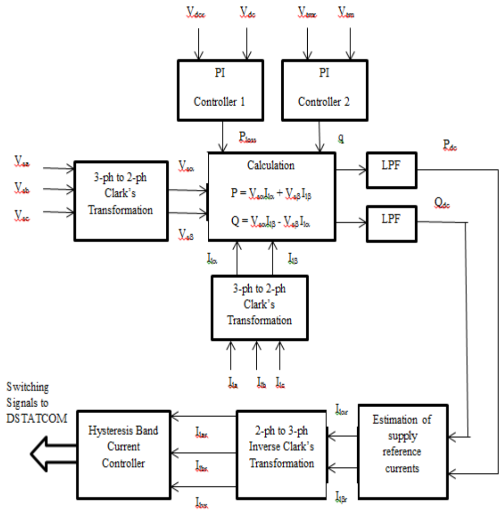

Fig. 2 .Block Diagram of Reference current generation using IRP theory.

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

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

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

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

And finally, these reference currents are given to Hysteresis Band Current Controller to generate gat signals of DSTATCOM.

B. Synchronously Rotating Reference Frame Theory

Synchronously Rotating Reference Frame (SRF) Theory is based on transformation of three phase a-b-c quantities to two d-q phase synchronously rotating reference frame quantities [6-7]. Fig. 3 shows the basic block diagram of SRF theory. As shown in the Fig. 3, three phase load currents (I_{la} , I_{lb} , I_{lc}), are given to the Parks Transformation which gives two 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) [9] 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, PI-controller I and PI-controller II are used for DC voltage regulation DSTATCOM and AC voltage regulation at the Point of Common Coupling (PCC) as shown in the Fig. 3.

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.

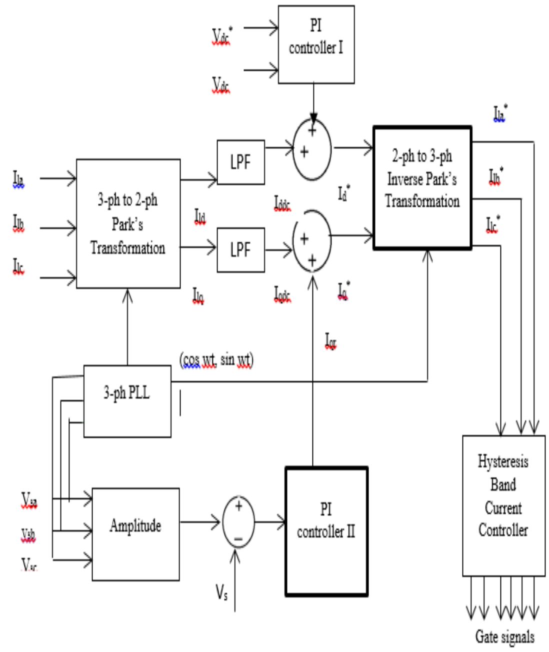

Fig.3.Block Diagram of Reference current generation using SRF theory

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

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

And similar to IRP theory these three phase currents are given to Hysteresis Band Current Controller to generate gate signals to DSTATCOM.

IV. MATLAB BASED MODELLING OF DSTATCOM SYSTEM

Fig. 4. Shows the 3-phase 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 This DSTATCOM model is simulated with the above described IRP and SRF theories. Fig.5(a),(b) shows Simulink models of IRP and SRF theories shown in fig. 2. and fig. 3. The model is assembled using mathematical blocks of Simulink block set.

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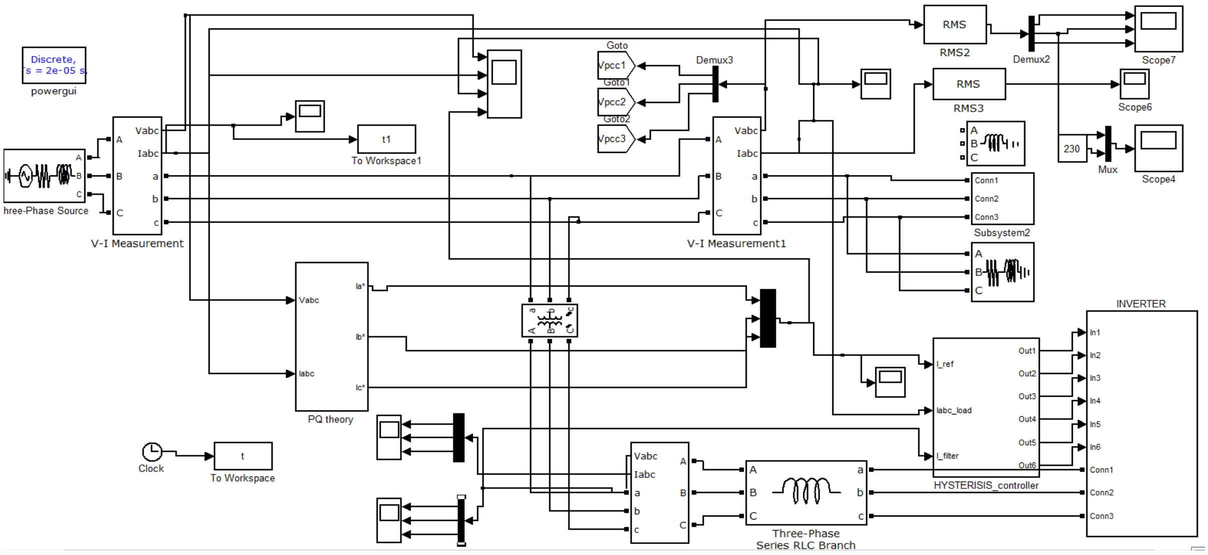

Fig. 4. Matlab model of DSTATCOM

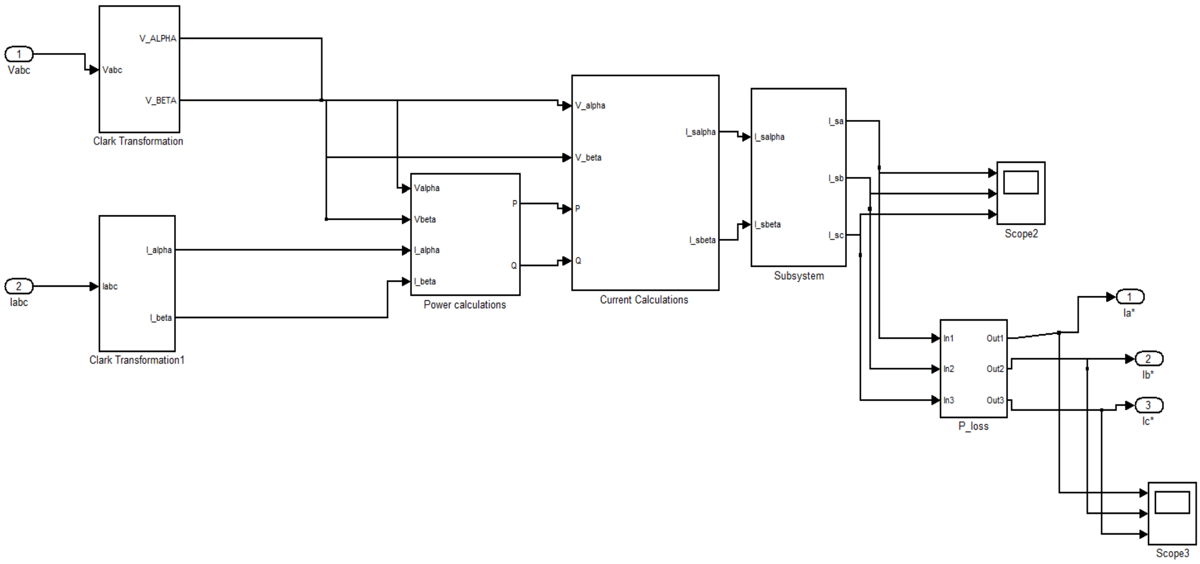

Fig. 5(a). Matlab model of reference current generation using IRP theory

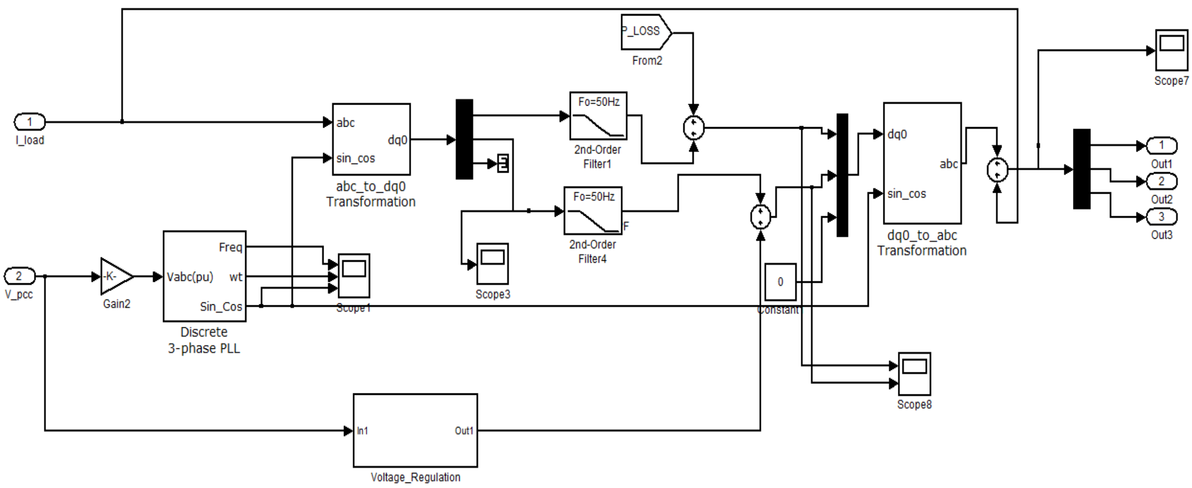

Fig. 5(b).Matlab model of reference current generation using SRF theory

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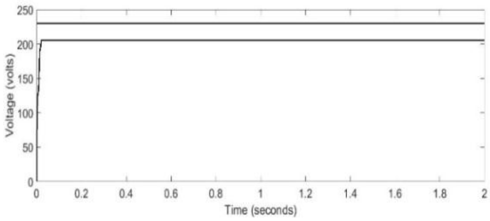
V. SIMULATION RESULTS

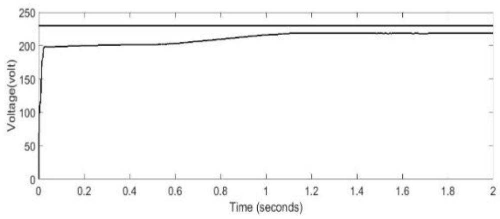
The performance of DSTATCOM is studied under the IRP and SRF theories and following results are observed. In this paper voltage regulation at the point of common coupling and harmonic contents in the source current is observed.

A. Control of DSTATCOM 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



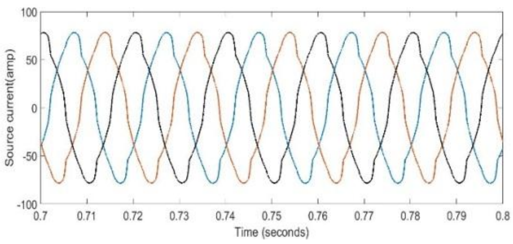
(b) With compensation

Fig.6.Voltage at the load end

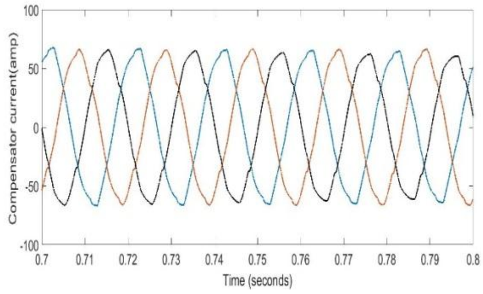
Fig. 7. Shows the harmonic elimination at source current. Because of nonlinear load source current contain harmonics fig.9(a) and due to compensating current fig 9(b) of DSTATCOM, which is injected to the circuit source current fig 9(c)become distortion free.

Table I: Voltage regulation and harmonic compensation using IRP theory

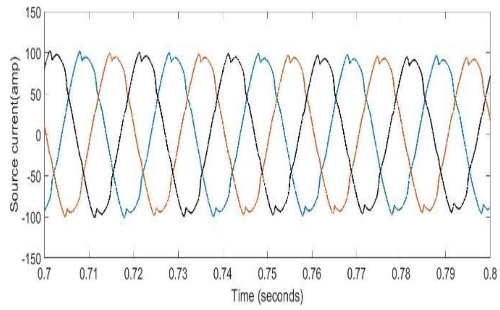
	Voltage at PCC (volts)	%THD at source current
Without compensation	205	8
With compensation	222	4



(a) Source current without compensation



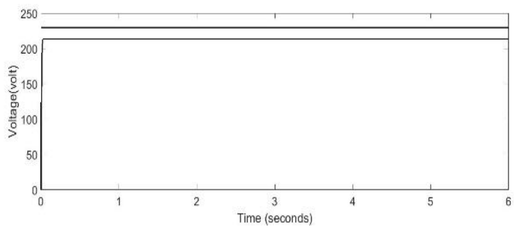
(b) Compensator current



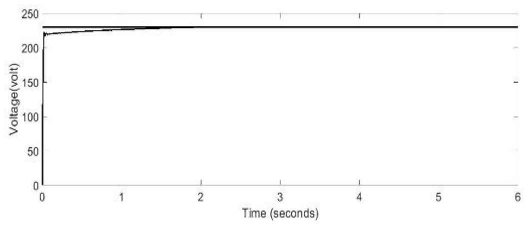
(c) Source current with compensation

Fig. 7. Source current compensation

B. Control of DSTATCOM using SRF theory

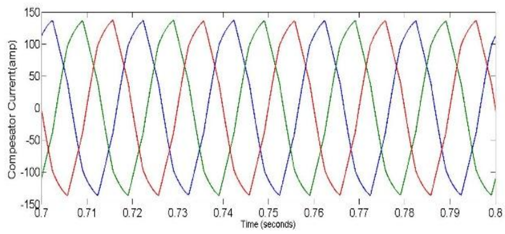


(a) Without compensation



(b) With compensation

Fig. 8. Voltage at the load end



(a) Source current without compensation

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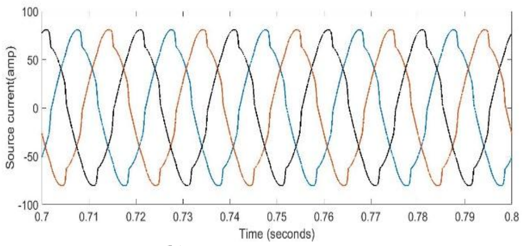
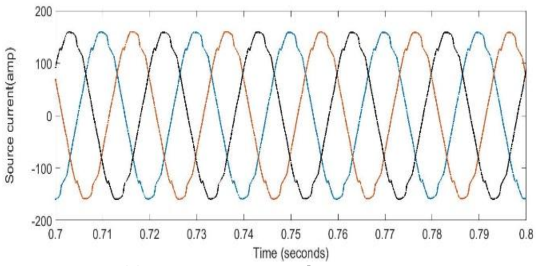


(b) Compensator current



(c) Source current with compensation

Fig. 9. 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.

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