International Journal of Engineering and Techniques - Volume 2 Issue 2, Mar – Apr 2016

RESEARCH ARTICLE OPEN ACCESS

Load Balancing and Harmonic Elimination Using Distribution Static Synchronous Compensator (DSTATCOM)

AnkurGheewala[1], Jay Chanawala[2],Nikhil Jadav[3],Modi Rishit[4], Chirag Machhi[5],Jenish Rana[6]
(Electrical Engineering Department, Shroff S. R. Rotary Institute of Chemical Technology,Ankleshwar)

Abstract:

Distribution Static Synchronous Compensator (DSTATCOM) is a shunt compensating device which is used to improve current profile by exchanging of reactive power with unbalanced and nonlinear load. DSTATCOM is a shunt compensating device used for power quality improvement in distribution systems. Relevant solutions are applied for harmonics, fluctuation of voltage, voltage deviation, unbalance of three phase voltage and current and frequency deviation. Different controlling schemes such as Phase Control Method (PCM), Fryze Power Theory (FPT), Synchronous Reference Frame Theory (SRFT) and Instantaneous Reactive Power Theory (IRPT) are used for reactive power compensation with the help of Voltage source Inverter (VSI). In this project we are going to balance the source current using different control schemes. The results of different source currents are compared with a different control schemes in terms of active and reactive power and in terms of Total Harmonic Distortion (THD) for nonlinear load using Fryze Power Theory (FPT) and Instantaneous Reactive Power Theory (IRPT). Reference currents are generated by the different control schemes have been dynamically traced in a hysteresis current controller. The performance of DSTATCOM for different control schemes is validated for load balancing and harmonic elimination by using simulation models in MATLAB/SIMULINK

Keywords—**DSTATCOM, Unbalanced load, Nonlinear load, Reactive power compensation, Reference currents, Load balancing, Harmonic elimination**

I. INTRODUCTION

Power systems voltage and current waveforms are deteriorates by highly use of power converters and nonlinear loads. Harmonics are generated because of high frequency of switching of power electronics converters. The presence of harmonics in voltage and current waveforms increases the power loss.The unbalanced load current with large reactive components leads results in voltage fluctuations and unbalance due to the source (system) impedances. Because of unbalanced current the harmonic components increases and reduction in power factor of distribution network. A shunt compensator also helps to reduce voltage fluctuation sat the point of common coupling (PCC). If the source voltages are unbalanced and varying, it is also possible for a shunt compensator to achieve this[1]. In distribution system the power quality can be improved by custom power devices which can able to exchange of extra demanded reactive power which are also called FACTS devices. The commonly FACTS controller devices used for improving the power quality are as follows:

- Static VAR Compensators (SVC)
- Thyristor Controlled Series Capacitors (TCSC)
- Static Compensators (STATCOM)
- Static Series Synchronous Compensators (SSSC)
- Unified Power Flow Controllers (UPFC)

Among of the various distribution FACTS controllers, Distribution Static Compensator (DSTATCOM) is an important shunt compensator which has the capability to solve power quality problems faced by distribution systems. DSTATCOM has effectively replaced a Static VAR Compensator (SVC), as it takes large response time in addition it is connected with the passive filter banks and capable only steady state reactive power compensation. A DSTATCOM is a Voltage Source Inverter (VSI) based

FACTS controller sharing similar concepts with a STATCOM used at transmission level. Moreover SVCs which have been largely used in arc welding plants for voltage flicker mitigation have been replaced by DSTATCOMs because SVCs exhibit limited reduction of instantaneous flicker level.A DSTATCOM is basically a Voltage Source Converter (VSC) based FACTS controller sharing many similar concepts with that of a STATCOM used at transmission level. A STATCOM at the transmission level handles only fundamental reactive power and provides voltage support while as a DSTATCOM is employed at the distribution level or at the load end for power factor improvement and voltage regulation. DSTATCOM have similar functionality as compared to shunt active filter, it can work as a shunt active filter to eliminate unbalance and distortion in source current and supply voltage.

The performance of the DSTATCOM depends on the control algorithm i.e. the extraction of the current components. So, for this, there are various control algorithms for the control of DSTATCOM block depending on various theories and strategies like phase shift control, instantaneous PQ theory, and synchronous frame theory. Each of the algorithms specified have their own merits and demerits. In this dissertation there are five control strategies have been implemented to compensate the required reactive power at the load side. Phase control method has used for enhancement of power transmission system performance. The other control strategies are Synchronous frame theory, instantaneous PQ theory and fryze method used for compensation of the unbalanced linear load and nonlinear power electronic load. The hysteresis current control strategy has implemented to compensate reactive power requirement of single-phase load.

II. Distribution STATCOM

The DSTATCOM is a voltage source inverter which is used for the modification of bus voltage sags. DSTATCOM is connected to the distribution network through a standard distribution power transformer. The DSTATCOM is continuously monitoring the line waveform and provide leading or lagging compensating current. The single line diagram of DSTATCOM is shown in fig.1. DSTATCOM consists of a dc capacitor, one or more converter modules, an L-C filter, a distribution transformer and a PWM control technique. In this implementation, a voltage-source inverter converts a dc voltage into a three-phase ac voltage that is synchronized with, and connected to, the ac line through a small tie reactor and capacitor (L-C filter).

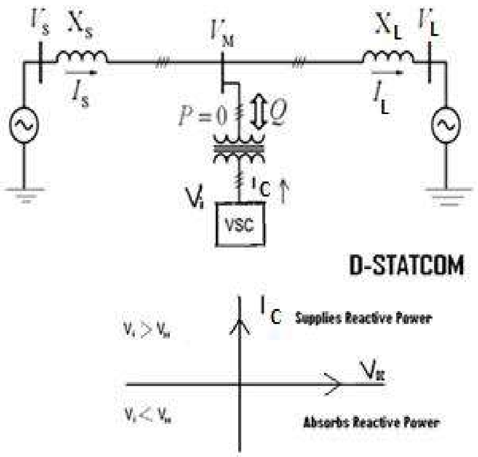


Fig.1 Single line diagram of DSTATCOM

The main principle of DSTATCOM is as follow:

1. $V_i > V_M \rightarrow$ DSTATCOM will supply the reactive power
2. $V_i < V_M \rightarrow$ DSTATCOM will absorb the reactive power
3. $V_i = V_M \rightarrow$ DSTATCOM will not exchange the reactive power which is also a balanced condition.

Where, V_i = Inverter voltage in volt
V_M = Point of common coupling voltage in volt
V_S = Source voltage in volt

Eachcontrol algorithm calculatesthe compensated current of compensator to supply or absorb the reactive power. The compensated current is given by

$$I_C = I_L - I_S \tag{A}$$

Where, I_C = Compensated current in ampere
I_L = Load current in ampere
I_S = Source current in ampere

III. Control Algorithms

The basic block diagram of compensator is as shown in fig.2. The main function of any control scheme is to generate required reference currents by sensing the load current and source current. Reference currents are faded to the hysteresis current controller. Hysteresis current controller generates the pulses which are injected to the gate of IGBT switches. According to these pulses the compensator supply or absorb the current and make the system balanced. The compensator can give desired performance as long as its bandwidth is sufficient to track the fluctuations in the load. In this configuration VSC is used with the dc storage capacitor. Two IGBT switches are used in one leg and three legs are connected in parallel with the dc capacitor. In this operation the capacitor must be precharged to a sufficient value such that it can give the better tracking performance to generate reference currents. Interfacing of filter resistance R_f and inductance L_f are used to filter the high frequency components of compensating current. The value of inductance L_f controls the switching frequency of converter.

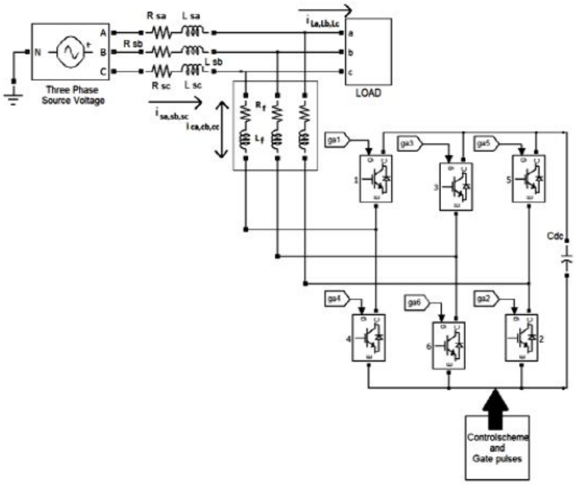


Fig.2 Basic block diagram of compensator

(1)Instantaneous Reactive Power Theory (IRPT):

This control scheme was invented by H. Akagi. The basic block diagram of IRPT is as shown in fig..3. In this algorithm instantaneous source voltages and load currents are sensed and are transformed from a-b-c to α-β-0, which is called Clark's transformation [2].

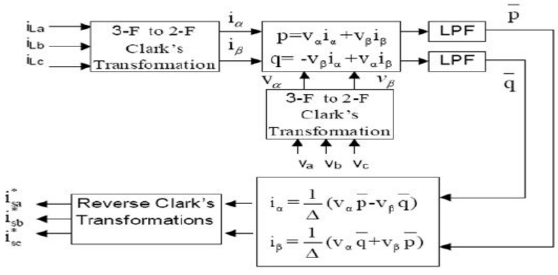


Fig.3 Basic block diagram of IRPT

The Clark's transformation of source voltage is given by

$$\begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{3}{\sqrt{2}} & -\frac{3}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

$$\begin{bmatrix} I_0 \\ I_\alpha \\ I_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{3}{\sqrt{2}} & -\frac{3}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

$$\begin{bmatrix} p_0 \\ p \\ q \end{bmatrix} = \begin{bmatrix} V_0 & 0 & 0 \\ 0 & V_\alpha & V_\beta \\ 0 & -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} I_0 \\ I_\alpha \\ I_\beta \end{bmatrix}$$

In three phase three wire system, $i_o = 0$ this implies $p_o = 0$. Equation (3) would be reduced to

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

When the system is balanced, the instantaneous active and reactive powers p and q can be decomposed into an average and an oscillatory component. p_{dc} and q_{dc} are average components and p_{ac} and q_{ac} are oscillatory part of real and reactive instantaneous powers. The compensating currents are calculated to compensate the instantaneous reactive power and the oscillatory component of the instantaneous active power. In this case the source transmits only the non-oscillating component of active power. Therefore the reference source currents in α-β co-ordinates are expressed as,

$$\begin{bmatrix} i^*_{s\alpha} \\ i^*_{s\beta} \end{bmatrix} = \begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} p_{dc} \\ 0 \end{bmatrix}$$

These currents can be transformed in a-b-c quantities to find the reference currents in a-b-c coordinate.

$$\begin{bmatrix} i^*_{sa} \\ i^*_{sb} \\ i^*_{sc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix}$$

(2) FRYZE Power Theory (FPT):

The block diagram of this control algorithm is as shown in fig.4 [3]. In this controlling algorithm the load current and the source voltages are sensed and the active fryze conductance G_e is calculated by,

$$G_e = \frac{V_{sa} i_{La} + V_{sb} i_{La} + V_{sc} i_{Lc}}{V_{sa}^2 + V_{sb}^2 + V_{sb}^2}$$

Where,

i_{La}; i_{Lb}; i_{Lc} = Load current of phase a, phase b and phase c respectively

V_{sa}; V_{sb}; V_{sc} = Source voltage of phase a, phase b and phase c respectively

Then this signal Ge is fed to the LPF which is denoted by $\bar{G}_e$. The active instantaneous currents are calculated as shown below:

$$i_{wa} = i_{sa} = \bar{G}_e V_{sa}$$
$$i_{wb} = i_{sb} = \bar{G}_e V_{sb}$$
$$i_{wc} = i_{sc} = \bar{G}_e V_{sc}$$

Where,

i_{wa}; i_{wb}; i_{wc} = Active instantaneous current of phase a, phase b and phase c respectively

i_{sa}; i_{sb}; i_{sc} = Source current of phase a, phase b and phase c respectively

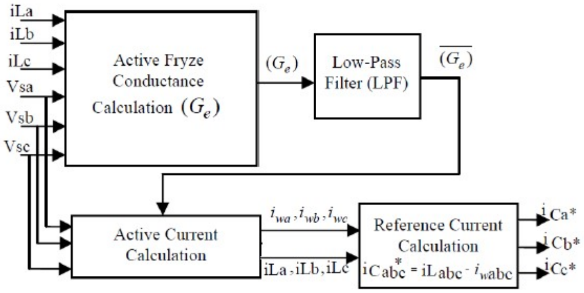


Fig.4 Basic block diagram of FPT

Then the reference current are calculated by,

$$i^*_{Ca} = i_{La} - i_{wa}$$
$$i^*_{Cb} = i_{Lb} - i_{wb}$$
$$i^*_{Cc} = i_{Lc} - i_{wc}$$

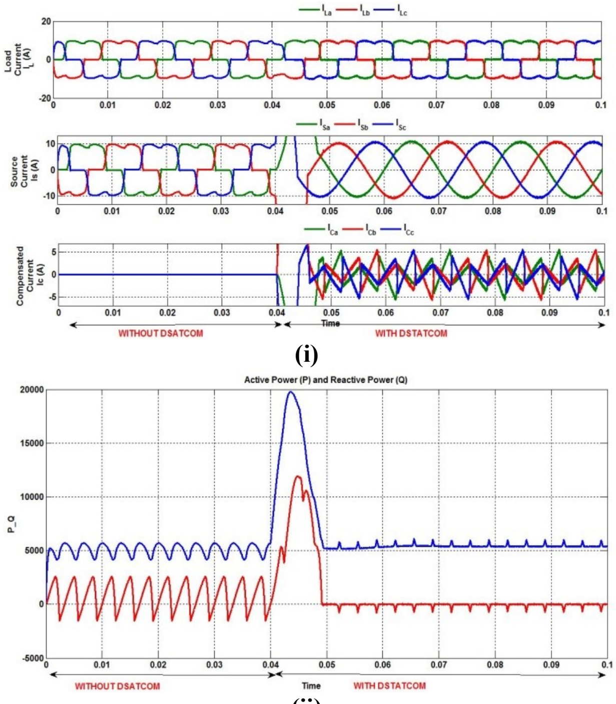
Where,

i_{Ca}; i_{Cb}; i_{Cc} = Measured compensating current of phase a ,b and c respectively

i^*_{Ca}; i^*_{Cb}; i^*_{Cc} = Calculated compensating current of phase a, b and c respectively

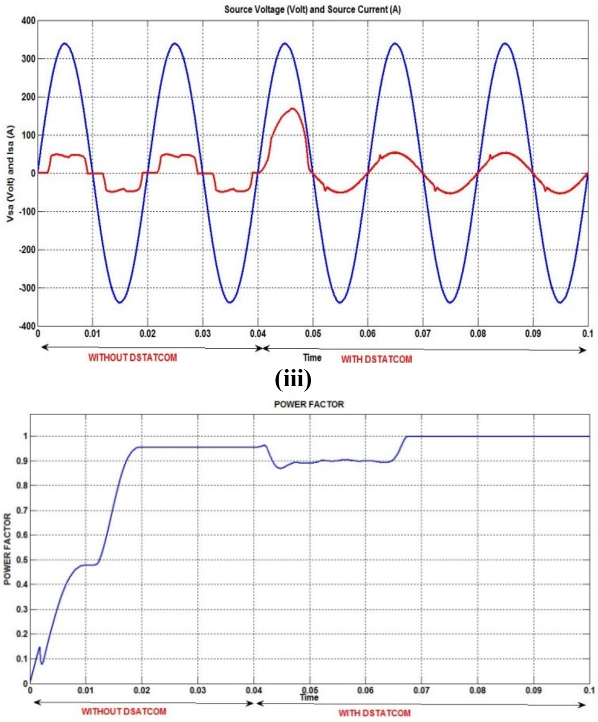
This calculated compensated current is compared by measured compensated current and the generated error signal is given tothe voltage source inverter which is generated triggering pulses and is fed to the gate of the inverter.

IV. SIMULATION RESULTS AND DISCUSSION



(i)

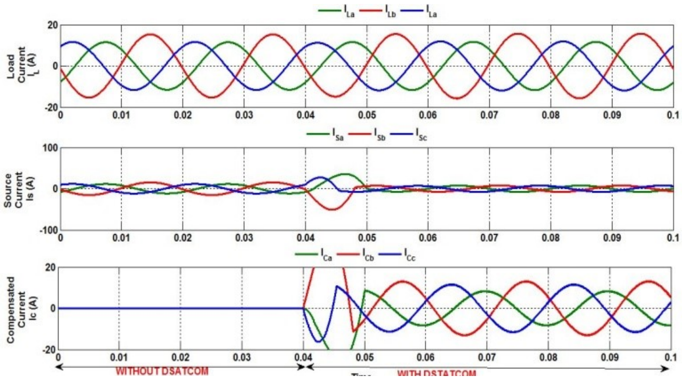
(ii)



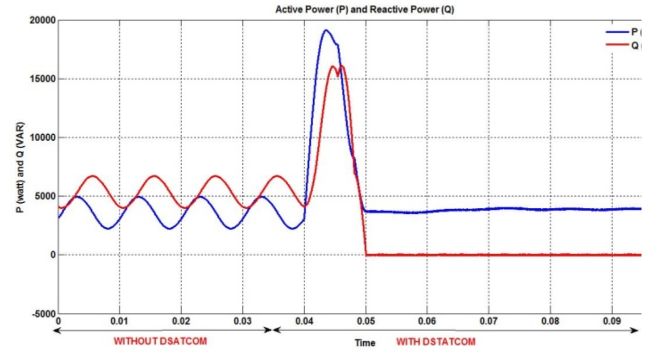
(iii)

(iv)

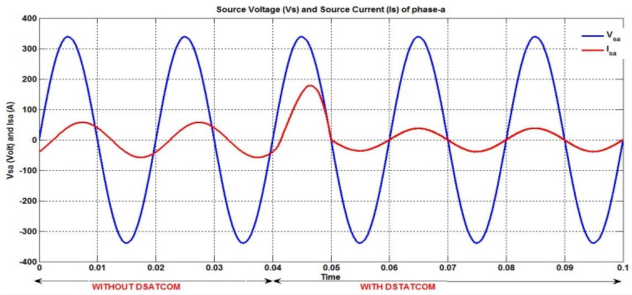
Fig.5 Waveform of (i) load, source and compensated current v/s time (ii) active and reactive power v/s time (iii) source voltage and current of phase of phase-a v/s time (iv) power factor v/s time (nonlinear load) for IRPT



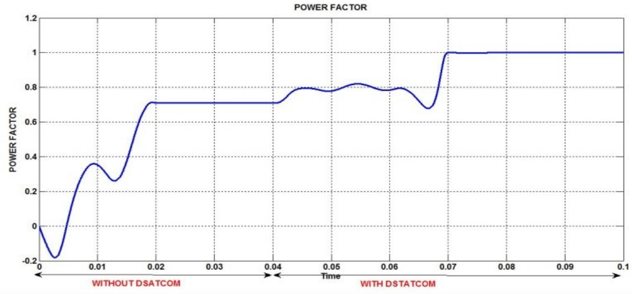
(i)



(ii)

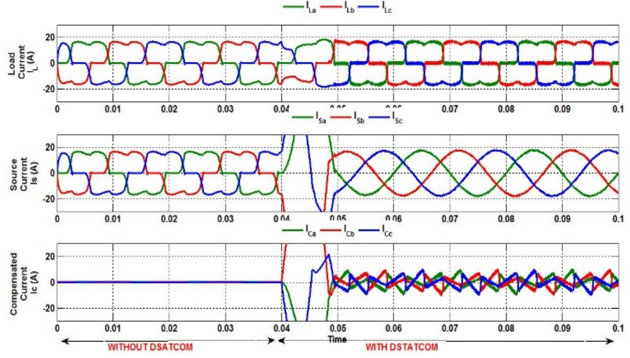


(iii)

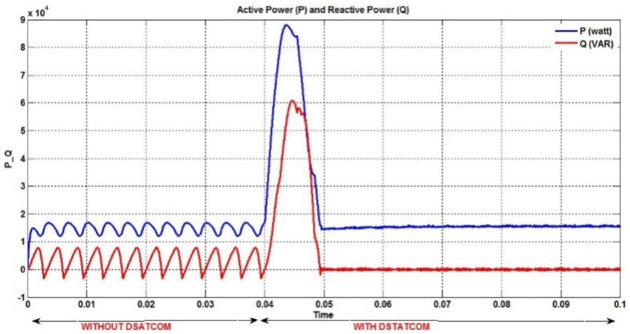


(iv)

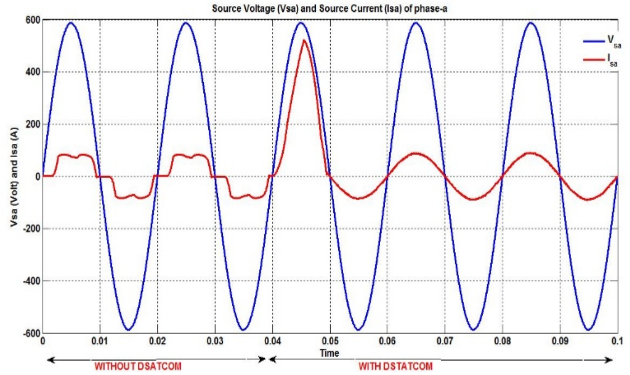
Fig.6 Waveform of (i) load, source and compensated current v/s time (ii) active and reactive power v/s time (iii) source voltage and current of phase of phase-a v/s time (iv) power factor v/s time (linear unbalanced Δ-connected load)for IRPT



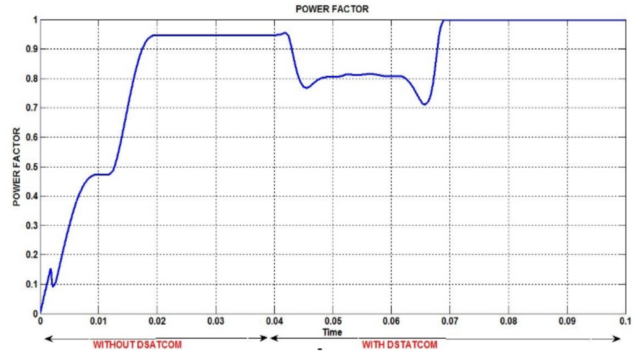
(i)



(ii)

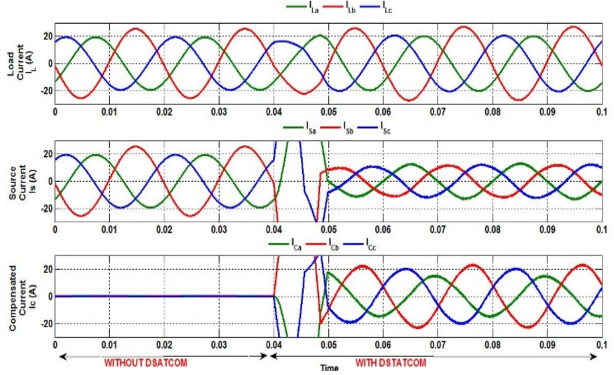


(iii)

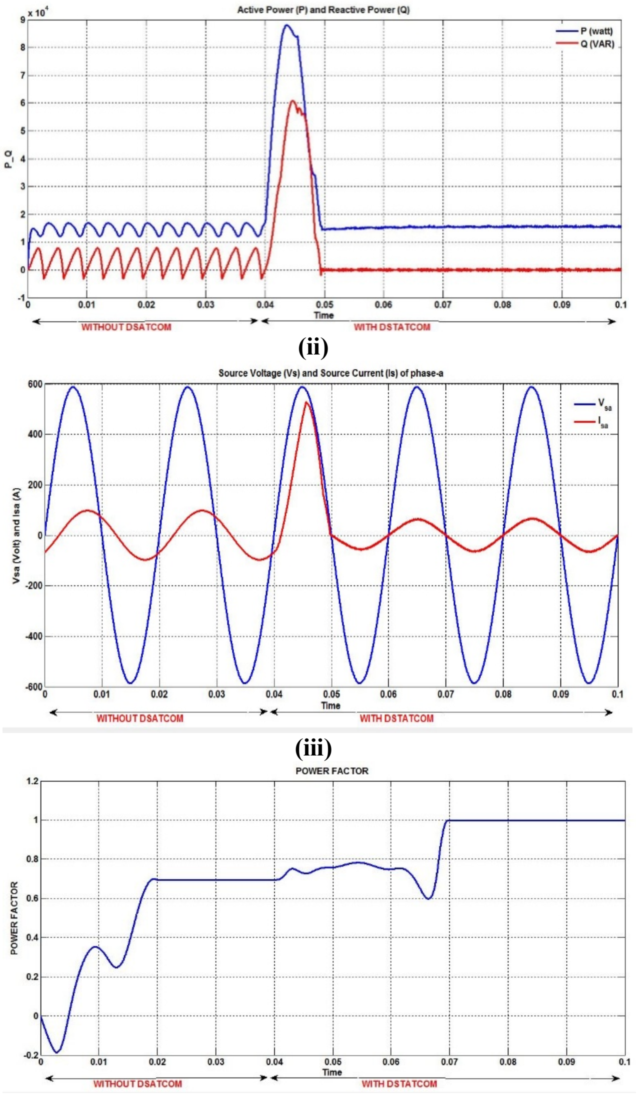


(iv)

Fig.7 Waveform of (i) load, source and compensated current v/s time (ii) active and reactive power v/s time (iii) source voltage and current of phase of phase-a v/s time (iv) power factor v/s time (nonlinear load) for FPT



(i)



(ii)

(iii)

(iv)

Fig.8 Waveform of (i) load, source and compensated current v/s time (ii) active and reactive power v/s time (iii) source voltage and current of phase of phase-a v/s time (iv) power factor v/s time (linear unbalanced Δ-connected load) for FPT

V. CONCLUSIONS

After implement of these two algorithms successfully, there is a making comparison between IRPT and FPT in terms of rms value of source current. From table-I results the conclusions are made as shown in table-II.

TABLE II: Comparison of IRPT and FPT

Objectives of Compensation	Control Scheme	
	IRPT	FPT
Computational Complexity	High	Simple
Reactive Power Compensation	Good	Excellent
Load Balancing	Excellent	Good
Harmonics Mitigation	Good	Excellent

APPENDIX

PARAMETERS	VALUE
Source parameters	V_S (rms value) = 415 V, R_S = 0.01 Ω, L_S = 2 mH
Compensators parameters	C_{dc} = 500 µF, Rf = 0.01 Ω, Lf = 15 mH
Linear unbalanced Δ-connected load	Z_{lab} = 50+ j 62.8 Ω, Z_{lbc} = 25+ j 54.95 Ω, Z_{lca} = 50 + j 70.65 Ω

TABLE I: Simulation Results of for Nonlinear Load and For Linear Unbalanced Δ-connected Load

Load And Control Algorithm	Compensation	Time of Operation (unit time)	Source Current (ampere)			Active Power (P) (watt)	Reactive Power (Q) (var)	Power Factor
			i_{Sa}	i_{Sb}	i_{Sc}			
Nonlinear Load (IRPT)	Before Compensation	0.00 to 0.04	7.137 (26.69%)	7.137 (26.69%)	7.137 (26.69%)	5071	774.8	0.9542
	After Compensation	0.04 to 0.1	7.229 (1.66%)	7.226 (1.66%)	7.228 (1.65%)	5197	3.967	0.9913
Unbalanced Linear Load (IRPT)	Before Compensation	0.00 to 0.04	8.155	10.84	8.235	3590	5355	0.7093
	After Compensation	0.04 to 0.1	5.419	5.419	5.377	3885	0.3644	0.9998
Nonlinear Load (FPT)	After Compensation	0.04 to 0.1	7.17 (1.22%)	7.16 (1.36%)	7.177 (1.32%)	5187	0.5084	0.9999
Unbalanced Linear Load (FPT)	After Compensation	0.04 to 0.1	5.268	5.02	5.086	3683	0.2	0.9994

REFERENCES

1. *K.R. Padiyar, ``FACTS CONTROLLERS IN POWER TRANSMISSION AND DISTRIBUTION''.*

2. *HIROFUMI AKAGI, YOSHIHIRA KANAZAWA AND AKIRA NABAE, "Instantaneous Reactive Power Compensators Comprising Switching Devices without Energy Storage Components ", IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. IA-20, NO. 3, MAY/JUNE 1984.*

3. *Jaruppanan P, Kanta Mahapatra, Jeyaraman.K and Jeraldine Viji, "Fryze Power Theory with Adaptive-HCC based Active Power Line Conditioners", International Conference on Power and Energy Systems (ICPS), Dec 22-24, 2011, IIT-Madras.*