SRF And IRPT Methods of Dstatcom for Combined Harmonics Elimination and Reactive Power Compensation

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***Abstract*— Distribution static compensator (DSTATCOM) is a good FACTs device used in distribution lines for power quality improvement. It can be used to filter the harmonics from source current, power factor correction, voltage regulation, reactive power compensation, balancing the source current etc. In this thesis work the DSTATCOM is studied for filtering the harmonics from load current, power factor correction, and reactive power compensation. Synchronous Reference Frame (SRF) or dq method and Instantaneous reactive power theory (IRPT) or pq method is used to find the reference current which is to be injected into the system through voltage source inverter and the result of them are compared to find which method is better than other. The simulation of the DSTATCOM is carried out in the MATLAB/Simulink based simulation platform.**

Keywords*— DSTATCOM, SRF or dq, IRPT or pq, current harmonics elimination, reactive power comensation.

I. INTRODUCTION

The need of control and conversion of power leads the consumers to use the converters and controllers which contain switches made of solid state devices. These devices are present in computers, air conditioners, chargers etc. Use of these devices could inject many power quality problems into the system such as harmonics, DC offset, noise, notching, flickers, imbalance etc. Other quality problems are transients, interruptions, sag, swell, poor power factor etc. which are caused due to faults, lightning, sudden load, addition or removal of load etc. Due to these problems the equipments at the loads may not work properly, the lines could be overloaded, audible noise in the machines and many more problems may occur. Electronic interference, audible noises, machine and lines heating and other losses are increased by harmonics [3]. Some of the loads like induction motors require huge amount of reactive power thus it takes a large amount of lagging current from the supply due to this the power factor as well as the voltage swell occurs . The reactive powers busy the lines and the capacity of the lines to supply the load decreases, best way to solve this problem is producing this power where it is needed. In this way the unnecessary line losses are also decreased.

Power quality issues can be mitigated with passive, active and hybrid filters. Active filters are precise, fast, smaller and light weighted [2] while Passive filter suffers with large size, fixed compensation, overloading, resonance etc problems [3][4]. Use of hybrid filter is shown in [11]. One type of filter is best for certain problems while other filter is best for other problems but when the group of problems occurs we require the best method for solving the problem thus we can use either one of them or combination of the filters according to the optimum solution where size, cost, effectiveness every aspect counts.

Active filters are controlled inverters which are connected with the lines with the use coupling transformers/inductors. The inverter contains capacitor in VSC or inductor in CSC. It could also contain energy storage element based on the working of filter. In switches of filters BJT/ MOSFET are used for small ratings and IGBT for medium and GTO for higher ratings [4]. MOSFET is used for high frequency applications like SMPS etc. The GTO must be switched at low frequency due to higher switching losses [8].

There are many names for the active power filter i.e. active power quality conditioner, active filters, instantaneous active power compensator and active power line conditioner [4]. There are many active filters some of them are SSSC, STATCOM, UPFC, DSTATCOM, DVR, SSTS etc [7][12]. These can be categorized based on the topology they are use such as shunt, series, shunt-series etc. Generally shunt active filters are used for current related problems while series are used for voltage related problems [4].

In DSTATCOM the size of elements should be optimal for the operation of DSTATCOM. The small inductor value doesn't remove complete ripples while large value doesn't allow the tracking of reference current. Small capacitor value leads to fluctuations in the DC voltage while large capacitors are costly [4].

The working of DSTATCOM can be controlled by controlling the filter current or by controlling the magnitude or phase of the filter output voltage [3][5]. For voltage regulation the filter current should be leading or lagging while for Power factor correction it should be in phase thus the Voltage regulation and power factor correction could not be achieved simultaneously from the DSTATCOM. The DSTATCOM can exchange both active and reactive power with the lines but for active power support the DSTATCOM requires some energy source [18].

The DSTATCOM can solve many issues such as low power factor, Reactive power need, voltage fluctuation, harmonics, imbalance etc [13][14][15][21]. There are several control strategies used for control of DSTATCOM some of them are IRPT or pq [1], SRF or dq [21], Adaline neural network [10], instantaneous symmetric component theory [16], modified single phase pq [13], symmetric component in SRF [17] etc. The use of digital signal processors like microprocessors and

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 7 Issue 07, July-2018

microcontrollers make the complex calculations easy in control algorithms like fuzzy logic, PI controller, and neural networks [4]. One or many problems can be solved using these methods and there is difference between effectiveness of them. In this paper the well known IRPT and SRF theory is used in DSTATCOM for the harmonics elimination, reactive power compensation and power factor correction and then the effectiveness of them are compared using MATLAB/Simulink environment.

II. DSTATCOM

Basic block diagram of DSTATCOM is shown in Fig. 1 in which the DSTATCOM is connected with the lines through coupling inductance/ transformer. DSTATCOM is made up of an inverter whose DC side is connected with a capacitor. There is no battery connected on the DC side because the capacitor can be charged by the inverter itself. The battery or energy source can be required by it according to its operation mostly in the active power support conditions during fault, sag, swell etc. But for the reactive power support and harmonic elimination there is no need of energy source. The inverter contains the switches which contains anti-parallel diodes these diodes reduces the stress across switches and also charge the capacitor as a rectifier. The mind of the DSTATCOM is a controller block whose inputs are the current and voltage measurements of supply load and inverter (both AC and DC side). Controller can process these data using different control methods and generate the reference current signal for the DSTATCOM. To track these reference currents signal different methods can be used such as hysteresis current control, PWM control, SPWM control etc for generating the pulses for gating signal of switches in inverter.

Source current(is)+Compensation current(ic)=Load current (il) (1)

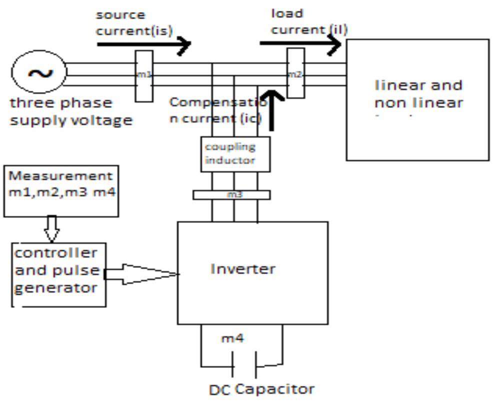

Fig1 basic block diagram of DSTATCOM

III. CONTROL STRATEGIES OF DSTATCOM

This paper is focused to discuss the two very much used control strategies for DSTATCOM which are IRPT or p-q theory and SRF or d-q theory. Both these theory are used to generate the reference source current which is used to generate the pulses for the switches of the VSC of the DSTATCOM. The IRPT uses the Clarke transform and SRF uses the Park transform whose basic concept and vector diagram is shown in the fig. 2. For park transformation the abc quantities are first Clark transformed and then Park transformed to get the dqo components. Similarly for getting abc components from the dqo components these are first inverse park transformed and then inverse Clark transformed.

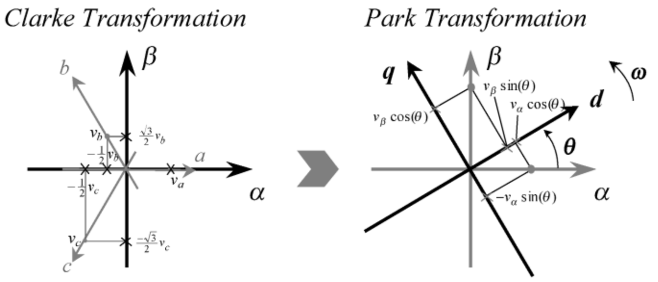

Fig 2 Clarks and parks transformation

a. IRPT (Instantaneous Reactive Power Theory) or p-q theory

This theory was discovered in 1983 and used since then for controlling which focus on the two forms of power component which are active and reactive power.

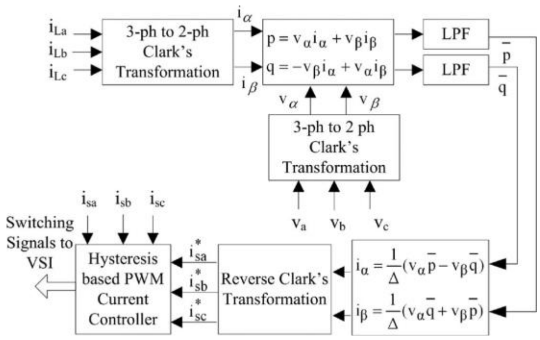

Fig 3 Basic IRPT control algorithm

In this theory the three phase components of voltage and current are Clarke transformed. Then these components are used to calculate the three phase active and reactive power. The beauty of using the Clarke transformed component for calculation of real and reactive is that the fundamental power components behaves like a dc signal thus it can be easily filtered out to calculate the reference source current signals. Then this current can be transformed back into the actual phase quantities using inverse Clarke transformation. The reference source currents generation can be modified by modifying the powers used to calculate them as per requirement or function of the DSTATCOM. For example if we want complete reactive power of the load to be supplied by the DSTATCOM then the reactive power used in the reference source current generation is set to be zero. In the fig 3 it is assumed that the zero sequence current in the supply is zero thus it is not considered here in Clarke transform.

$$\begin{bmatrix}\alpha\\ \beta\\ o\end{bmatrix} = Tc * \begin{bmatrix}a\\ b\\ c\end{bmatrix} \tag{2}$$

Where Tc is the Clark transformation matrix which is given by

$$Tc = \sqrt{\frac{2}{3}} * \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \tag{3}$$

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 7 Issue 07, July-2018

$$\begin{bmatrix} a \\ b \\ c \end{bmatrix} = Tc^{-1} * \begin{bmatrix} \alpha \\ \beta \\ o \end{bmatrix} \quad (4)$$

Where Tc^{-1} is the inverse Clark transform

$$Tc^{-1} = \sqrt{\frac{2}{3}} * \begin{bmatrix} 1 & 0 & 1/\sqrt{2} \\ -1/2 & \sqrt{3}/2 & 1/\sqrt{2} \\ -1/2 & -\sqrt{3}/2 & 1/\sqrt{2} \end{bmatrix} \quad (5)$$

The total instantaneous active and reactive power can be calculated by

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} v\alpha & v\beta \\ -v\beta & v\alpha \end{bmatrix} \begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} \quad (6)$$

Where, $\Delta = v\alpha^2 + v\beta^2$ (7)

P is the total instantaneous real power absorbed by load,

Q is the total instantaneous reactive power absorbed by the load

vα and iα is the alpha component of terminal voltage and load current

vβ and iβ is the beta component of terminal voltage and load current

$$P = v\alpha * i\alpha + v\beta * i\beta \quad (8)$$

$$P = \bar{p} + \breve{p} \quad (9)$$

Where, $\bar{p}$ is the fundamental active power component,

$\breve{p}$ is the oscillating active power component.

Active power can also be calculated by

$$P = Va*Ila + Vb*Ilb + Vc*Ilc \quad (10)$$

Where Va, Vb and Vc are the three phase source voltage

And Ila, Ilb and Ilc are the three phase load current

The (9) shows that the active power P contain both fundamental ($\bar{p}$) and oscillating component ($\breve{p}$) active power component. This instantaneous active power can also be calculated using the actual three phase quantities as shown in (10).Similarly the instantaneous reactive power can be calculated by the equation

$$Q = -V\beta * I\alpha + V\alpha * I\beta \quad (11)$$

The instantaneous reactive power (Q) absorbed by the load contains both fundamental ($\bar{q}$) and oscillating component ($\breve{q}$) which can be given by the (12).

$$Q = \bar{q} + \breve{q} \quad (12)$$

b. SRF (synchronous reference frame) theory or d-q theory

In SRF or d-q theory the load current quantities are clark-park transformed to dq0 components and the transformation sin and cos components used for that are extracted from the supply voltage. The significance of dqo is the direct, quadrature and zero axes. In park transformation the three phase components are rotated at the reference frame with fundamental frequency thus the fundamental frequency component seems to be stationary while the signals other than the fundamental frequency seems to be oscillating signals. Now in the dqo current quantities are low pass filtered to get the fundamental current quantities. The filtered current quantities are transformed back into the phase quantities using inverse park-clark transformation which are the reference source current.

The d current component shows the current responsible for active power, similarly q component of current show the current responsible for reactive power and o component current shows the unbalance in the supply. The system considered here is balanced for simplicity.

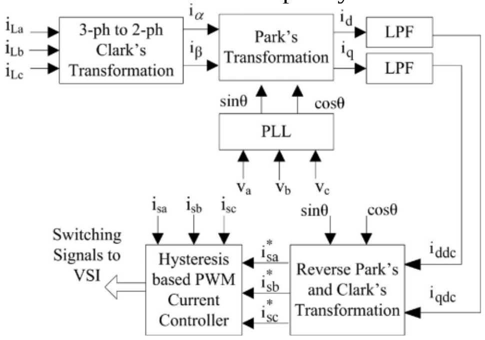

Fig 4 Basic SRF control algorithm

Tp and Tc are the park and clark transformation matrixes, and Tpc is the product of them

$$\begin{bmatrix} d \\ q \\ o \end{bmatrix} = Tp * Tc * \begin{bmatrix} a \\ b \\ c \end{bmatrix} = \text{Tpc} * \begin{bmatrix} a \\ b \\ c \end{bmatrix} \quad (13)$$

$$Tpc = \sqrt{\frac{2}{3}} * \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin\theta & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \quad (14)$$

Equation (15) shows that the dqo transformed current component contains both average and oscillating component. When Id is passed with low pass filter (LPF) the oscillating component is filtered out and we only get fundamental component.

$$Id = \overline{Id} + \breve{Id} \quad (15)$$

$$Iq = \overline{Iq} + \breve{Iq} \quad (16)$$

Where, Id is the direct axis current component

$\overline{Id}$ is the direct axis average current component

$\breve{Id}$ is the direct axis oscillating current component

$$\begin{bmatrix} a \\ b \\ c \end{bmatrix} = Tcp^{-1} * \begin{bmatrix} d \\ q \\ o \end{bmatrix} \quad (17)$$

Where, Tcp^{-1} is the inverse transformation matrix of Tpc and is given by the (18).

$$Tcp^{-1} = \sqrt{\frac{2}{3}} * \begin{bmatrix} \cos\theta & -\sin\theta & 1/\sqrt{2} \\ \cos\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{2\pi}{3}\right) & 1/\sqrt{2} \\ \cos\left(\theta + \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) & 1/\sqrt{2} \end{bmatrix} \quad (18)$$

IV. MODELING AND SIMULATION

The simulation is done in MATLAB where a three phase source is connected to the three phase load using a RL branch as line resistance and inductance. The DSTATCOM is connected at the load end using a switch and coupling inductor. The DSTATCOM consists of two capacitors (with neutral grounded) and a universal bridge made of six IGBT and diodes is used as an inverter. The capacitors are connected on DC side of bridge and coupling inductor on AC side. The two voltmeters are used for measuring the voltages of the

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 7 Issue 07, July-2018

capacitors. Three phase measurement blocks are used at supply, load and DSTATCOM for measuring the three phase voltage and current at these points. The load consists of a non-linear load and a linear load. The nonlinear load consists of a rectifier is supplying a RL load. The rectifier is a three phase full bridge diode rectifier.

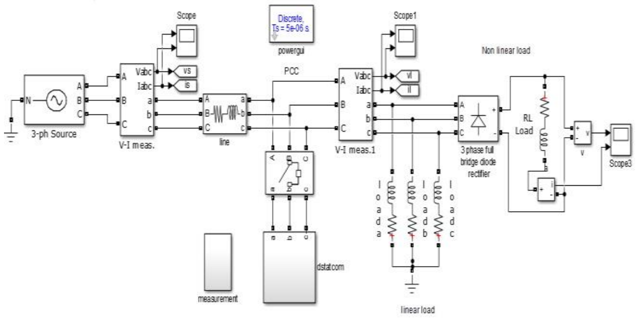

Fig 5 Simulation diagram of DSTATCOM

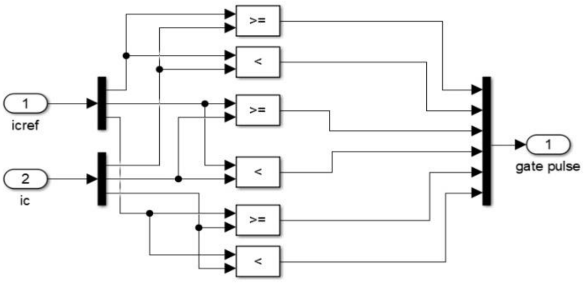

Fig 6 Gate pulse generator

a. SRF or dqo method

As shown below the load current is park transformed for which the sin and cos signals are generated using the discrete three-phase phase-locked-loop block and source voltage is used for the synchronizing. The d component of the load current is low pass filtered to pass only the fundamental component. The q load current component is set to zero as there should be no reactive power given by the source. The zero sequence current is taken as it is. Next these current quantities are inverse-park transformed to generate the reference source current. To generate the reference filter current the reference source current is subtracted from the load current. Then the reference current is given to the pulse generation block.

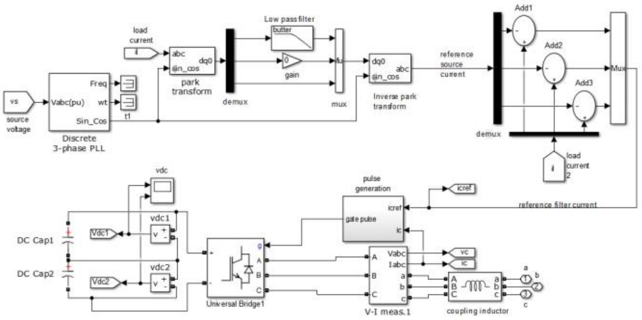

Fig 7 Simulation diagram of SRF method

b. IRPT or pq method

The source voltage and load current quantities are Clark transformed using Clark transformation block. Then the active power P and reactive power Q is calculated using the function blocks. The active power is low pass filtered and subtracted from the non filtered active power to get the non fundamental active power. The reactive power is taken as it is because the complete reactive power should be supplied through active filter. Now these two quantities along with transformed source voltage quantities are used to calculate the reference alpha and beta source current using function block. These quantities are converter back to actual phase quantities using inverse-Clark transformation block to get the reference filter current which is then given to the pulse generation block.

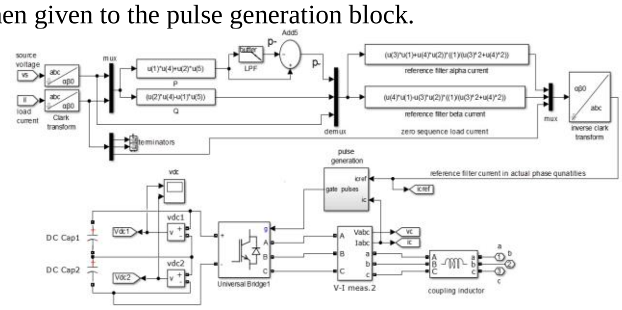

Fig 8 Simulation diagram of IRPT method

c. Simulations

Simulation of DSTATCOM is done under different loading conditions using different methods in two cases. The details of these cases and system parameters are given in table 1

Table 1 Simulation parameters

Three phase source	200 Volts RMS phase to phase, 50 Hz
Line resistance and inductance	1 ohms and 0.1milli-Henry
Coupling inductor	7milli-Henry
DC Capacitors	600 micro-Farads each
Case 1	Linear loads Za=200+j103 ohms, Zb=160+j63 ohms, Zc=100+j110 ohms Non linear load 120+j63
Case 2	Linear loads Za=200+j103 ohms, Zb=160+j63 ohms, Zc=100+j110 ohms Non linear load 120+j63 ohms At 0.1sec 1000 Watts and 1000 positive VARs At 0.2sec 1000 Watts and 2000 negative VARs

d. Simulation in Case 1.

The loading values are given in the simulation parameters table in case 1. The figure 9 shows that the voltage and current output of the non-linear load. This three phase rectified current and voltage introduces harmonics in the system.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 7 Issue 07, July-2018

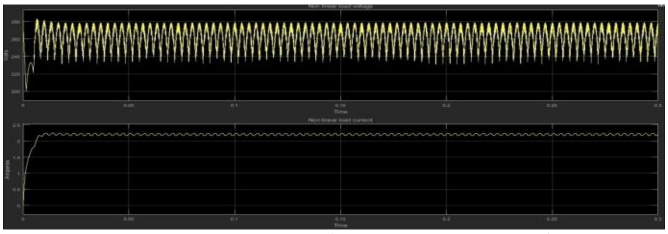

Fig 9 Voltage and current of Non-linear load in case first

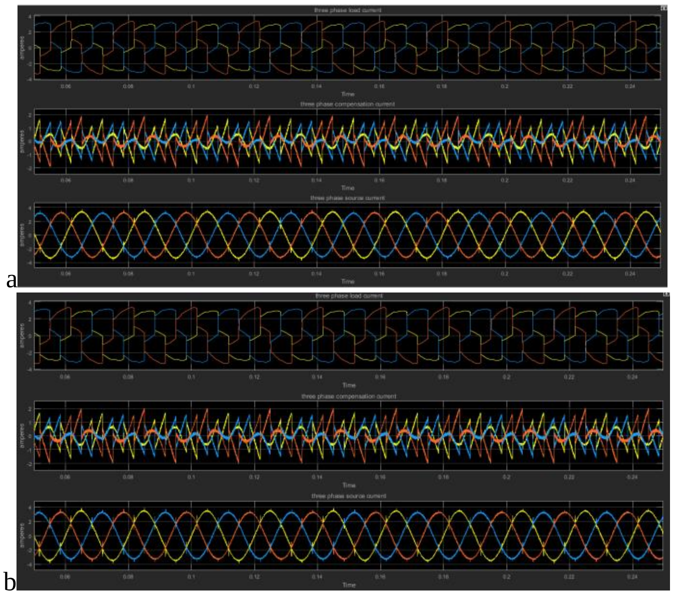

Fig 10 Different currents in case first using a.SRF and b. IRPT method

The fig. 10 shows the three phase load, compensation and source current from top to bottom respectively.

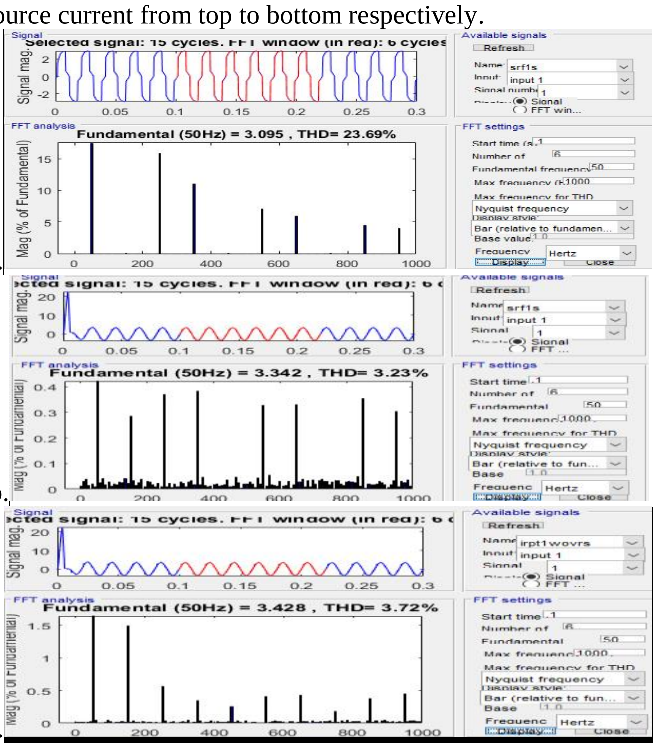

Fig 11 Source current THD in case first a. without DSTATCOM b. using SRF c. using IRPT method

The fig.11 shows that the THD in case first without DSTATCOM, with SRF method and with IRPT method are 23.69%, 3.23% and 3.72% respectively.

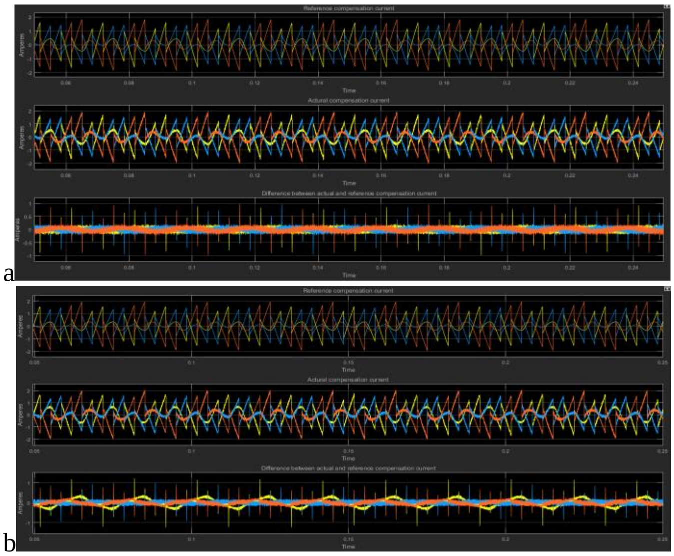

Fig 12 Reference, actual compensation current and their difference in a.SRF and b. IRPT method

The fig. 12 shows that the difference between the reference and actual compensation current is more in the IRPT method than in the SRF method.

e. Simulation in Case 2

The inductive and capacitive loads are connected using switches. The inductive load is connected at the 0.1 sec and the capacitive load is connected at 0.2 sec.

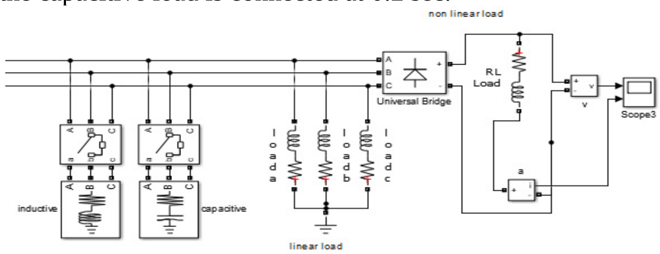

Fig 13 Load diagram in case second

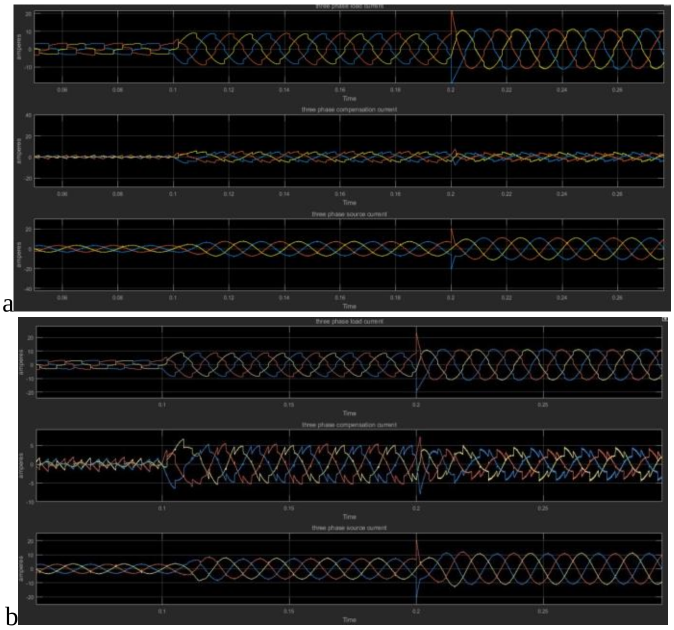

Fig 14 Different currents in case second using a.SRF and b. IRPT method

The fig. 14 shows the three phase load, DSTATCOM and source current form top to bottom respectively.

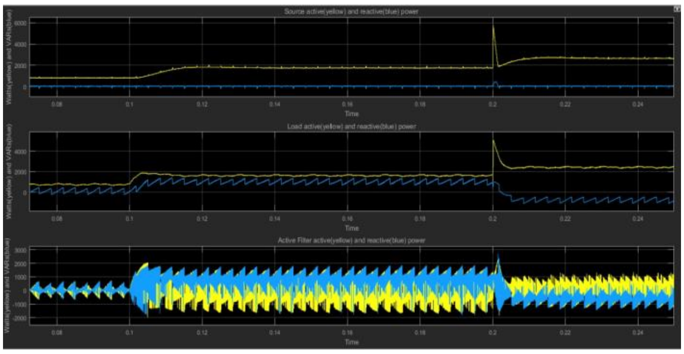

Fig 15 Different Powers in case second using SRF method

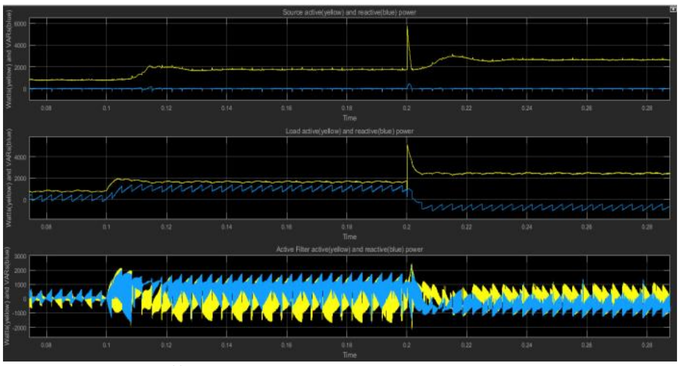

Fig 16 Different Powers in case second using IRPT method

The fig 15 and 16 shows the active power(yellow) and reactive power (blue) of source, load and active filter respectively from top to bottom in SRF and IRPT method.

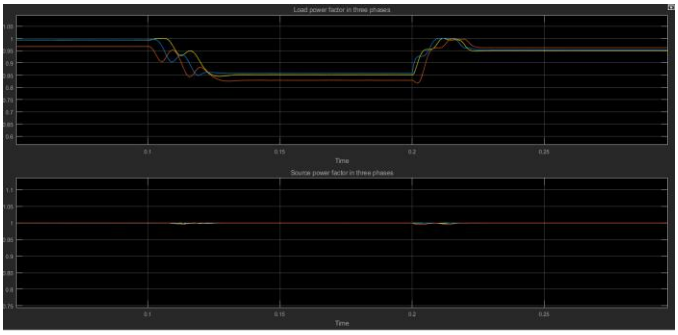

Fig 17 Different power factors in case second using SRF method

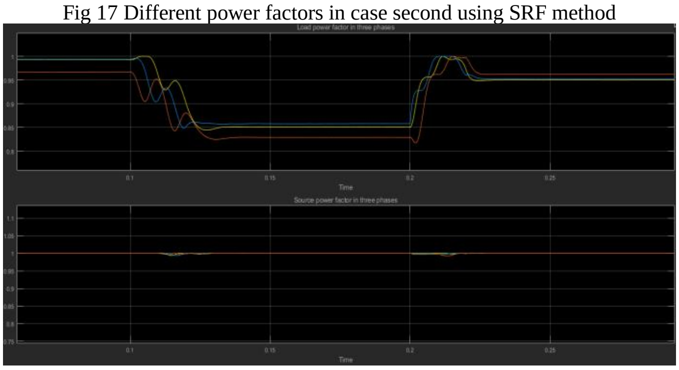

Fig 18 Different power factors in case second using IRPT method

The fig 15 to 18 shows that the reactive power compensation in both the methods are equal which makes the power factor of the source equal to unity.

a.
b.
c.

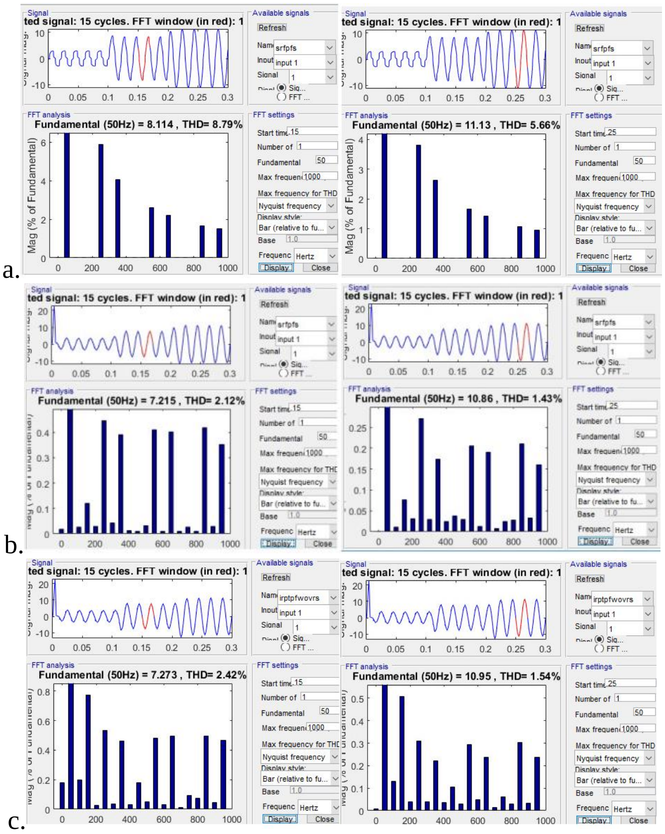

Fig 19 Source current THD in case second a. without DSTATCOM b. using SRF c. using IRPT method

RESULT

Table 2 THD in source current under different conditions

	THD(%)	
	Case 1	Case 2
Without DSTATCOM	23.69%	8.114Ampere,8.79 %(.15sec) and 11.13Ampere,5.66%(.25sec)
SRF or dqo method	3.23%	7.215Ampere, 2.12 %(0.15sec) and 10.86Ampere,1.43%(0.25sec)
IRPT or pq method	3.72%	7.273Ampere,2.42 %(0.15sec) and 10.95Ampere,1.54%(0.25sec)

The harmonics of source current in both the cases are reduced below the 5% which is a standard in IEEE 519. The harmonics in SRF method is less than harmonics in IRPT method thus we can say that the SRF method is reducing more harmonics than IRPT method. The error in the reference current generation by DSTATCOM is less in SRF than in IRPT method.

In case second both of the methods are reducing the source current but the SRF method is reducing more fundamental source current than IRPT method. This less source current shows the less loading on the source and transmission lines in SRF method than in IRPT method.

Conclusion

The reactive power compensation and the power factor correction (in both inductive and capacitive load) using both the methods are nearly equal but the source current harmonics and magnitude, and the error in reference current production by DSTATCOM is less in SRF method than in IRPT method thus we can say that the SRF method is better than IRPT method for combined current harmonics compensation and reactive power compensation. The possible reason for SRF method being better is that the SRF method contains less calculation and deals directly in the current quantities than in IRPT method thus the chances of errors and delay in the signals is less in SRF. Although we generate the reference current but working of DSTATCOM also depend on the compensation current generation which should be equal to the reference compensation current.

Future Scope

In Future work we can also use the DSTATCOM for voltage regulations, imbalance, load balancing etc There are many other methods in the DSTATCOM which can also be used such as instantaneous symmetric component theory, modified single phase pq, symmetric component in SRF, PI control, Fuzzy logic control, Adaline based ANN etc. We can also use the DSTATCOM and other FACTs devices in the renewable power systems, hybrid power systems, micro grids and smart grids for many power quality problems. In short as a future aspect we need to find the best optimal solution for specific situations, problems, and combination of them; which lead to the best engineering solution in terms of cost, time, safety, standards etc. and then we have to find how to increase the efficiency of these devices by using different methods and taking the optimal parameters in designing of these devices and the best location for the use of these devices to increase the quality of power and get the maximum output in minimum inputs.

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