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Performance Analysis of DSTATCOM for Mitigation of Power Quality Issues in Distribution System

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Abstract—*Now a days there is great need to improve power quality and maintaining power system security and reliability in highly complex and interconnected power system network. The under loading and overloading of lines arises a problem of deteriorating voltage profile and power system stability. These power quality problems are due to nonstandard voltage, current and frequency that results in failure of end use equipments. To overcome these problems custom power devices and emerging branch of technology providing the power system versatile with new control capabilities. To overcome these problems, in this paper a new custom power device, distribution static compensator (DSTATCOM) is used for power conditioning in distribution system. DSTATCOM is developed for compensation of reactive power demanded by highly inductive loads, nonlinear loads and in unbalanced supply system. DSTATCOM inject current into supply system to maintain voltage sag and swell and maintain power factor between source voltage and current unity. The unit template algorithm is used for reference current generation of DSTATCOM. The model of DSTATCOM connected in shunt configuration is connected in distribution system feeding nonlinear load is developed using SIMULINK and PSB of MATLAB software. Simulated result represents that DSTATCOM can be considered as viable solution for mitigation of power quality issues in nonlinear load condition.*

Keywords*: Distribution static compensator (DSTATCOM), Total harmonic distortion (THD), Power quality, Voltage source converter (VSC).*

1. INTRODUCTION

Electric Power quality is a term which has captured increasing attention in power engineering in the recent years. Even though this subject has always been of interest to power engineers, it has assumed considerable interest in the 1990's. Electric power quality means different things for different people. To most electric power engineers, the term refers to a certain sufficiently high grade of electric service but beyond that there is no universal agreement. The measure of power quality depends upon the needs of the equipment that is being supplied. What is good power quality for an electric motor may not be good enough for a personal computer [1]-[4]. Usually the term power quality refers to maintaining a sinusoidal waveform of bus voltages at rated voltage and frequency. The electricity supply plays an important role in economic development and technology achievement throughout the world. The quality and reliability of power supplies relates closely to the economic growth of country [2]-[3]. However, power quality disturbances such as sags, swells, flickers harmonics, voltage imbalance etc, create a lot of problem in achieving a reliable and quality power supply . Now-a-days most of the loads in industries, homes, agriculture are inductive in nature like induction motors, ceiling fans, agricultural pumps, etc . In case of these inductive loads current drawn by the load from source is lagging with respect to voltage. So that reactive power burden on distribution system increases which will increase losses in the system and capacity of active power flow through the distribution system get reduced [6]. The insertion of non-linear load like rectifiers, inverters computers produces harmonics in the supply current waveform. Therefore quality of power gets affected. FACTS is essentially alternating current transmission system incorporating controllers which are\power electronic-based or other static controllers that enhance controllability and increase transfer capability of power through line which increases the stability margin of the system. It aims at addressing one or more of the aforementioned power quality issues. Recently, Voltage Source Inverters (VSI) employing fully controlled high power switches such as GTOs, IGBTs have emerged compared to the traditional compensation devices, like passive inductive and capacitive filters, these are of smaller size, have better dynamic performance and enhance system stability [8]-[12]. Many custom power devices such as DSTATCOM, DVR (Dynamic Voltage Restorer), etc. have been proposed in this regard. In this paper, we consider the use of DSTATCOM to address the issue of harmonics mitigation. The advantage of DSTATCOM is that its maximum compensating current is maintained independent of system voltage and maximum capacity of VAR output deceases linearly with decreased voltage. DSTATCOM can be used for compensation of reactive power and unbalance loading in the distribution system. The performance of DSTATCOM depends on control strategies used for extraction of reference current component. In this paper MATLAB based simulation of the DSTATCOM is carried out using unit template algorithm for compensation of the reactive power, unbalance, reducing total harmonic distortion (THD) and improving power factor of the system.

2. POWER QUALITY PROBLEMS

The power disturbances occur on all electrical systems, the sensitivity of today's sophisticated electronic devices make them more susceptible to the quality of power supply. For

Some sensitive devices, a momentary disturbance can cause

Scrambled data, interrupted communications, crashes and equipment failure etc .Power quality problems encompass a wide range of disturbances such as voltage sags, swells, flickers, harmonic distortion, impulse transients, and interruptions.

Sources of power quality problems:

$$\left.\begin{array}{c}\text{Large motor starting}\\ \text{Different faults}\\ \text{lightning}\end{array}\right\}\text{Leads to voltage sag}$$

$$\left.\begin{array}{c}\text{Capacitive load}\\ \text{Open circuit}\end{array}\right\}\text{Leads to voltage swell}$$

$$\boldsymbol{Nonlinear\ loads}\}\ \text{Production of harmonics}$$

Solution of power quality problems

There are two approaches to mitigate the power quality problems. The solution to the power quality can be done from consumer side or from utility side; first approach is called load conditioning, which ensures that the equipment is less sensitive to power disturbances, allowing the operation even under significant voltage distortion. The other solution is to install line conditioning systems that suppress or counteract the power system disturbances by injecting current into the supply system locally. Currently they are converters based and connected in shunt or in series with to low and medium voltage distribution system. Series active power filters must operate in conjunction with shunt passive filters in order to Compensate load current harmonics. Shunt active power filters operate as a controllable current source and series active power filters operate as a controllable voltage source. Both schemes are implemented in preferable with voltage source inverter, with a dc bus having a reactive element such as a capacitor. However, with the restructuring of power sector and with shifting trend towards distributed and dispersed generation, the line conditioning systems or utility side solutions will play a major role in improving the inherent supply quality.

Arrester is designed for lightning protection of transformers, but is not limited to sufficient voltage limit for protecting sensitive electronic control circuits from voltage surges.

The static switch is a versatile device for switching a new element into the circuit when the voltage support is needed. It has a dynamic response to correct quickly for voltage spikes, sags or interruptions. Static switch can used to switch one or more devices such as capacitor, filter, alternate power line, energy storage systems etc.

3. DSTATCOM CONFIGRATION

A DSTATCOM is schematically shown in fig. 1. It consists of voltage source converter (VSI) with dc energy storage and coupling transformer which is connected in shunt with the distribution system. DSTATCOM inject reactive power into the system or absorb reactive power from the system at the point of PCC. If the line voltage is greater than converter voltage, converter draw a lagging current and behaves like an inductor .If line voltage is less than converter voltage it will inject current into the supply system and converter behaves like a capacitor. DSTATCOM is mainly used in power system to maintain voltage level and improve power quality such as voltage regulation, reactive power compensation, and power factor correction and load balancing.[1]-[8]

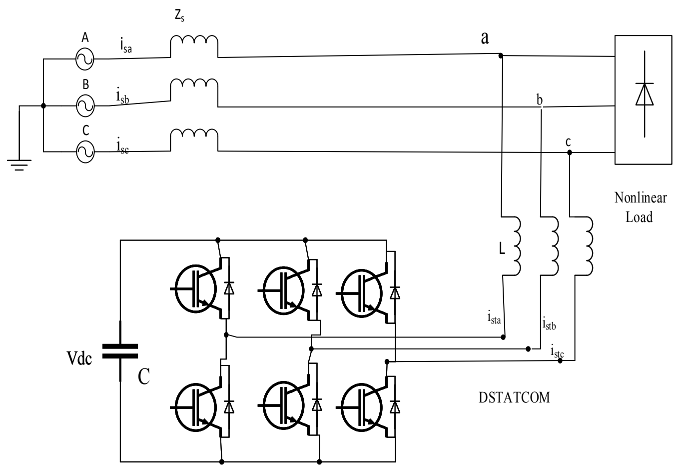

Fig. 1: Basic circuit diagram of DSTATCOM system

A. Equation of DSTATCOM

From fig.1 let's assume that V_s , I_s, and V_r, I_r are voltage and current at sending and receiving end respectively. Both are connected through line impedance Z_{th},

Then shunt injected current I_{sh} can be written as

$$I_{sh} = I_l - I_s \quad (1)$$

Where

$$I_s = \frac{V_s - V_r}{Z_{th}} \quad (2)$$

So that

$$I_{sh} = I_l - \frac{V_s - V_r}{Z_{th}} \quad (3)$$

Complex power injection of DSTATCOM can be written as

$$S_{sh} = V_r I_{sh}^{*} \quad (4)$$

B. voltage source converter (VSC)

Voltage source converter is a power electronic device which consists of six IGBT switches with diode is connected in parallel with dc energy storing element. By giving proper switching pulses it can generates a sinusoidal voltage with any required magnitude, frequency and phase angle. Voltage source converters are widely used in adjustable speed drives, but can also be used to mitigate voltage dips. The VSC is used to either completely replacing the voltage or to inject the 'missing voltage'. The 'missing voltage' is the difference between the nominal voltage and the actual voltage. The converter consist energy storage, which will supply the converter with a DC voltage source.

4. CONTROL ALGORITHM

The characteristics of good control strategy are dynamic response, flexibility and implementation procedure. Control techniques are used for generation of reference source current used to decide switching of DSTATCOM has real fundamental frequency component of the load current.

UNIT TEMPLATE ALGORITHM

In this control scheme two PI controllers are used. One PI controller is realized over the sensed and reference values of dc bus voltage of the DSTATCOM. The second PI controller is realized over the sensed and reference values of ac voltage at PCC. The output of the first PI controller $\left(I_{spdr}\right)$ is considered as amplitude of in-phase components of reference supply currents and the output of second PI controller $\left(I_{spqr}\right)$ is considered as amplitude of quadrature components of reference supply currents. A set of in-phase unit current vector $(u_a, u_b$ and $u_c)$ are computed by dividing the terminal voltages $(v_{ta}, v_{tb}$ and$v_{tc})$ by their amplitude (v_t). Another set of three-phase quadrature unit current vectors $(w_a, w_b$ and $w_c)$ are derived. The multiplication of in-phase amplitude with in-phase unit current vectors results in the in-phase components $(I_{sadr}, I_{sbdr}$ and $I_{scdr})$ of three-phase reference supply currents and similarly multiplication of quadrature amplitude with quadrature unit current vectors results in the quadrature components $(I_{saqr}, I_{sbqr}$ and $I_{scqr})$ of three-phase reference supply currents. Algebraic sum of these in-phase and quadrature components results in the three-phase reference supply currents $(I_{sar}, I_{sbr}$ and $I_{scr})$. These three-phase reference supply currents are computed using three-phase supply voltages and dc bus voltage of the DSTATCOM.

CALCULATION OF IN PHASE COMPONENT OF REFERENCE CURRENTS

The amplitude of in-phase component of reference supply currents (I_{spdr}) is computed using first PI controller over the

Average value of dc bus voltage of the DSTATCOM and its

reference counterpart.

$$I_{spdr(n)} = I_{spdr(n-1)} + K_{pd}\left\{V_{de(n)}\right\} + K_{id}V_{de(n)} \quad (5)$$

Where $V_{de(n)} = V_{dcr} - V_{dca(n)}$ denotes the error in V_{dc} calculated over reference V_{dcr} and average value V_{dc} and K_{pd} and K_{id} are proportional and integral gains of the dc bus voltage PI controller. The output of this PI controller is taken as the amplitude of in-phase component of the reference supply currents. Three phase, in-phase components of the reference supply currents are computed using their amplitude and in-phase unit current vectors derived from the supply voltages and amplitude of supply voltage which is computed by:

$$V_{tm} = \sqrt{\frac{2}{3}\left(V_{ta}^2 + V_{tb}^2 + V_{tc}^2\right)} \quad (6)$$

The unit vectors $(u_a, u_b$ and $u_c)$are calculated as:

$$U_a = V_{ta}/V_{tm}$$
$$U_b = V_{tb}/V_{tm} \quad (7)$$
$$U_c = V_{tc}/V_{tm}$$

The in-phase magnitudes of reference current $(I_{sadr}, I_{sbdr}$ and $I_{scdr})$ are calculated by:

$$I_{sadr} = I_{spdr}\, u_a$$
$$I_{sbdr} = I_{spdr}\, u_b \quad (8)$$
$$I_{scdr} = I_{spdr}\, u_c$$

CALCULATION OF QUADRATURE COMPONENT OF REFERENCE SUPPLY CURRENTS

Reactive power component of source current can be expressed as

$$I_{snq} = \frac{2}{3}\frac{\bar{q}}{V_t} \quad (9)$$

Where, $\bar{q}$ is reactive power component of load current.

The amplitude of quadrature component of reference supply

Currents $\left(I_{spqr}\right)$ is computed using another PI controller over the average value of amplitude of supply voltage and its reference counterpart

$$I_{spqr(n)} = I_{spqr(n-1)} + K_{pq}\{C\} + K_{iq}V_{ae(n)}. \quad (10)$$

Where $V_{ae(n)} = V_{tmr} - V_{tm(n)}$ denotes the error in V_{tm} calculated over reference V_{tmr} and average value of V_{tm} and K_{pq} and K_{iq} are the proportional and integral gains of the second PI controller.

Calculation of quadrature unit template are given by

$$W_a = \left\{-\frac{u_b}{\sqrt{3}} + \frac{u_c}{\sqrt{3}}\right\}$$
$$W_b = \left\{\frac{\sqrt{3}}{2}u_a + \frac{u_b - u_c}{\sqrt{3}}\right\} \quad (11)$$
$$W_c = \left\{-\frac{\sqrt{3}}{2}u_a + \frac{u_b - u_c}{\sqrt{3}}\right\}$$

Amplitude of reactive power component of reference source current

$I_{spqr} = I_{spqr(n)} - I_{spqr(n)}$

After multiplying quadrature unit template with I_{sn} we get quadrature component of reference source current is

$I_{saqr} = I_{spqr} W_a$

$I_{sbqr} = I_{spqr} W_b$ (12)

$I_{scqr} = I_{spqr} W_c$

CALCULATION OF TOTAL REFERENCE SOURCE CURRENT

Total reference current can be found by taking sum of direct and quadrature component of reference source current.

$I_{sa}^{*} = I_{sadr} + I_{saqr}$

$I_{sa}^{*} = I_{sadr} + I_{saqr}$ (13)

$I_{sa}^{*} = I_{sadr} + I_{saqr}$

HYSTERESIS CURRENT CONTROLLE

This control technique requires defining upper hysteresis band limit and lower hysteresis band limit. In open loop control strategy, the variation in output DC voltage is common problem if load is variable, but we can get steady output if close loop strategy is used. In close loop control, output current signal is compared with reference current signal which decrease the error in output and gives desired output. The generated gate pulses can be controlled by PI or PID controllers. These signals are for power switching devices, when upper and lower limits of hysteresis bands are exceeded. The conventional method of hysteresis control is known as two-level hysteresis current control technique. It is nonlinear method and it is based on current error. This method consists of a comparison between the load current and band limit given to it. When it crosses the upper band limit, the switches turns off, when current crosses the lower band limit, switches turns on.

In this controller, the hysteresis band of the value 'h' is added to the calculated value of the reference current from unit template algorithm. When the value of the error > +h then pulse generation takes place for the lower level switch S2 of phase 'a' leg and when the value of the error < -h, then the pulse generation for the upper switch S 1 of the phase 'a' leg of the VSC. And the same is applicable for remain two phase 'b' and 'c'.

Simulaed model of hysteresis controller is shown in fig2. In this model actual current are compared with reference current and error signal are produced. These signal are applied to the relay which provides hysteresis band for controlling of current. Once signal of upper switch is produced, signal for lower switch can be obtained by inverting the upper signal.

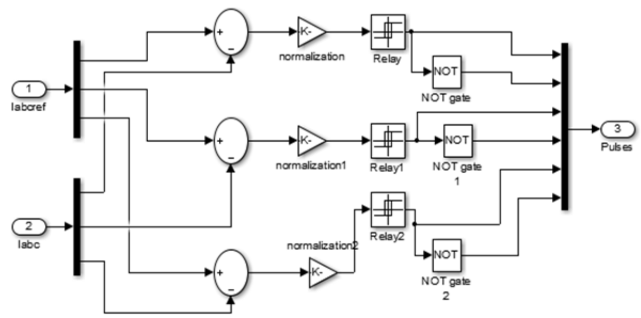

Fig. 2: Simulation model of hysteresis current controller

5. PERFORMANCE OF DSTATCOM

In this paper a test system is employed with three phase source feeding a variety of consumer loads. The source is connected to load by source impedance (R, L). The DSTATCOM is connected in shunt configuration at the PCC. The modeled system is tested on two different load conditions such as highly inductive linear load and three phase bridge rectifier connected with RL load.

Table I: SYSTEM PARAMETER

Parameter	Value
Source voltage ,V	550V
Frequency, f	50Hz
Capacitor for DSTATCOM	600µF
Active & Reactive power for main load	20KW
Active and reactive power for switching load	20KVAR
Nonlinear load ,three phase bridge rectifier with Rand L	15KW
DC reference voltage	40KVAR

CASE A. PERFORMANCE OF DSTATCOM WITH LINEAR LOAD

In this case a 3-phase series RL load drawing active power

Component 20kW and reactive power component 20kVAR is considered. Another linear 3-phase series RL load is switched on of duration 0.5 sec between 0.15 and 0.20 sec. The additional load draws active power component of 10kW and reactive power of 40kVAR. Fig 3 shows the response of system with load change introduced at t = 0.15 sec which is brought back to normal conditions at t = 0.2sec.This figure shows that when heavy load is connected at load end then reactive power demand in the load from source increases which cause voltage dip between 0.15sec to 0.20 sec. Figure 4 shows that when DSTATCOM has introduced in system cause improvement in voltage profile at PCC. This represents that DSTATCOM is best suitable for voltage regulation in distribution system.

CASE B PERFORMANCE OF DSTATCOM WITH NONLINEAR LOAD (RL load connected at end of diode rectifier)

In this case a series combination of resistance and inductance of values 100 Ω and 0.001 H respectively are connected across three phase diode bridge rectifier. Fig5 shows that when DSTATCOM is not connected supply current waveform is nonsinusodal which consist of harmonics component along with fundamental. When DSTATCOM is introduced into system it injects current into supply system to mitigate harmonic component of load current. THD level of supply currents is observed to be improved from 30.11% to 3.69% with the help of DSTATCOM. The plots showing the waveform & the FFT analysis of supply currents without/with DSTATCOM are shown in Fig. 5 & Fig 6.

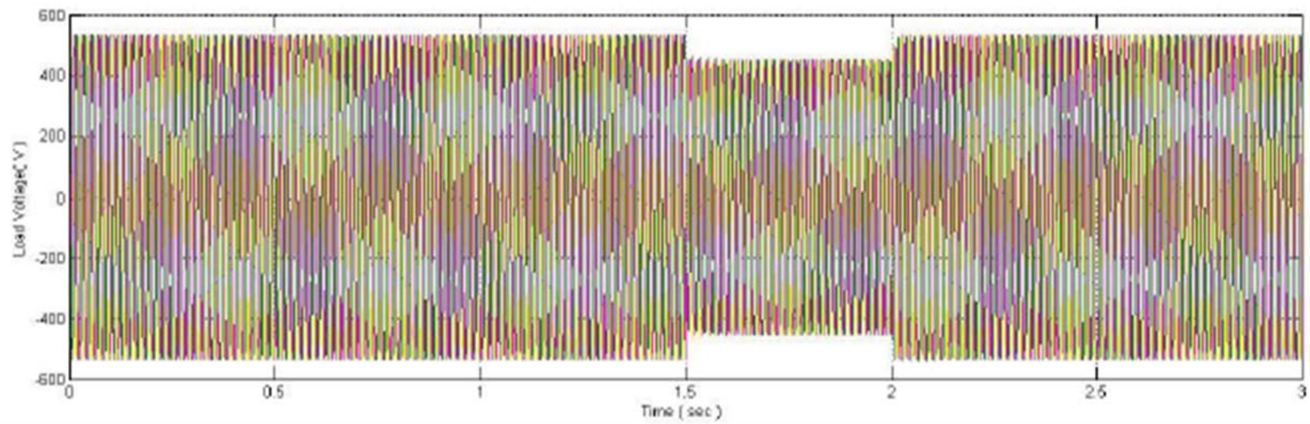

Fig. 3: Result of case A without DSTATCOM

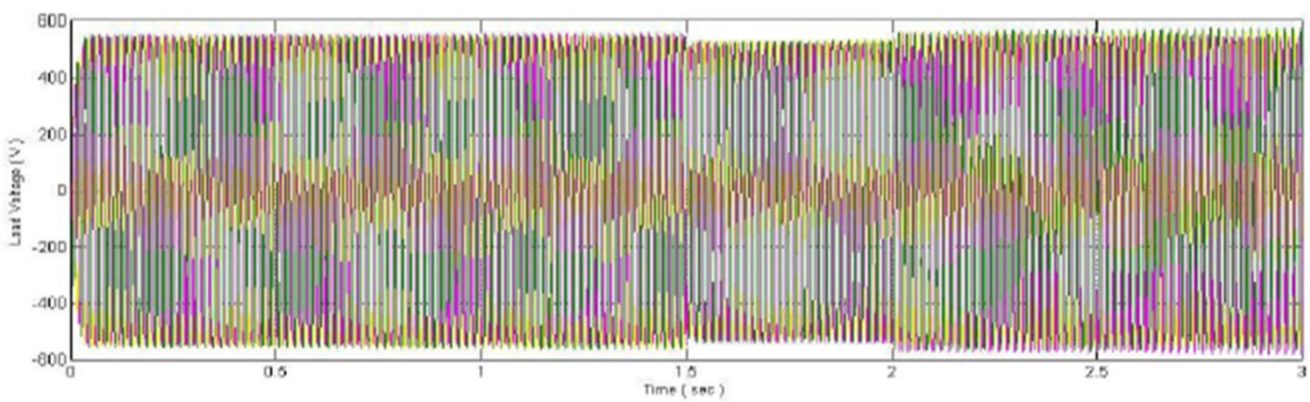

Fig. 4: Result of case A with DSTATCOM

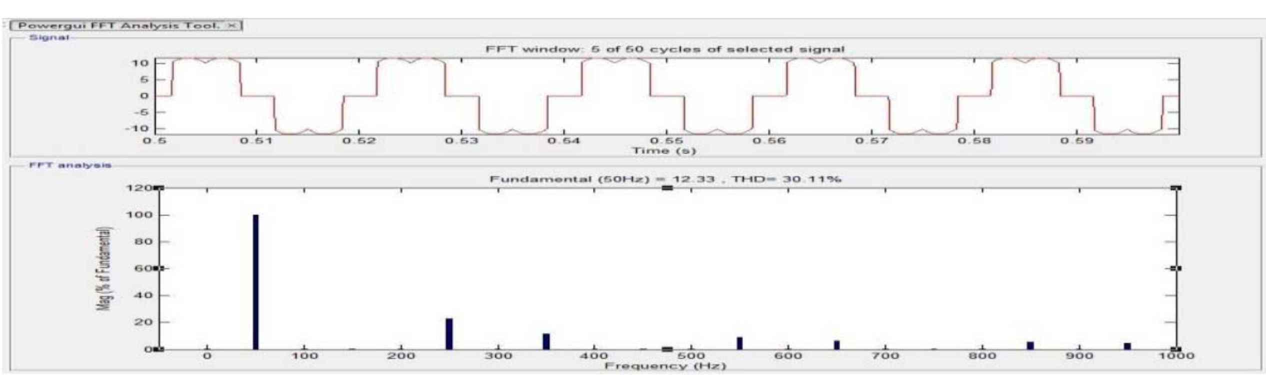

Fig. 5: Source current in case B without DSTATCOM

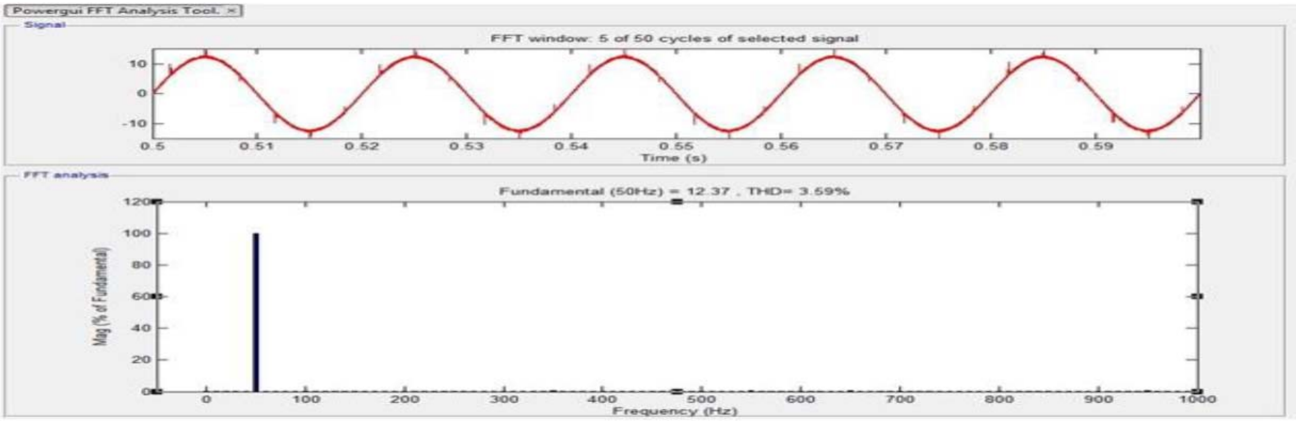

Fig. 6: Source current of case B with DSTATCOM

6. CONCLUSION

In this paper DSTATCOM has been modeled and simulated in MATLAB environment. The performance of DSTATCOM has been analyzed for varying linear and non-linear loads condition. The 16% decrement in voltage magnitude is observed during 1.5 to 2 sec due to switching of heavy loads. DSTATCOM has been found to regulate PCC voltage under highly inductive load conditon.The performance of DSTATCOM with non-linear loads is also found to be satisfactory and it is able to reduce the supply current THD to less than 5% level as per IEEE 519 standards, even though the load current THD has a value of 30.1%. The power quality improvement in distribution line with DSTATCOM has proved its effectiveness.

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