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Simulation of D-STATCOM under Fault condition And Nonlinear Loads

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Abstract- **DSTATCOM (Distribution Static Compensator) is used for compensation of reactive power and unbalance caused by various loads in distribution system. D-STATCOM Distribution Static Compensator) is a shunt device which is generally used to solve power quality problems in distribution systems. D-STATCOM is a shunt device used in correcting power factor, maintaining constant distribution voltage and mitigating harmonics in a distribution network.**

D-STATCOM is used for Grid Connected Power System, for Voltage Fluctuation, for Wind Power Smoothening and Hydrogen Generation etc. This paper presents the enhancement of voltage sags, harmonic distortion and low power factor using Distribution Static Compensator (D-STATCOM) with LCL Passive Filter in distribution system. The model is based on the Voltage Source Converter (VSC) principle. The D-STATCOM injects a current into the system to mitigate the voltage sags. The system is modeled by using MATLAB/SIMULINK software and performance is observed.

Index Terms— D-STATCOM, Voltage Sags, Voltage Source Converter (VSC), LCL Passive Filter, Total harmonics Distortion (THD)

I. INTRODUCTION

In recent years, the custom power technology, the low voltage counterpart of the more widely known flexible ac transmission system (FACTS) technology, aimed at high voltage power transmission applications, has emerged as a credible solution to solve many of the problems relating to continuity of supply at the end-user level. Both the FACTS and custom power concepts are directly credited to EPRI [1], [2]. At present, a wide range of very flexible controllers, which capitalize on newly available power electronics components, are emerging for custom power applications.

The DSTATCOM is a shunt device. It should therefore be able to regulate the voltage of a bus to which it is connected. The operating principle of a DSTATCOM in this mode has been termed as the DSTATCOM in voltage control mode. This report shows that even though the structure of DSTATCOM used in both current control and voltage control modes is the same, its operating principle is different. In the current control mode it is required to follow a set of reference currents while in the voltage control mode it is required to follow a set of reference voltages.

DSTATCOM is to suppress voltage variation and control reactive power in phase with system voltage. It can compensate for inductive and capacitive currents linearly and continuously. Figure.1 shows the vector diagram at the fundamental frequency for capacitive and inductive modes and for the transition states from capacitive to inductive and vice versa. The terminal voltage (V_{bus}) is equal to the sum of the inverter voltage (V_{vsc}) and the voltage across the coupling transformer reactive V_L in both capacitive and inductive modes. I mean that if output voltage of DSTATCOM (V_{vsc}) is in phase with bus terminal voltage (V_{bus}) and V_{vsc} is greater than V_{bus}, DSTATCOM provides reactive power to system.

And if V_{vsc} is smaller than V_{bus}, DSTATCOM absorbs reactive power from power system. V_{bus} and V_{vsc} have the same phase, but actually they have a little phase difference to component the loss of transformer winding and inverter switching, so absorbs some real power from system.

Figure 1 is DSTATCOM vector diagrams, which show inverter output voltage V_I, system voltage V_T, reactive voltage V_L and line current I in correlation with magnitude and phase δ. Figure 1.a and b explain how V_I and V_T produce capacitive or inductive power by controlling the magnitude for inverter output voltage VI in phase with each other. Figure 1.c and d show DSTATCOM produces or absorbs real power with V_I and V_T having phase ±δ. The transition from inductive to capacitive mode occurs by charging angle δ from zero to a negative value. The active power is transferred from the AC terminal to the DC capacitor and causes the DC link voltage to rise. The active and reactive power may be expressed by the following equations:

$$P = (V_{bus} V_{vsc}/X_L)\sin\delta \quad (1)$$

$$Q = (V^2_{bus}/X_L) - (V_{bus} V_{vsc}/X_L)\cos\delta \quad (2)$$

In any practical DSTATCOM there are losses in the transformer windings and in the converter switches. These losses consume active power from the AC terminals. Accordingly, a small phase difference always exists

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between the VSC voltage and the AC system voltage. A summary of the power exchanges between the DSTATCOM and the AC system as a function of the DSTATCOM output voltage V_{vsc} and the AC system voltage V_{bus}.

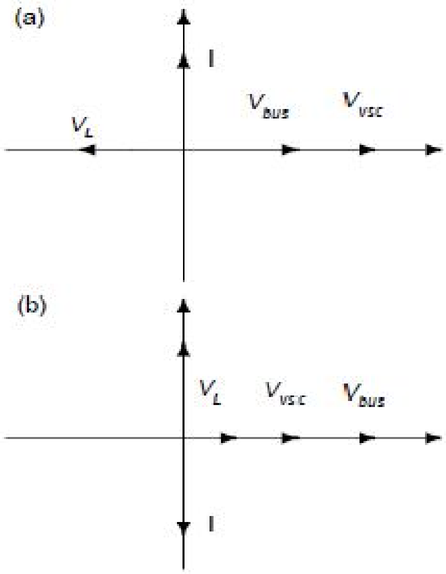

Fig 1: Vector diagram of DSTATCOM (a) capacitive mode, (b) inductive mode

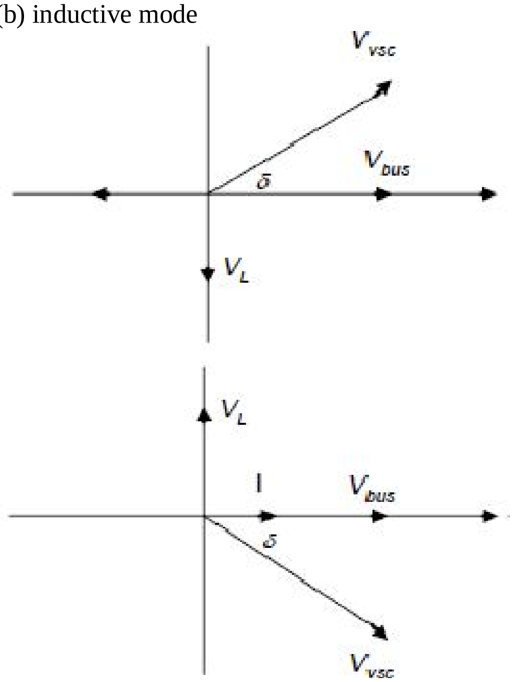

Fig 1: (c) Active power release and (d) Active power absorption

II. DISTRIBUTION STATIC COMPENSATOR (D-STATCOM)

A D-STATCOM consists of a two-level VSC, a dc energy storage device, controller and a coupling transformer connected in shunt to the distribution network. Fig.2 shows the schematic diagram of D-STATCOM.

$$I_{out} = I_L - I_S = I_L - \frac{V_{th} - V_L}{Z_{th}} \quad (3)$$

$$I_{out} < \gamma = I_L < (-\theta) - \frac{V_{th}}{Z} < (\delta - \beta) + \frac{V_L}{Z} < (-\beta) \quad (4)$$

Referring to the equation 4, output current, I_{out} will correct the voltage sags by adjusting the voltage drop across the system impedance, (Z_{th} =***R+jX***). It may be mention that the effectiveness of D-STATCOM in correcting voltage sags depends on:

a) The value of Impedance, Z_{th} = ***R+jX***

b) The fault level of the load bus

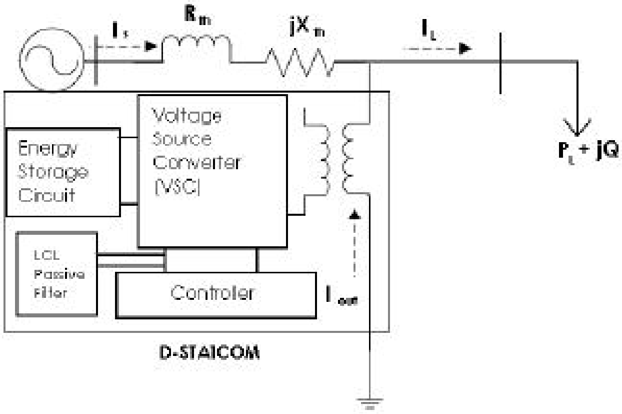

Fig 2. Schematic diagram of a D-STATCOM

A. Voltage Source Converter (VSC)

A voltage-source converter is a power electronic device that connected in shunt or parallel to the system. It can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. The VSC used to either completely replace the voltage or to inject the 'missing voltage'. The 'missing voltage' is the difference between the nominal voltage and the actual. It also converts the DC voltage across storage devices into a set of three phase AC output voltages [8, 9].

In addition, D-STATCOM is also capable to generate or absorbs reactive power. If the output voltage of the VSC is greater than AC bus terminal voltages, D-STATCOM is said to be in capacitive mode. So, it will compensate the reactive power through AC system and regulates missing voltages. These voltages are in phase and coupled with the AC system through the reactance of coupling transformers. Suitable adjustment of the phase and magnitude of the DSTATCOM output voltages allows effectives control of active and reactive power exchanges between D-STATCOM and AC system. In addition, the converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage [10].

B. Controller

Fig 3 shows the block diagram of Controller system. The controller system is partially part of distribution system.

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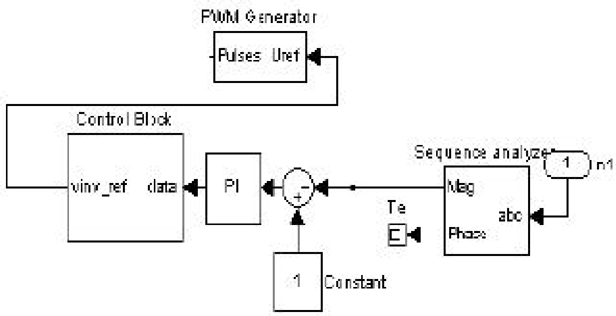

Figure 3.Block Diagram of Controller System

Proportional-integral controller (PI Controller) is a feedback controller which drives the system to be controlled with a weighted sum of the error signal (difference between the output and desired set point) and the integral of that value.

In this case, PI controller will process the error signal to zero. The load r.m.s voltage is brought back to the reference voltage by comparing the reference voltage with the r.m.s voltages that had been measured at the load point. It also is used to control the flow of reactive power from the DC capacitor storage circuit.

PWM generator is the device that generates the Sinusoidal PWM waveform or signal. To operate PWM generator, the angle is summed with the phase angle of the balance supply voltages equally at 120 degrees. Therefore, it can produce the desired synchronizing signal that required. PWM generator also received the error signal angle from PI controller. The modulated signal is compared against a triangle signal in order to generate the switching signals for VSC valves.

C. Energy Storage Circuit

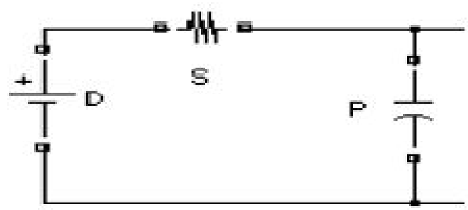

Figure 4: circuit diagram of DC storage

DC source is connected in parallel with the DC capacitor. It carries the input ripple current of the converter and it is the main reactive energy storage element. This DC capacitor could be charged by a battery source or could be recharged by the converter itself.

D. LCL Passive Filter

LCL Passive filter is more effective on reducing harmonic distortion. To design it, equation (5), (6) and (7) are used.

$$L_g = \frac{E_n}{2\sqrt{6}\, i_{ripm} \cdot f_{sw}} \quad (5)$$

$$L_g = \frac{E_n}{2\sqrt{6}\, i_{ripm} \cdot f_{sw}} \quad (6)$$

$$C_f = \frac{L + L_g}{L L_g \left(2\pi f_{res}\right)^2} \quad (7)$$

To design an efficient LCL Passive filters make sure that,

$$10 f_n \le f_{res} \le 0.5 f_{sw}$$

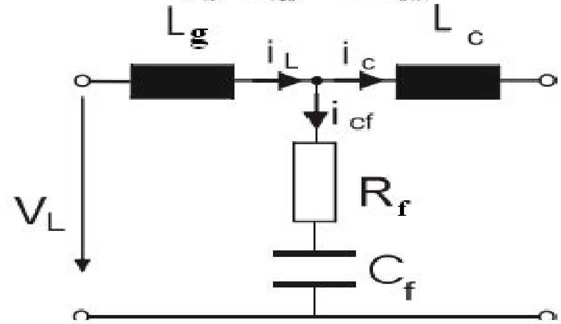

Figure 5.circuit diagram for single phase LCL Passive Filter

III. METHODOLOGY

. To enhance the performance of distribution system, DSTATCOM was connected to the distribution system. DSTATCOM was designed using MATLAB simulink version R2009b.

A. Test System

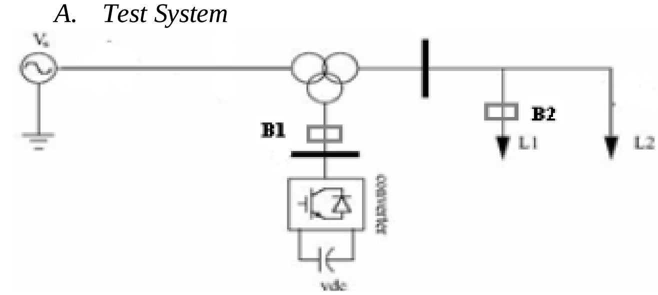

Fig. 6 Single line diagram of the test system

B. Simulink Model for the test system

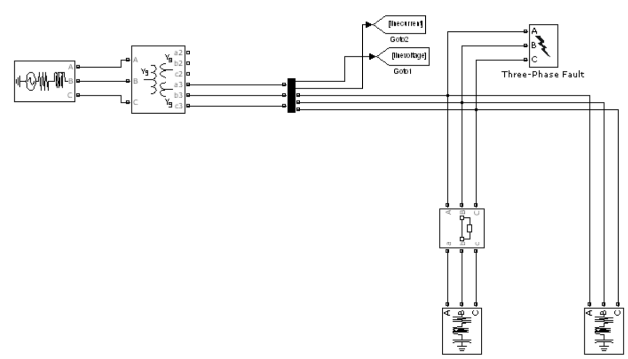

Fig. 7 System without DSATCOM

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To create distortion in the distribution system, different types of fault such as Three Phase to Ground (LLLG), Double Line to Ground (LLG), Line to Line (LL), and Single Line to Ground (LG) are injected.

IV. RESULTS

A. Without insertion of D-STATCOM

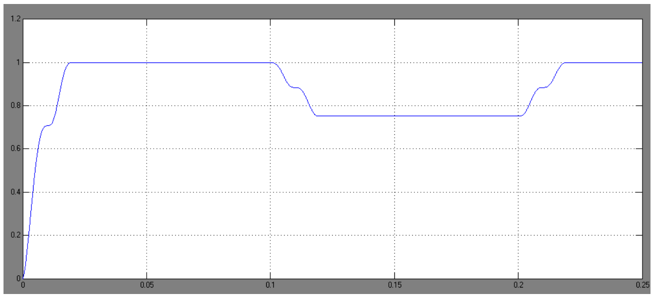

Fig 8(a).voltage at load point is 0.75 p.u during LLLG fault

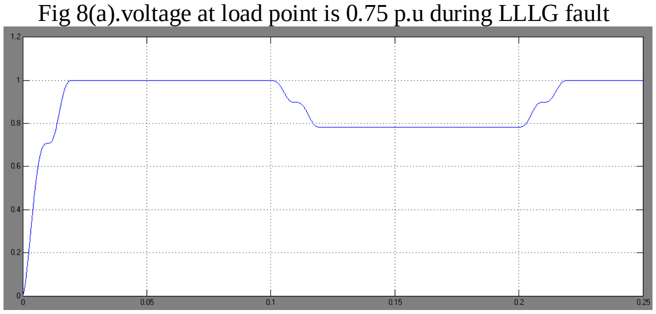

Fig 8(b).voltage at load point is 0.78 p.u during LLG fault

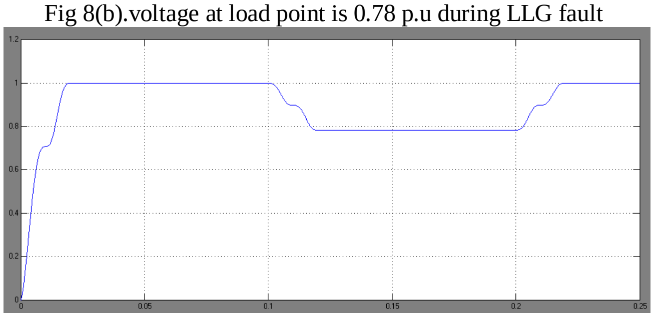

Fig 8(c).voltage at load point is 0.7487 p.u during LL fault

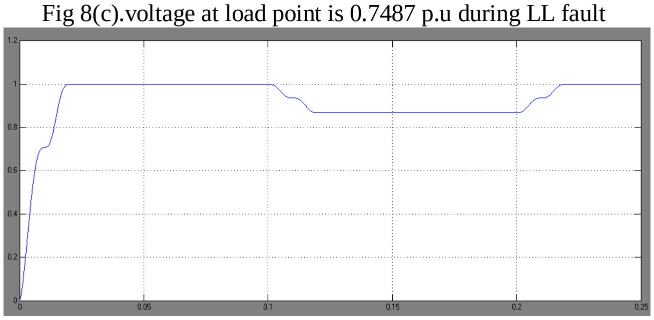

Fig 8(d).voltage at load point is 0.868 p.u during LG fault

Fig 8(a) to 8(d) show the simulation results of the test system for different types of fault. The fault occur during (100-200ms) when the fault resistance, $R_f = 0.86\ \Omega$.

B. With insertion of D-STATCOM

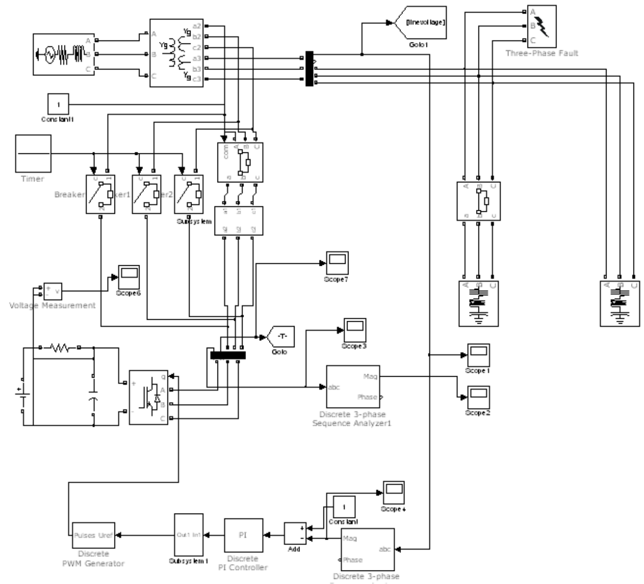

Fig. 9 Simulink model of the system with DSTATCOM

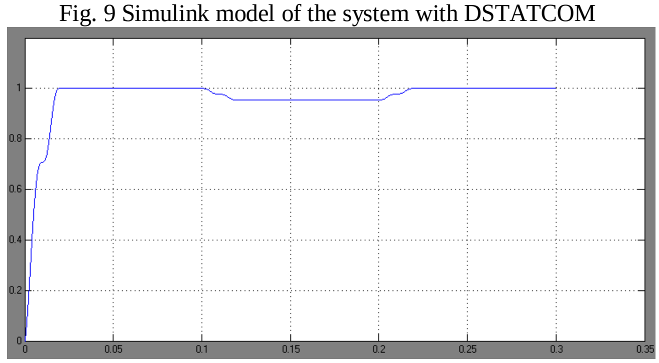

Fig 10(a).voltage at load point is 0.9543 p.u during LLLG fault

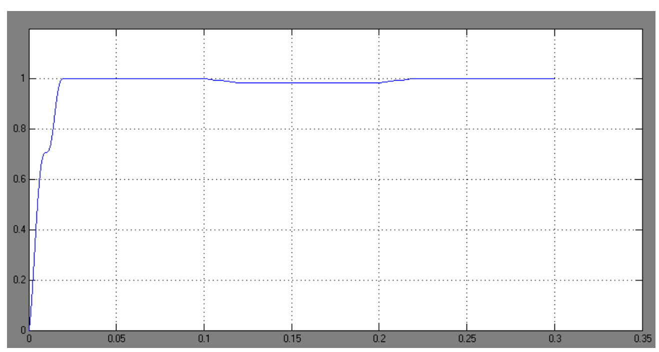

Fig 10(b).voltage at load point is 0.9858 p.u during LLG fault

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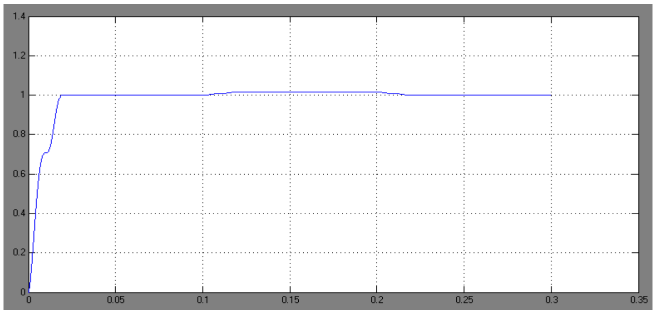

Fig 10(c).voltage at load point is 1.0152 p.u during LL fault

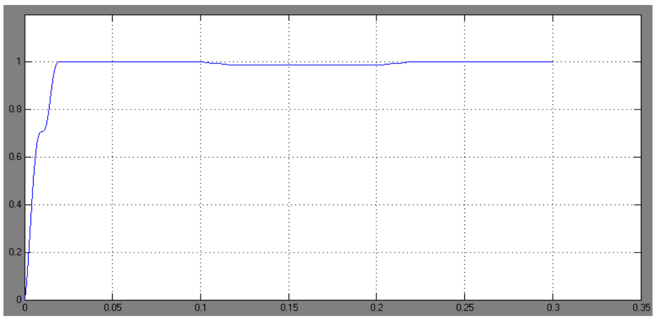

Fig 10(d).voltage at load point is 0.9863 p.u during LG fault

From Fig.10 it can be observed that voltage sags improved with insertion of D-STATCOM. The value of voltage sags is between (0.9 to 1.02 p.u.).

B. *Load Side Sensing*

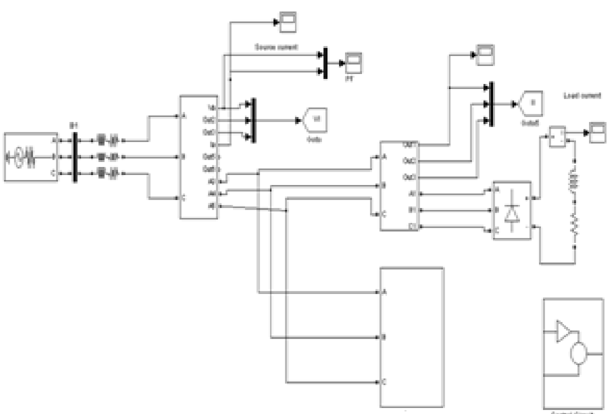

Figure.11Simulink model of DSTATCOM

Figure.11 shows the Simulink model of the DSTATCOM with the Load side sensing control method

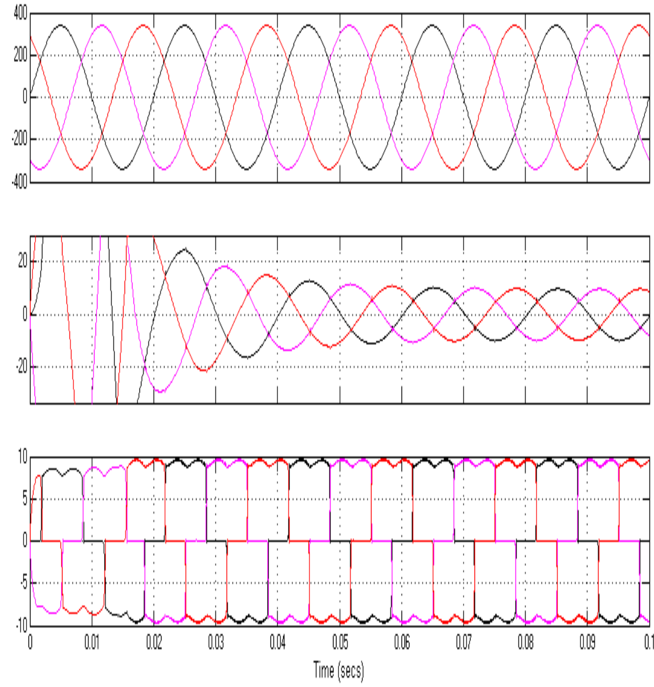

Figure.12 Source voltage, current, load current

Figure.12 shows the source voltage, source current and the load current of the system with DSTATCOM. Source current is not having as much harmonics as load current do have.

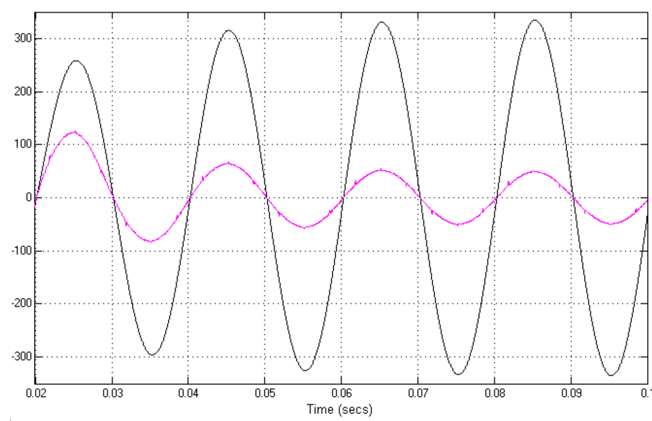

Figure.13 Power Factor

Figure.13 shows the power factor wave form which indicates that source current is not deviated from the voltage waveform

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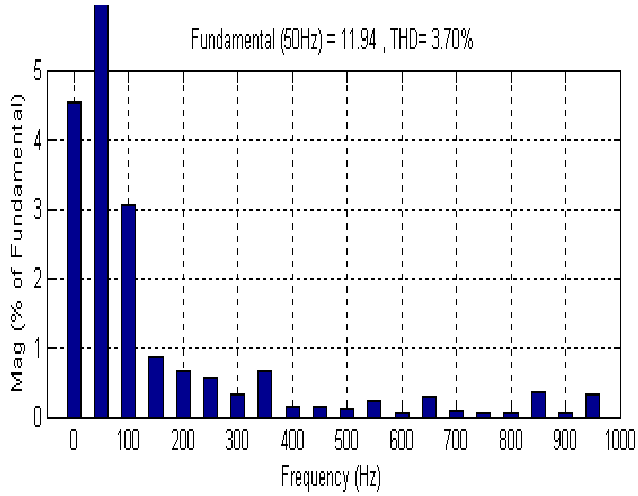

Figure.14 Spectrum analysis of source current

Figure.14 shows the spectrum analysis of the source current it is having the THD of 3.70%.

V. CONCLUSION

The simulation results show that the voltage sags can be mitigate by inserting D-STATCOM to the distribution system. By adding LCL Passive filter to D-STATCOM, the THD reduced within the IEEE STD 519-1992. The power factors also increase close to unity. Thus, it can be concluded that by adding D-STATCOM with LCL filter the power quality is improved. In addition to this by using the DSTATCOM harmonics can be eliminated on the source side which is caused due to non linear load.

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