International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 5 (2015) pp. 12079-12091

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Power Quality Improvement Using A Voltage Controlled Dstatcom

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Abstract

During Last decade power quality problems has become a problem at all level of power system. Nowadays, the Power electronics controllers are commonly used to provide the quality of power for both power suppliers and consumers. Various power filters like active power filters, hybrid filters, passive filters has been applied from time to time for giving the solution of power quality problems to users, but could not fully satisfied them. Nowadays a new concept of custom power device is used for customers' satisfaction. This paper presents one of the custom power devices known as distribution static compensator to reduce the total harmonic distortion. A reference voltage is generated for the DSTATCOM which is operating in voltage controlled mode. The DSTATCOM uses a three phase, four wire, neutral point clamped two level voltage source inverter. A proportional integral controller is used to regulate the dc capacitor voltage at the reference value. A simulation model is developed in MATLAB to demonstrate the efficacy of the proposed algorithm.

Keywords: DSTATCOM, Total Harmonic Distortion, Voltage-control mode, Voltage- source inverter.

Introduction

Recently, Power quality problems have become an important issues for electricity consumers at all the level [2]. The electric power energy deregulation has increased the public awareness towards power quality among the different categories of users . To provide an active & flexible solution for power quality problems, various efforts have been taken from time to time. Among these different types of solution, lossless passive filters consists of L-C tuned component have been widely used to suppress harmonic. These filters are advantageous as its initial cost is low and high efficiency. But it has various drawbacks like instability, fixed compensation, resonance with supply as well as loads and utility impedance. In order to overcome these problems active power filters have been used. Active power filter has various types such as shunt, series and hybrid. Hybrid is the combination of series and shunt filters. Shunt APF is used for compensating current related distortions while series APF compensates voltage related distortions. Hybrid APF is applied for filtering high order harmonics. But, they have a problem that their rating is sometimes very close to load (up to load 80 %) in typical applications. Due to this problem, power quality level is not obtained. This will result in power disturbances and customer dissatisfaction. To increase the reliability of the power distribution system and to face the power quality problems, an advanced power electronics controller devices have launched over last decades. The development of power electronics controller devices have given to the birth of custom power devices. A DSTATCOM connected at the point of common coupling has been used to reduce the power quality problems [1]-[3], [5]-[10]. When operating in current controlled mode, the DSTATCOM will make the source current balanced, sinusoidal [1], [3], [6], [7] [9]. In voltage controlled mode, the DSTATCOM regulates the PCC voltage at a reference value to prevent from the power quality problems like sag, swell, unbalances [5], [8], [10]. This paper proposes a method to operate a distribution static compensator (DSTATCOM) as a voltage regulator to maintain the voltage of a specified bus. The magnitude of the bus voltage is pre specified while its phase angle is generated from the dc capacitor control loop. Here, the DSTATCOM is used to reduce the total harmonic distortion of source voltage and current by generating a reference terminal voltage instead of assuming the reference terminal voltage as 1 p.u. [2], [5], [8] since a load can work satisfactorily for a permissible range of voltage [4].

Custom Power Devices

Custom power is a strategy, which is meant principally to summon the requirement of industrial and commercial consumers. The idea of the custom power is tools of application of power electronics controller devices into power distribution system to supply a quality of power, demanded by the users. These power electronics controller devices are also called custom power devices because through these quality powers are delivered to the customers. They have good performance at the distribution levels. For the generation of custom power devices VSI is generally used, as they have the feature of self-supporting of the dc bus voltage with a large dc capacitor. The custom power devices are mainly classified into two groups: network reconfiguring type and compensating type. The classification of custom power devices is shown in the Fig. 1.

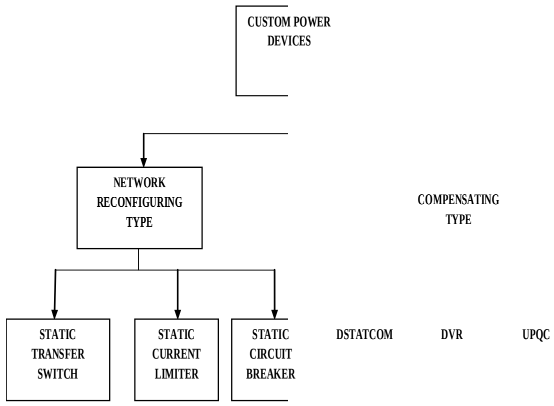

Figure 1: Classification of Custom Power Devices

Distribution Static Compensator

DSTATCOM is a Voltage source inverter (VSI) based static compensator device (STATCOM, FACTS controller) applied to maintain bus voltage sags at the required level by supplying or receiving of reactive power in the distribution system. It is connected in parallel with distribution feeder with the help of coupling transformer. The placement of DSTATCOM in distribution lines is shown in Fig. 3. The DSTATCOM consists of a VSI, dc energy storage device, an ac filter and coupling transformer. A DSTATCOM is capable of compensating both bus voltage and line current. When the DSTATCOM operates in a voltage control mode, it will make the voltage of the bus to which it is connected a balanced sinusoid, irrespective of the unbalance and distortion in the supply side voltage or line current. Similarly when operated in a current control mode, it can make the source side currents to become balanced sinusoids. Consider a radial distribution system, as shown in Fig. 2.

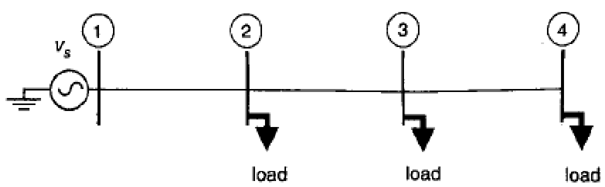

Figure 2: Radial distribution system

It consists of three load buses and a stiff source connected at bus 1. Assume that customers are supplied from these buses. A DSTATCOM can be connected in any of these buses to improve the quality of the power which is to be delivered to the customers. For example, if the voltage is distorted at bus 3, it affects customers both at buses 3 and 4. The utility may then install a DSTATCOM at this bus to maintain the voltage. On the other hand, assume that the consumer at bus 4 has loads that draw unbalanced and distorted current from the supply. In order to avoid a penalty, an option for the consumer is to install a DSTATCOM, so that the current drawn from bus 4 is a balanced sinusoid. A DSTATCOM can be realized using a VSI and a DC storage capacitor. One of the needs of a DSTATCOM in a three-phase four-wire distribution system is that it must have the capability of injecting three unbalanced and distorted currents into the AC system in order to cancel voltage or current unbalance or distortions. Therefore there arises a need for DSTATCOM to force three independent currents through three phases. An important problem of using an ordinary three-phase bridge inverter as the power circuit of the DSTATCOM is that the sum of three currents must be equal to zero. This prevents its use as a four-wire DSTATCOM power circuit.

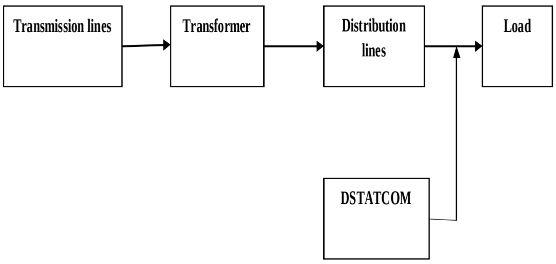

Figure 3: Placement of Dstatcom

In the power circuit, VSI converts DC voltage into controllable ac voltage, coordinated by ac filter and connected to AC distribution line through coupling transformer. The operating principle of DSTATCOM is that it continuously monitors the load voltages and currents and determines the amount of compensation required by distribution system for a variety of disturbances. In this method the active power flow is controlled by the angle between the ac system and VSI voltages, the reactive power flow is controlled by the difference between the magnitudes of these voltages.

The distribution bus voltage is equal to the sum of inverter voltage and voltage across the coupling transformer in both capacitive and inductive modes. This means, the output voltage of bus is in phase with output voltage of DSTATCOM. If bus voltage is greater than output voltage of VSI a reactive current will flow through DSTATCOM, it observes reactive power from the distribution system. But when bus distribution bus voltage is less than sum of the inverter voltage will provide reactive power to system.

Generally, there are three types of DSTATCOM structure namely,

1. Three separate voltage source inverter
2. Neutral clamped voltage source inverter
3. Four leg voltage source inverter

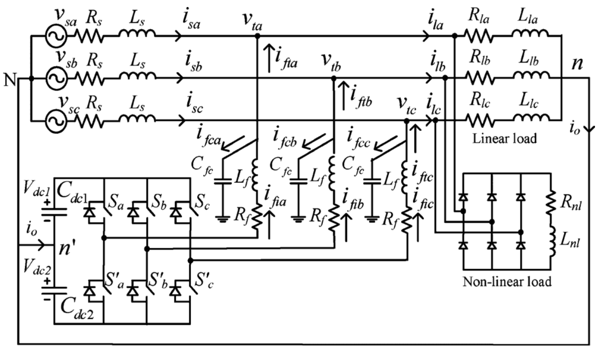

Figure 4: Circuit Diagram of DSTATCOM

The neutral clamped DSTATCOM shown in Fig. 4. has two DC storage capacitors, Filter inductance, Filter capacitance and a shunt capacitance. The distribution system is connected to both linear and non linear loads.

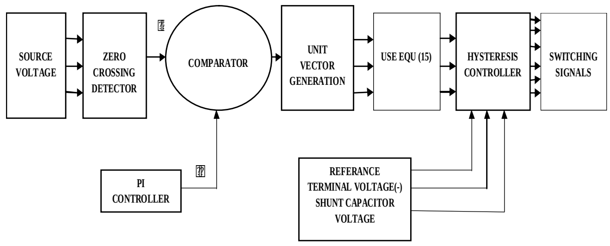

Figure 5: Controller for DSTATCOM

The controller for DSTATCOM is shown in Fig. 5. The controller has a zero crossing detector, PI controller, Hysteresis controller. The hysteresis controller will provide the switching signals to the voltage-source inverter. A proportional-integral (PI) controller is used to regulate the dc capacitor voltage at a reference value.

Principle of D-Statcom

DSTATCOM is used to suppress voltage variation and control reactive power in phase with system voltage. It can also be used for compensating inductive and capacitive currents linearly and continuously. Fig. 6. shows the vector diagram for capacitive and inductive modes at the fundamental frequency 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 inductive and capacitive modes. It means that if output voltage of DSTATCOM (V_{vsc}) is in phase with bus terminal voltage (V_{bus}) and if V_{bus} is smaller than V_{vsc}, DSTATCOM provides reactive power to system. And if V_{bus} is greater than V_{vsc}, DSTATCOM absorbs reactive power from power system. V_{bus} and V_{vsc} have the same phase, but they have a little phase difference to compensate the loss of transformer winding and inverter switching, to absorb some real power from system. Fig. 6. represents DSTATCOM vector diagrams, which show, system voltage V_T , inverter output voltage V_I, reactive voltage V_L and line current I in relation with magnitude and phase δ. Fig. 6.a and b explain the method of how V_I and V_T produce capacitive or inductive power by controlling the magnitude for inverter output voltage V_I in phase with each other. Fig. 7. show how the DSTATCOM produces or absorbs real power with V_I and V_T having phase ±δ. The transition from inductive to capacitive mode occurs by changing the angle δ from zero to a negative value. The active power is transferred to the DC capacitor from the AC terminal and it will cause the DC link voltage to rise. The active and reactive power may be expressed by the following equations:

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

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

Usually in any practical DSTATCOM there are losses in the transformer windings and in the converter switches. These losses will consume active power from the AC terminals. Normally, a small phase difference always exists between the VSC voltage and the AC system voltage. A summary of the power exchanges between the DSTATCOM and the AC system is a function of the DSTATCOM output voltage V_{vsc} and the AC system voltage V_{bus}

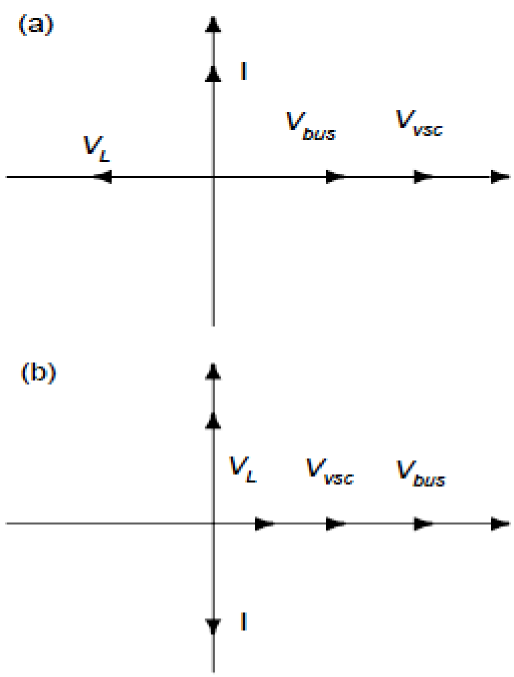

Figure 6: Vector diagram of DSTATCOM (a) Capacitive mode, (b) Inductive mode

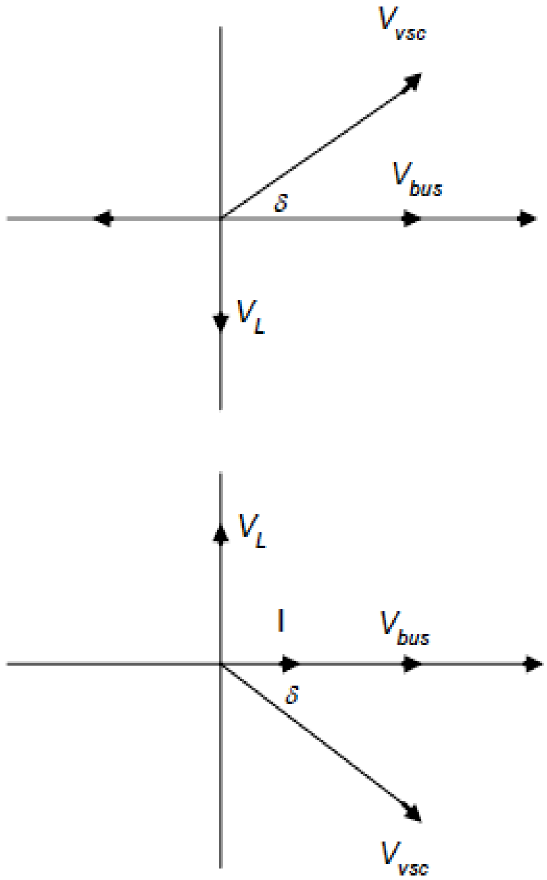

Figure 7: Active power release and active power absorption

Reference Voltage Generation

The three phase load current can be given by,

$$i_{lj}(t) = \sum_{n=1}^{m} \sqrt{2} I_{ljn} \sin(n\omega t + \varphi_{ljn}) \tag{3}$$

The instantaneous positive sequence, negative sequence, zero sequence current components are given by,

$$\begin{pmatrix} i_{la}^{0}(t) \\ i_{la}^{+}(t) \\ i_{la}^{-}(t) \end{pmatrix} = \frac{1}{3}\begin{pmatrix} 1 & 1 & 1 \\ 1 & \propto & \propto^2 \\ 1 & \propto^2 & \propto \end{pmatrix} \begin{matrix} i_{la}(t) \\ i_{lb}(t) \\ i_{lc}(t) \end{matrix} \tag{4}$$

By applying the complex Fourier transform, the fundamental positive sequence component of load current is denoted as,

$$\bar{I}_{la1}^{+} = \frac{\sqrt{2}}{T} \int_0^T i_{la}^{+}(t) e^{-j(\omega t - 90)} dt. \tag{5}$$

The instantaneous fundamental positive sequence component of load current is given as,

$$i_{la}^{+}(t) = \sqrt{2}|\bar{I}_{la1}^{+}| \sin(\omega t + \bar{I}_{la1}^{+}) \tag{6}$$

The fundamental positive sequence component of load current must be given by the source at the nominal load. Therefore the source current is given by,

$$\left.\begin{aligned} i_{sa}^{*} &= i_{la1}^{+}(t)\sqrt{2}|\bar{I}_{la1}^{+}| \sin(\omega t - \delta_0) \\ i_{sb}^{*} &= i_{lb1}^{+}(t) = \sqrt{2}|\bar{I}_{lb1}^{+}| \sin(\omega t - \tfrac{2}{3}\pi - \delta_0) \\ i_{sc}^{*} &= i_{lc1}^{+}(t) = \sqrt{2}|\bar{I}_{lc1}^{+}| \sin(\omega t + \tfrac{2}{3}\pi - \delta_0) \end{aligned}\right\} \tag{7}$$

When these reference source currents are supplied by the source, the three phase terminal voltage can be calculated by,

$$V_{tj}(t) = V_{sj}(t) - L_s \frac{di_{sj}^{*}}{dt} - R_s i_{sj}^{*}. \tag{8}$$

By considering UPF at PCC,

$$v_{ta}(t) = \sqrt{2}\, V_t^{*} \sin \omega\, t. \tag{9}$$

$$i_{sa}^{*} = i_{la1}^{+}(t) = \sqrt{2}|\bar{I}_{la1}^{+}| \sin \omega\, t. \tag{10}$$

$$v_{sa}(t) = \sqrt{2}\, V \sin(\omega\, t + \delta_0). \tag{11}$$

Substitute (9) & (8) in (6),

$$V_t^{*} \angle 0 = V \angle \delta_0 - (R_s + jX_s)\bar{I}_{la1}^{+}. \tag{12}$$

By equating the real and imaginary parts,

$$\mathrm{V} \cos \delta_0 = V_t^{*} + \bar{I}_{la1}^{+} R_s. \tag{13}$$

$$\mathrm{V} \sin \delta_0 = \bar{I}_{la1}^{+} X_s. \tag{14}$$

The reference voltage magnitude is given by,

$$V_t^{*} = \sqrt{V^2 - (|\bar{I}_{la1}^{+}| X_s)^2} - \bar{I}_{la1}^{+} R_s. \tag{15}$$

Experimental Results

When the DSTATCOM operates with the traditional method where the terminal voltage is assumed as 1 p.u., the source current is sinusoidal even though load current is distorted, implying that the compensator supplies reactive and harmonic component of load current. However, in traditional method, the source current leads terminal voltage, indicating that the compensator supplies additional reactive current to overcome feeder drop as well. In the proposed scheme, source current is a sinusoidal waveform and in phase with terminal voltage. Hence, the compensator supplies only reactive and harmonic component of load current. It provides the advantages of CCM.

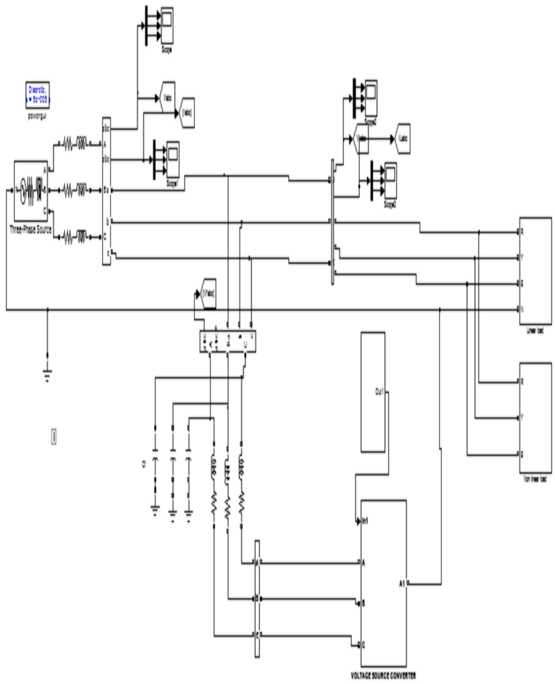

Figure 8: Simulink block of DSTATCOM

The Simulink model of voltage controlled DSTATCOM for the reduction of total harmonic distortion is shown in Fig. 8.

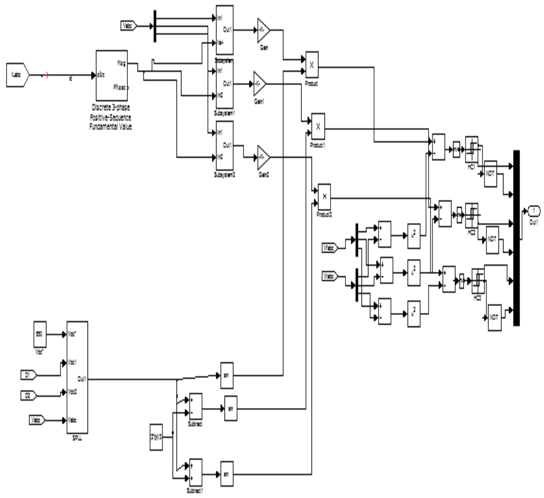

Figure 9: Simulink block for controller

The controller block for the voltage controlled DSTATCOM which has the PI controller to maintain load angle which indirectly regulates dc capacitor voltage is shown in Fig. 9.

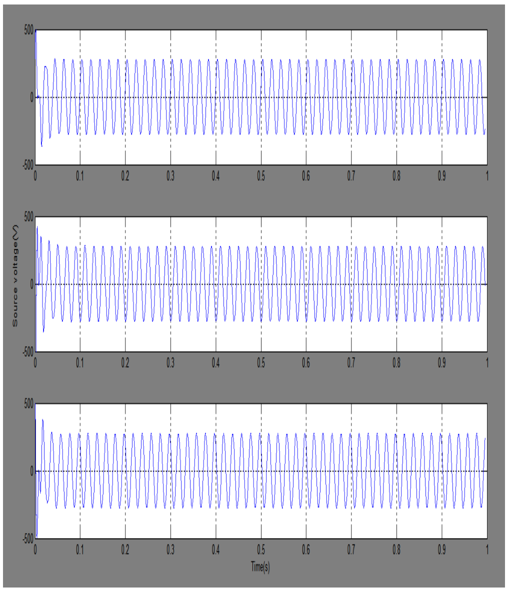

Figure 10: Source Voltage Waveform vs. Time

Fig. 9. and Fig. 10. shows the waveform for three phase source voltage vs. time and for source current vs. time

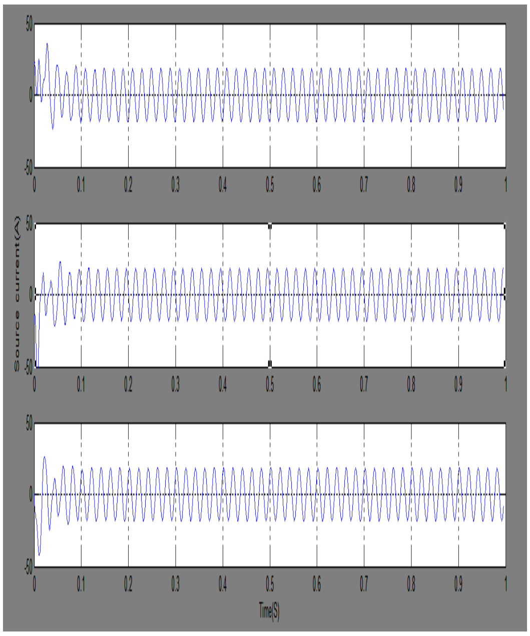

Figure 11: Source Current Waveform vs. Time

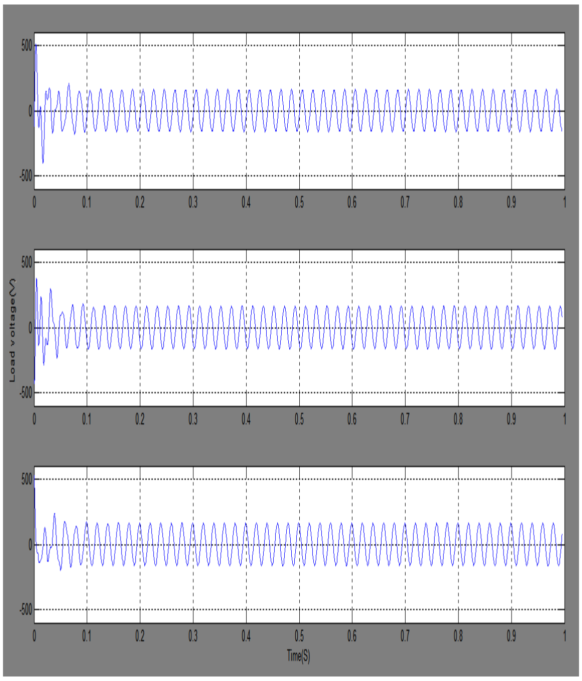

Figure 12: Load Voltage vs. Time

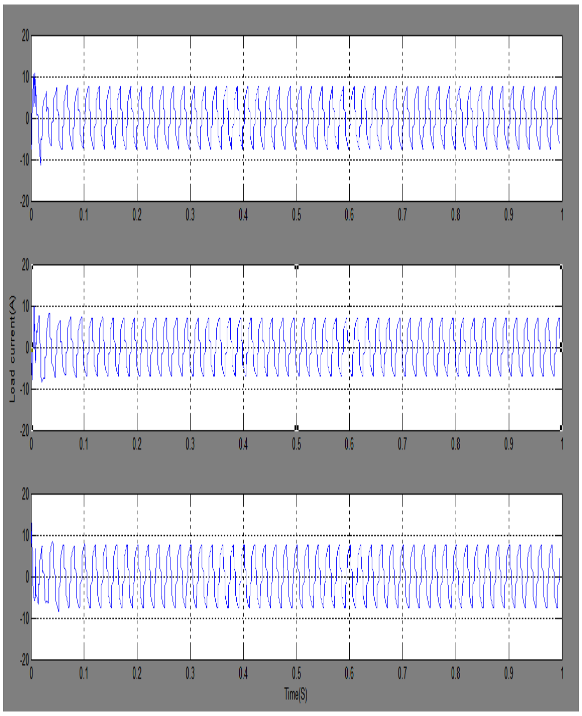

Figure 13: Load Current Waveform vs. Time

Fig. 12. and Fig. 13. shows the waveform for load voltage vs. Time and load current vs. Time respectively. From Fig. 11. and Fig. 13., it is shown that the source current is sinusoidal even though the load current is distorted.

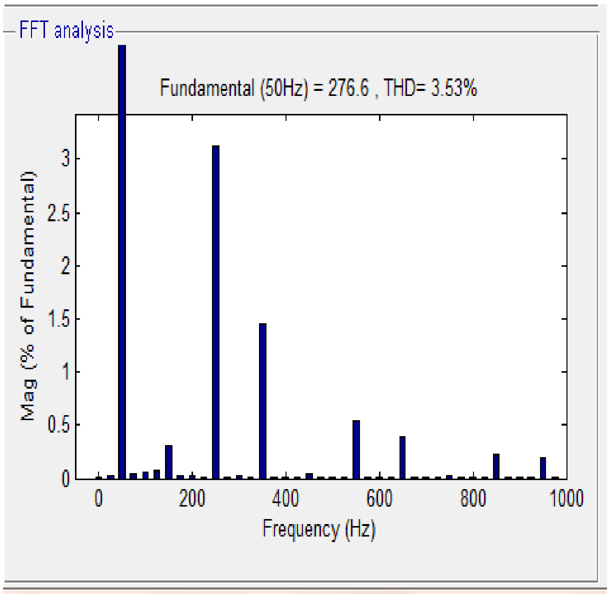

Figure 14: FFT Analysis for source voltage

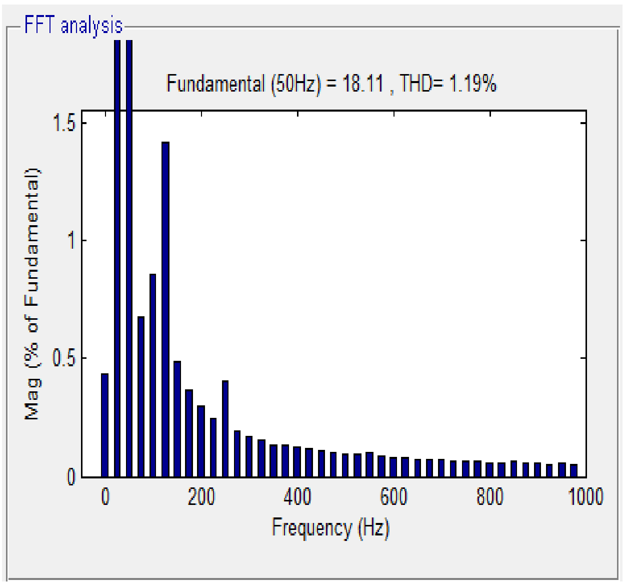

Figure 15: FFT Analysis for source current

To find THD value of voltage and current waveform, FFT analysis is used. By using a voltage controlled DSTATCOM, the THD obtained for source voltage and current is 3.53% and 1.19% respectively.

Conclusion

The Simulink model of proposed Voltage Controlled DSTATCOM for the reduction of power quality problems has been developed and analyzed. In this project the DSTATCOM is operated in voltage controlled mode. A reference voltage is generated instead of assuming a particular value to obtain the advantages of both voltage controlled mode and current controlled mode. Harmonics generated in the distribution system through non linear diode rectifier load is significantly reduced by DSTATCOM. Simulated results are shown with good dc bus voltage regulation, reduced total harmonic distortions of source voltage and current.

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