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Design and Implementation of Hybrid D-STATCOM for Providing Quality of Supply at Distribution Level under Non Linear Load Conditions

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Abstract : *Modern power systems are highly complex and are designed to fulfill the growing demands of power with better power quality. In recent years power engineering is giving more attention to electrical power quality. At distribution system, due to non linear loads and increasing of load demand the quality of power supply is not present. So in order to provide quality of supply research has been carried out for many years. For that custom power devices and filters have been used. Normally D-STATCOM has been used for voltage regulation and Hybrid Active Power Filter is used for harmonics reduction. In this, VSI will have the above two properties in it and so there will be a better power supply to the utility under any power system disturbances.*
Keywords: *D-STATCOM, Harmonic Compensation, Hybrid Active Power Filter, Power Quality, VSI.*

I. Introduction

In recent years, the power system network has been spread over wide area and usage of loads has also been increased. Due to this power distribution system is suffering from severe power quality problems. These power quality problems include high reactive power burden, harmonic(s) currents, load unbalance, excessive neutral current etc. so many researchers have paying much attention towards to make a better power quality of supply to the system [1], [2]. Particularly, in order to compensate highly inductive and/or nonlinear loads, the D-STATCOM configuration and also Hybrid Active Power Filter are most popularly used. In general, for poor voltage regulation problem variable capacitor banks and for constant terminal voltage fixed capacitors, thyristor controlled inductor (SVC), saturable core reactor; shunt connections of capacitors have been used. But the above schemes are of a discrete type and inject harmonics in the generating system. So for better operation D-STATCOM is used for providing required reactive power for varying loads to provide constant voltage [3], [4]. In other case, with the wide use of power electronic equipments and nonlinear loads, the power quality has been lost in distribution system. Current harmonics cause serious harmonic problems in distribution feeders for sensitive consumers. Some technology solutions have been reported in order to solve power quality problems. Initially, lossless passive filters have been used to mitigate harmonics and for compensation of reactive power at nonlinear loads. However, passive filters have the drawbacks of fixed compensation, large size and resonance with the supply system. Active filers have been explored in shunt and series configurations to compensate different types of nonlinear loads; nevertheless, they have some demerits. As a case in point, their power rating is sometimes close to load, and thus it becomes a costly option for power quality improvement. Many analysts have classified various types of nonlinear loads and have suggested different filter options for their compensation. In response to these factors, a series of hybrid filters has been evolved and widely used in practice as a cost effective solution for the compensation of nonlinear loads. Mainly shunt hybrid active filters are used in all over the world. These filters provided the required harmonic filtering [5], [6].

In this paper an idea is proposed, where D-STATCOM device is made to work as a hybrid active power filter by using a control mechanism in order to provide voltage regulation and harmonics compensation so that utilities and industries will be free from power quality problems. Here in this device will consists of a current controlled voltage source inverter (VSI), dc bus capacitor, a controller to provide gate pulses to the VSI as shown in Fig.1.

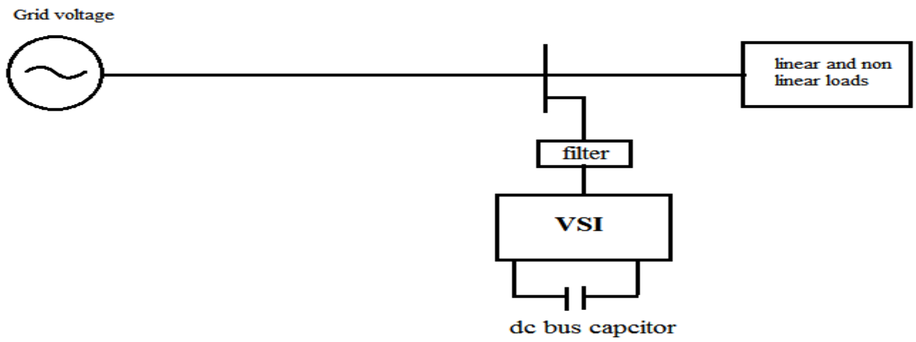

Fig.1 Schematic diagram of proposed device at PCC

Distributed Static Compensator (D-Statcom)

D-STATCOM is power electronics based power quality improving device, which generates and /or absorbs the reactive power whose output can be varied so as to maintain control of specific parameters of the electric power system. The D-STATCOM comprises a three phase voltage source inverter (VSI) with self commutating switches (GTO/IGBT), and a DC-link capacitor and an LCL filter is connected at the front end of VSI. Fig.2 shows the basic configuration of D-STATCOM.

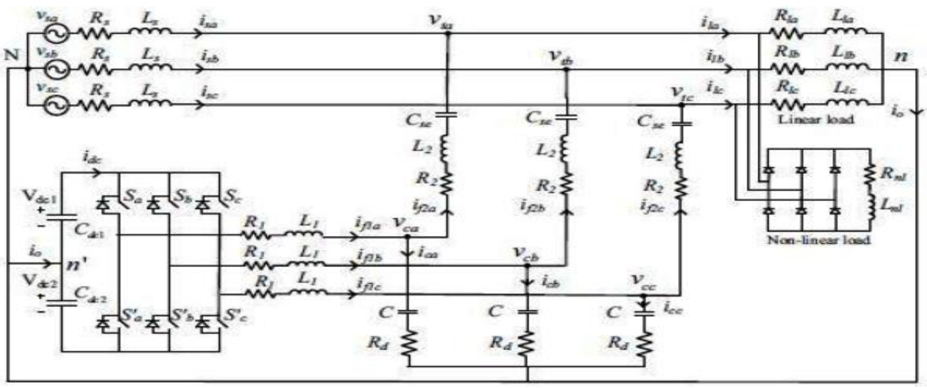

Fig.2 Equivalent circuit of D-STATCOM with LCL filter

The VSI converts the dc voltage across the storage device into ac output voltages. These ac voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Inverter is the main component of the D-STATCOM. The objective of a VSI is to produce a sinusoidal AC voltage with minimal harmonic distortion from a DC voltage. The operation of the D-STATCOM is as follows: The voltage is compared with the AC bus voltage system (Vs). When the magnitude of AC bus voltage is above that of the VSI magnitude (Vc), the AC system considered that, D-STATCOM as inductance connected to its terminals. Otherwise if the voltage magnitude of VSI is above that of the AC bus voltage magnitude, the AC system sees the D-STATCOM as capacitance connected to its terminals. If the VSI voltage magnitude is equal to AC bus voltage magnitude, then the reactive power exchange is zero. Suppose D-STATCOM has a DC active element or energy storage elements or devices on its DC side, it can able to deliver real power to the power system. This can be done by varying the phase angle of the D-STATCOM terminals and the phase shift of the AC power system. When VSI phase angle lags phase angle of the AC power system, the D-STATCOM absorbs the real power from the AC system, if the phase angle of VSI leads phase angle of AC power system, the D-STATCOM supplies real power to AC supply mains. The main feature is governing of bus voltage magnitude by dynamically absorbing or generating reactive power.

II. Hybrid Active Power Filter (Hapf)

Parallel hybrid power filter which is the main concern of this research is formed by the use of a three phase voltage source PWM converter, and a series connected LC passive filter. The series connection between the passive filter and the voltage source converter is made directly, without using a transformer (Fig. 3). The series connected LC filter is tuned to the dominant harmonic component of the load. It absorbs the current harmonics arising from the non-linear load; however, the filtering characteristic of just the passive filter itself is not satisfactory. Hence, the active power filter is used to improve the filtering performance of the overall system and to suppress the resonance risk of the passive filter. The power circuit of the inverter includes an energy storage element of a DC link capacitor and controllable semiconductor switches with their anti parallel diodes. The active power filter injects compensation currents by operating as a current controlled voltage source. In the conventional voltage source active power filter topology, the DC link capacitor voltage is required to be higher than the peak value of the utility voltage; otherwise the generated compensation currents cannot be injected to the mains. However, the presence of filter capacitor in this topology (Fig.3) ensures a reduced DC link voltage and a low rated voltage source converter at the expense of additional fundamental current, passing through the converter.

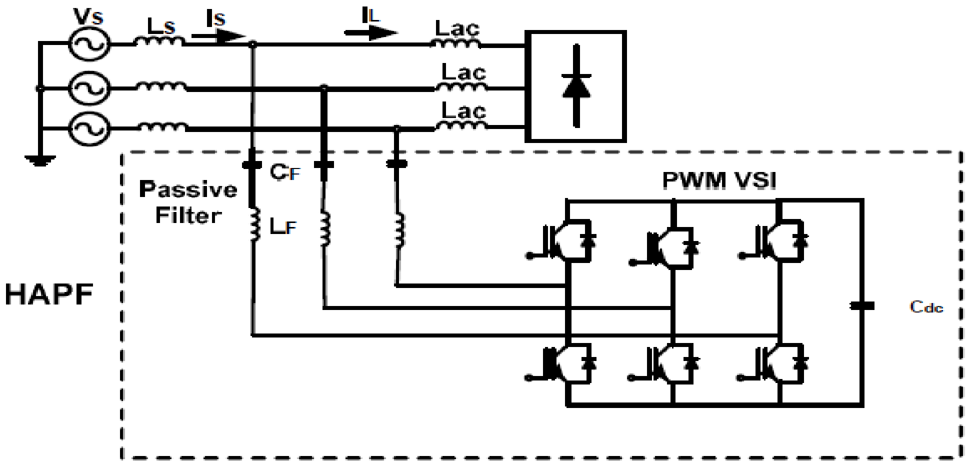

Fig.3 Shunt connected Hybrid Active Power Filter

As a result, for low voltage applications, PWM converter can be formed by power MOSFETs instead of using IGBTs. So that, the initial cost of the converter can be decreased by using MOSFETs instead of IGBTs. Similar to the conventional VSC based APFs; hybrid power filter does not require a DC power supply for its DC link voltage regulation.

III. Proposed Hybrid D-Statcom

In this proposed system, the D-STATCOM itself acts as Hybrid Active Power Filter. This can be achieved by control strategy as shown in Fig.4. There are many control strategies individually for generating pulses for voltage source inverter by sensing the load voltages, load currents, source voltages, source currents, dc bus voltage. By implementing a desired control strategy we can achieve a better voltage regulation and also effective harmonics reduction. When there is a poor voltage regulation then the device acts as a D-STATCOM and makes the terminal voltage to be constant. In the same way when there is harmonics due to the non linear loads then it will acts as a Hybrid Active Power Filter (HAPF). In this manner we can make a single device to work as both according to the situation in system.

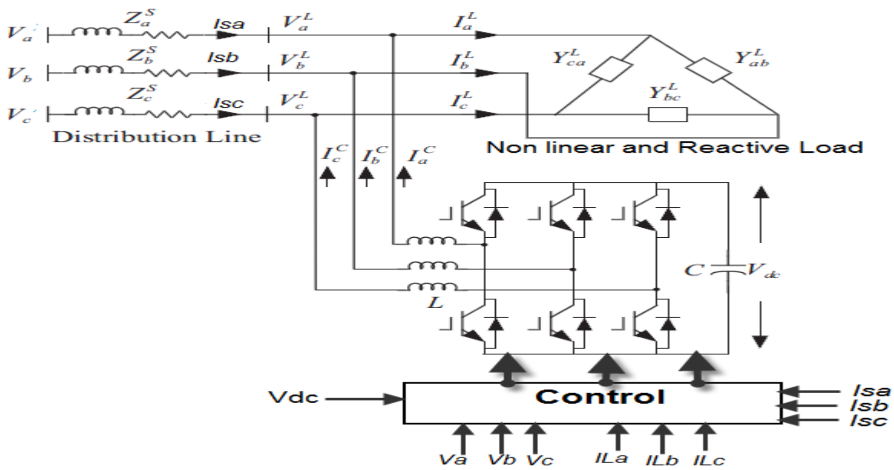

Fig.4 Schematic Diagram of Hybrid D-STATCOM

3.1 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 [7, 8]. 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 [9].

3.2 Controller

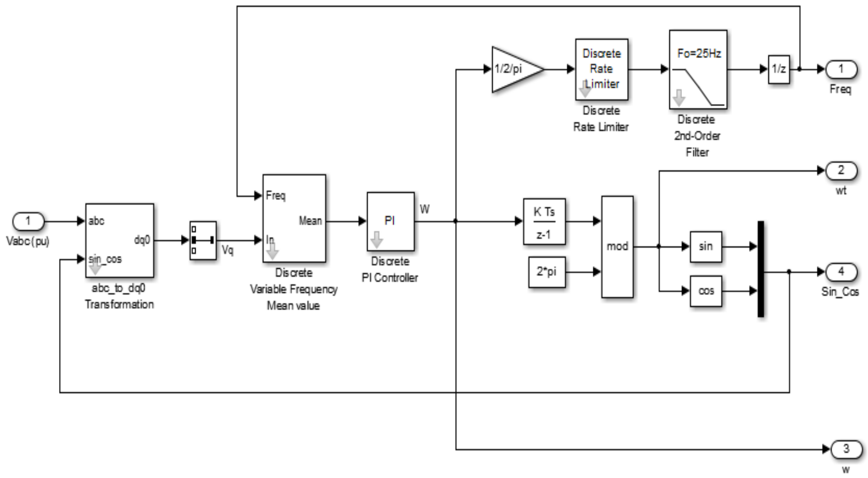

Fig.5 Shows the Block Diagram of Controller System

The controller system is partially part of distribution system. Fig.5. 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 is also 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.

3.3 Test System

A Distribution Static Synchronous Compensator (D-STATCOM) is used to regulate voltage on a 25-kV distribution network. Two feeders (21 km and 2 km) transmit power to loads connected at buses B2 and B3 as shown in Fig.6. A shunt capacitor is used for power factor correction at bus B2. The 600-V load connected to bus B3 through a 25kV/600V transformer represents a plant absorbing continuously changing currents, similar to an arc furnace, thus producing voltage flicker. The variable load current magnitude is modulated at a frequency of 5 Hz so that its apparent power varies approximately between 1 MVA and 5.2 MVA, while keeping a 0.9 lagging power factor. This load variation will allow you to observe the ability of the D-STATCOM to mitigate voltage flicker. The D-STATCOM regulates bus B3 voltage by absorbing or generating reactive power. This reactive power transfer is done through the leakage reactance of the coupling transformer by generating a secondary voltage in phase with the primary voltage (network side). This voltage is provided by a voltage-sourced PWM inverter. When the secondary voltage is lower than the bus voltage, the D-STATCOM acts like an inductance absorbing reactive power. When the secondary voltage is higher than the bus voltage, the D-STATCOM acts like a capacitor generating reactive power.

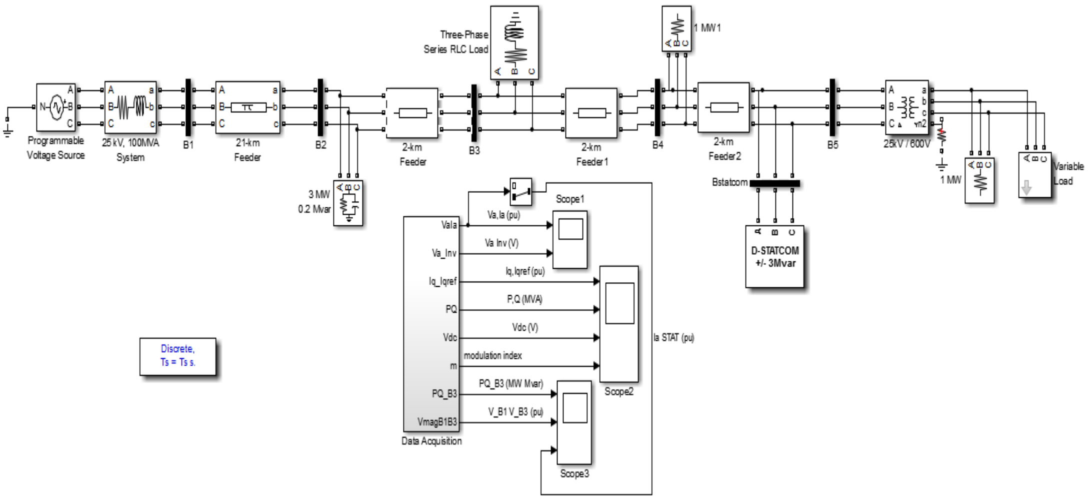

Fig.6 Radial Distribution system with D-STATCOM

1. **25kV/1.25kV coupling transformer** which ensures coupling between the PWM inverter and the network.
2. **Voltage sourced PWM inverter** consisting of two IGBT bridges. This twin inverter configuration produces lesser harmonics than a single bridge, resulting in smaller filters and improved dynamic response. In this case, the inverter modulation frequency is 28*50=1.4 kHz so that the first harmonics will be around 2.8 kHz.
3. **LC damped filters** connected at the inverter output. Resistances connected in series with capacitors provide a quality factor of 40 at 50 H**z.**
4. **10000-microfarad capacitor** acting as a DC voltage source for the inverter
5. **voltage regulator** that controls voltage at bus B3
6. **PWM pulse generator** using a modulation frequency of 1.4 kHz.
7. **Anti-aliasing filters** used for voltage and current acquisition.

The D-STATCOM controller consists of several functional blocks:

1. **Phase Locked Loop (PLL)** The PLL is synchronized to the fundamental of the transformer primary voltages.
2. **two measurement systems** Vmeas and Imeas blocks compute the d-axis and q-axis components of the voltages and currents by executing an abc-dq transformation in the synchronous reference determined by sin(wt) and cos(wt) provided by the PLL.
3. **An inner current regulation loop** This loop consists of two proportional-integral (PI) controllers that control the d-axis and q-axis currents. The controllers outputs are the V_d and V_q voltages that the PWM inverter has generate. The V_d and V_q voltages are converted into phase voltages V_a, V_b, V_c which are used to synthesize the PWM voltages. The I_q reference comes from the outer voltage regulation loop (in automatic mode) or from a reference imposed by Q_{ref} (in manual mode). The I_d reference comes from the DC-link voltage regulator.
4. **An outer voltage regulation loop** In automatic mode (regulated voltage), a PI controller maintains the primary voltage equal to the reference value defined in the control system dialog box.
5. **DC voltage controller** which keeps the DC link voltage constant to its nominal value (Vdc=2.4 kV).

The electrical circuit is discredited using a sample time Ts=5 microseconds. The controller uses a larger sample time (32*Ts= 160 microseconds).

The performance of the system is measured by switching the STATCOM at time 0.7s in the system and how the STATCOM responds to the step change command for increase in additional load at 1.0 s is shown in the simulation Fig.8. The compensated current for the nonlinear load and demanded reactive power is provided by the inverter. The real power transfer from the batteries is also supported by the controller of this inverter. The source current with and without STATCOM operation is shown in Fig.7. The unity power factor is maintained for the source power when the STATCOM is in operation. The DC link voltage regulates the source current in the grid system. The DC link voltage is maintained constant across the capacitor it is observed that the source current on the grid is affected due to the effects of nonlinear load and wind generator. Thus purity of waveform may be lost on both sides in the system.

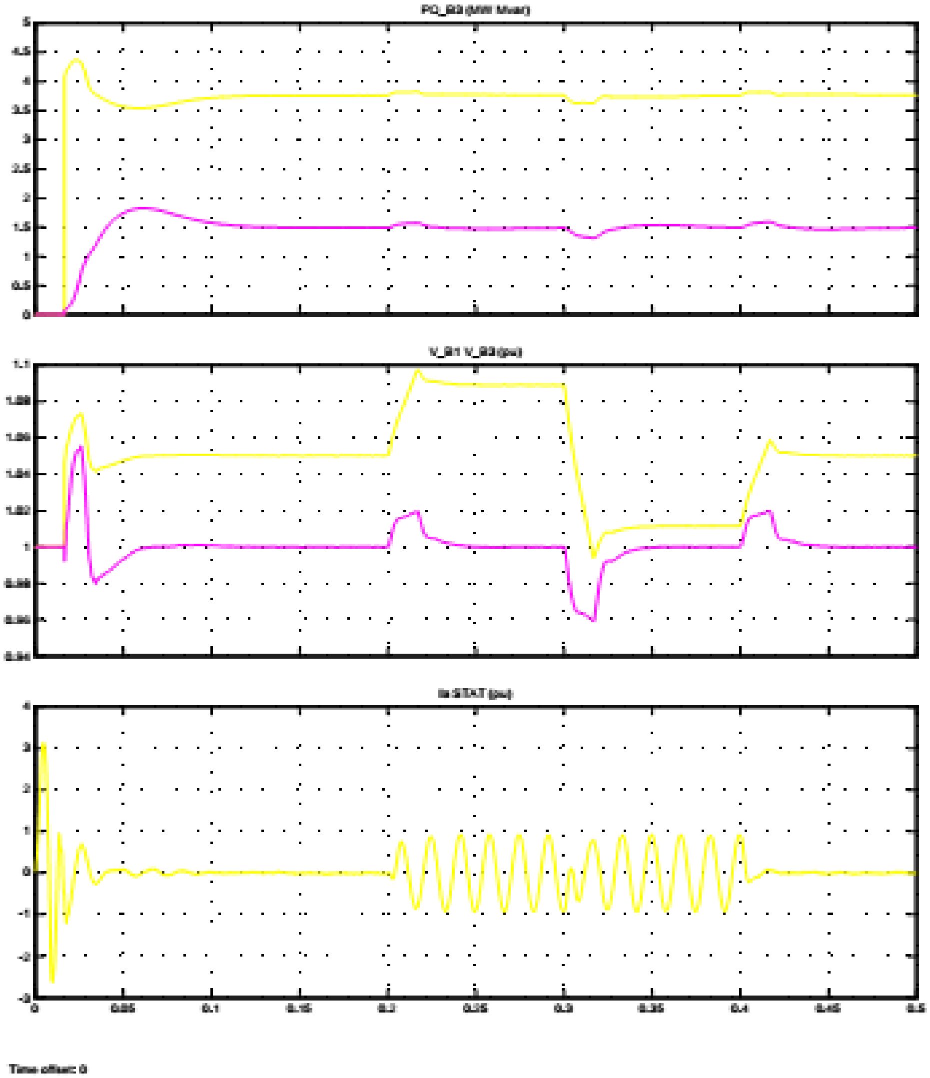

Fig.7 DSTATCOM Results

The FFT analysis of the system is as shown in Fig.9 where the THD values can be noted for the simulated system.
VTHD = Percentage of the Total Harmonic Distortion of a non sinusoidal voltage waveform

$$VTHD = \frac{\sqrt{\sum_{h \geq 1} V_{LH}^2}}{V_{L1}} \qquad (1)$$

ITHD = Percentage of the Total Harmonic Distortion of a non sinusoidal current waveform

$$ITHD = \frac{\sqrt{\sum_{h \geq 1} I_{SH}^2}}{I_{S1}} \qquad (2)$$

V_h = hth harmonic component of the voltage.
I_h = hth harmonic component of the current.

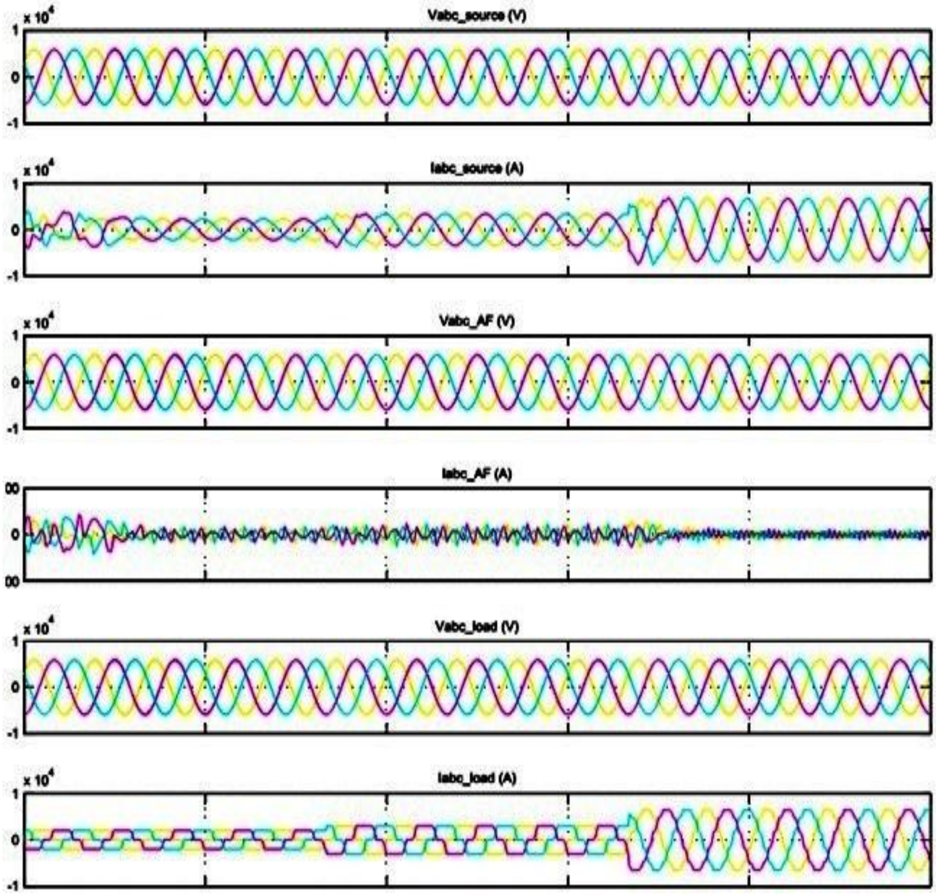

Fig.8 Sample Responses of the System with D-STATCOM

The use of the power electronic devices in power distribution system gives rise to harmonics and reactive power disturbances. A voltage dip will occur, if the reactive power is consumed from the grid, this affects other sensitive loads which are connected to the grid. Hence compensation is necessary for these types of loads for requiring reactive power. Among the different new technical options available to improve power quality, D-STATCOM have proved to be an important and flexible alternative to compensate for current and voltage disturbances in power distribution systems.

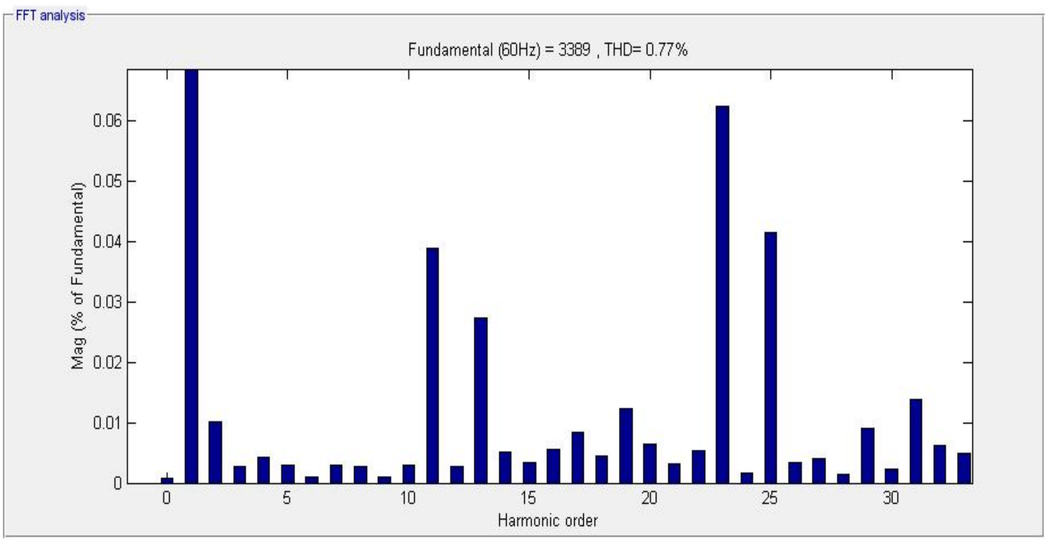

Fig.9 FFT Analysis

IV. Conclusion

The Power quality issues like voltage sag and harmonics are eliminated using D-STATCOM. In this, orders of harmonics are reduced with Hybrid Active Power Filter which acts to improve the VTHD, ITHD Values as shown in simulation results. The power factors also increase close to unity. Thus, by this proposed type of control device the power quality issues can be eliminated effectively in distribution system. VTHD, ITHD, DPF can be made to be presented in permissible values only.

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