

DSTATCOM With LCL Filter Topology for Mitigation of Harmonics in Distribution System

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Abstract—In this paper a Distribution Static Compensator (DSTATCOM) with LCL filter topology has been planned to compensate varied issues of power quality in distribution system with non linear loads. A 2 level voltage source inverter (VSI) is employed in conjunction with LCL filter to extend voltage support to the VSI. The instantaneous reactive power theory has applied for the effective and economical operating of the DSTATCOM, for this hysteresis current controller (HCC) is enforced to come up with pulses to the VSI and PI controller is employed to keep up constant DC link voltage. The proposed DSTATCOM topology has compensated Source Current Harmonics by injecting shunt currents into the distribution system. Planned topology has been simulated by using MATLAB/SIMULINK.

Keywords—DSTATCOM; VSI; LCL Filter; PI; HCC

I. INTRODUCTION

The most common power quality issues now a day are voltage sag, swell, low power factor and harmonic distortion, an influence quality drawback ends up in failure of user instrumentality. The employment of power electronic circuits in an exceedingly big selection of applications for energy economical operation and for higher management of the method has resulted in distorted current waveforms in power system, leading to a non-sinusoidal voltage offer at the point of Common Coupling (PCC). Asymmetrical distribution of enormous loads additional complicates the difficulty by inflicting imbalance in line currents of the 3 phase system. Various harmonic mitigation techniques are planned to scale back the result of harmonics as well as passive filters, Active Power Filters (APFs) and hybrid filters etc.

Harmonic currents in distribution system will cause harmonic distortion, low power factor and extra losses further as heating within the electrical equipment. Static capacitors and passive filters are utilized to enhance power quality (PQ) in distribution systems. However there are few issues like mounted compensation, system-parameter-dependent performance and attainable resonance in line reactance using these. Therefore to beat these drawbacks Distribution Static Compensator (DSTATCOM) is planned. Among varied custom power devices, the DSTATCOM is one among the foremost effective devices used for provision reactive and harmonic currents of load demand in distribution system. DSTATCOM is connected in parallel to load at the point of

common coupling (PCC) through LCL filter. It injects reactive and harmonic parts of load currents to create supply currents sinusoidal and in-phase with load voltages. Higher order LCL filter has higher switching ripple attenuation capability compared to L filter, and this may be achieved by exploitation little values of overall inductance and capacitance that improves trailing performance. Another serious issue of LCL filter is resonance damping, which can push system towards instability. One among the solutions is to use passive damping, inserting of damping resistors in shunt part of LCL filter. Hysteresis current control theme has been enforced to regulate the electronic valves within the DSTATCOM to enhance power quality by reducing harmonic distortion in power distribution network in this proposed paper.

II. PROPOSED TOPOLOGY

A three phase equivalent circuit diagram of proposed DSTATCOM topology is shown in fig.1. Here in this scheme LCL filter is connected at the front end of the Source. Introduction of LCL filter significantly reduces the size of passive component and increases tracking performance. A damping resistance R_d is used in series with capacitor to damp out resonance. The DSTATCOM, Source with LCL filter and Load are connected at a point called point of common coupling (PCC).

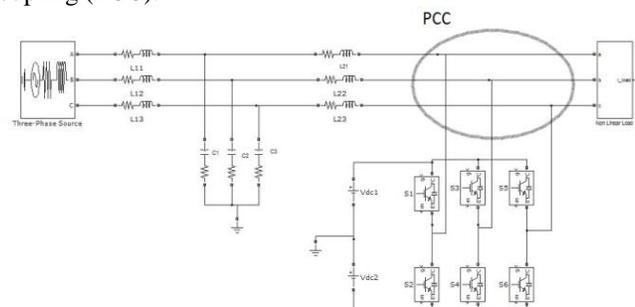


Fig.1. Equivalent Circuit of Proposed DSTATCOM

III. DSTATCOM CONTROLLER MODELING

The fig.2 shows the control block of the DSTATCOM, with the controller the source currents are always maintained sinusoidal and are in phase with the voltages. Therefore Power factor is also improved. The Controller is designed in such a

way that the average load power and the losses in the Voltage Source Converter are supplied by the source. This is implemented using a PI controller whose output is proportional to the loss in the VSC i.e., discharge of the capacitor connected as source to the VSC is resemblance of the power loss.

To maintain the source currents sinusoidal, harmonics present in the system are to be eliminated. The Instantaneous PQ theory along with Hysteresis Current Controller (HCC) is used to compensate harmonics. HCC provides gating pulses to the valves by comparing the Reference and the actual currents. Instantaneous PQ theory is one of the methods used for calculation of the reference currents.

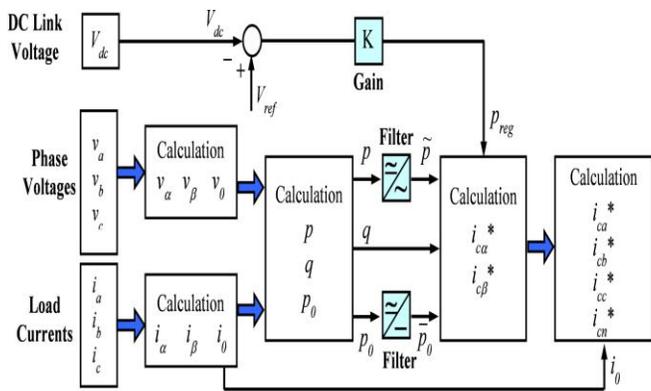


Fig.2. Controller Block diagram of DSTATCOM

PQ theory calculates the instantaneous values of active and reactive power consumed by the load. The calculated powers consist of both mean and Oscillating components. Only mean component of the active power is used for energy transfer from source to load. Oscillating component not contributes in energy transfer, this component must be compensated and this is due to harmonic currents. The oscillating component of the active power and the reactive power are to be compensated by the DSTATCOM.

PQ theory deals with $\alpha\beta$ coordinates. Therefore the PCC voltages and load currents are transformed to α, β and 0 components. This can be achieved using Clarke transformation.

$$\begin{bmatrix} v_\alpha \\ v_\beta \\ v_0 \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 2 & -1 & -1 \\ 0 & \sqrt{3} & -\sqrt{3} \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \dots\dots\dots (1)$$

$$\begin{bmatrix} p \\ q \\ p_0 \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta & 0 \\ -v_\beta & v_\alpha & 0 \\ 0 & 0 & v_0 \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} \dots\dots\dots (2)$$

The Zero sequence components of current, voltage and power are not present in 3 wire system.

$$\begin{bmatrix} i_{f0} \\ i_{f\alpha} \\ i_{f\beta} \end{bmatrix} = \frac{1}{v_0(v_\alpha^2 + v_\beta^2)} \begin{bmatrix} v_\alpha^2 + v_\beta^2 & 0 & 0 \\ 0 & v_0 v_\alpha & -v_0 v_\beta \\ 0 & v_0 v_\beta & v_0 v_\alpha \end{bmatrix} \begin{bmatrix} p_{f0} \\ p_{f\alpha\beta} \\ q_{f\alpha\beta} \end{bmatrix}$$

$$p_{f\alpha\beta} = (p_f - p_{f0}) - p_{f0} = \tilde{p}_f$$

$$p_f = p_{f0} + p_{f\alpha\beta} = \tilde{p}_f$$

The power components and various components of currents are related as following.

$$\begin{bmatrix} p_\alpha \\ p_\beta \end{bmatrix} = \begin{bmatrix} v_\alpha i_\alpha \\ v_\beta i_\beta \end{bmatrix} = \begin{bmatrix} v_\alpha (i_{\alpha p} + i_{\alpha q}) \\ v_\beta (i_{\beta p} + i_{\beta q}) \end{bmatrix} = \begin{bmatrix} v_\alpha i_{\alpha p} \\ v_\beta i_{\beta p} \end{bmatrix} + \begin{bmatrix} v_\alpha i_{\alpha q} \\ v_\beta i_{\beta q} \end{bmatrix} = \begin{bmatrix} p_{\alpha p} \\ p_{\beta p} \end{bmatrix} + \begin{bmatrix} q_{\alpha q} \\ q_{\beta q} \end{bmatrix}$$

The following quantities are defined

- α – Axis instantaneous active power = $p_{\alpha p} = v_\alpha i_{\alpha p}$
- α – Axis instantaneous reactive power = $p_{\alpha q} = v_\alpha i_{\alpha q}$
- β – Axis instantaneous active power = $p_{\beta p} = v_\beta i_{\beta p}$
- β – Axis instantaneous reactive power = $p_{\beta q} = v_\beta i_{\beta q}$

$$p_{\alpha p} + p_{\beta p} = v_\alpha i_{\alpha p} + v_\beta i_{\beta p} = \frac{(v_\alpha)(v_\alpha)}{v_\alpha^2 + v_\beta^2} p + \frac{(v_\beta)(v_\beta)}{v_\alpha^2 + v_\beta^2} p = \left(\frac{v_\alpha^2 + v_\beta^2}{v_\alpha^2 + v_\beta^2} \right) p = p$$

$$p_{\alpha q} + p_{\beta q} = v_\alpha i_{\alpha q} + v_\beta i_{\beta q} = \frac{-(v_\beta)(v_\alpha)}{v_\alpha^2 + v_\beta^2} p + \frac{(v_\beta)(v_\alpha)}{v_\alpha^2 + v_\beta^2} p = 0$$

Thus, it can be observed that the sum of $p_{\alpha p}$ and $p_{\beta p}$ is equal to total instantaneous real power $p(t)$ and the sum of $p_{\alpha q}$ and $p_{\beta q}$ is equal to zero. Therefore,

$$p_{\Sigma p} = p + p_0 = p_\alpha + p_\beta + p_0 = p_{\alpha p} + p_{\beta p} + p_0$$

For an ideal compensator,

$$p_{f0} = p_{l0} = v_0 i_{l0} = p_0$$

$$p_{f\alpha\beta} = -p_{l0}$$

$$q_{f\alpha\beta} = q_l$$

For practical compensator, the switching and ohmic losses should be considered. These losses should be met from the source in order to maintain the dc link voltage constant. Let these losses are denoted by p_{loss} , then the following formulation is used to include this term. Let the average Power that must be supplied to the compensator be

$$\Delta \bar{p} = \bar{p}_0 + p_{loss}$$

Thus, the compensator powers can be expressed as,

$$\begin{aligned} p_{f0} &= \bar{p}_{i0} \\ p_{f\alpha\beta} &= \bar{p}_i - \Delta \bar{p} \\ q_{f\alpha\beta} &= q_i \end{aligned}$$

$$\begin{bmatrix} i_{f0} \\ i_{f\alpha} \\ i_{f\beta} \end{bmatrix} = \frac{1}{v_0(v_\alpha^2 + v_\beta^2)} \begin{bmatrix} v_\alpha^2 + v_\beta^2 & 0 & 0 \\ 0 & v_0 v_\alpha & -v_0 v_\beta \\ 0 & v_0 v_\beta & v_0 v_\alpha \end{bmatrix} \begin{bmatrix} \bar{p}_{i0} \\ \bar{p}_i + \bar{p}_0 - \bar{p}_{loss} \\ q_{i\alpha\beta} \end{bmatrix}$$

$$\begin{bmatrix} i_{fa}^* \\ i_{fb}^* \\ i_{fc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ 1 & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{f0} \\ i_{f\alpha} \\ i_{f\beta} \end{bmatrix}$$

Now once we know compensating current signals, these have to be synthesized using voltage source inverter. HCC produces gating pulses so as to reduce the error between reference currents and actual DSTATCOM output currents. Reference currents are the Compensation currents produced in phase opposition to the harmonic currents so as to nullify its effect on the source side. i.e., source currents remain sinusoidal even with non linear loads with DSTATCOM connected to the system.

IV. DESIGN OF LCL FILTER

The LCL-filters offer benefits in prices and dynamic performance since smaller inductors are often used compared to L-filters so as to realize the required damping of the switching harmonics. However, LCL-filter design is complicated and desires to think about several constraints, such as the current ripple through inductors, total resistance of the filter, resonance development, reactive power absorbed by filter capacitors. The filter values and bus voltages are calculated supported the procedure mentioned in [9]. For a offer voltage of 230 V, a load rating of 10 KVA, a maximum switch frequency of 10 kHz, and a ripple current of 1 A the dc-link voltage and interfacing inductance values are found to be 520 V and 26 mH. The design procedure of the filter is given below:

1. Reference Dc link voltage: The voltage across Dc electrical condenser could be a supply of energy and is chosen to attain sensible trailing performance. In this case, a dc-link voltage of

520 V is chosen, that is found to supply satisfactory compensation.

2. LCL Filter Design: System incorporating LCL-filter is of second order, and there exists a peak amplitude response at the resonant frequency of the LCL-filter. This needs a lot of careful design of the LCL-filter parameters and current management strategy to take care of system stability since the filters tend to oscillate with the filter resonance frequency. The foremost standard methodology is to insert a damping electrical device within the capacitance shunt branch of the LCL-filter. Whereas coming up with appropriate values of LCL filter elements, constraints like price of inductance, resonance frequency (f_{res}), selection of damping resistance R_d , and attenuation at switch frequency f_{sw} ought to be thought of.

Considering L_1 , the value of L_1 is chosen such that it provides a high switching frequency and a sufficient rate of change of the filter current. Taking these into consideration the formula for calculating L_1 is given by,

$$L_1 = \frac{V_{dcref}}{(2ha)(2f_{max})} = \frac{V_{dcref}}{4haf_{max}}$$

Where $2ha$ is allowable ripple in the current, and f_{max} is the maximum switching frequency achieved by the HCC.

If the ripple current is larger the losses will be less. However, it can be seen from that the smaller ripple current results in higher inductance and, thus, more core losses. Therefore, a ripple current of 20% is taken while compromising the ripple and inductor size, therefore substituting the values of the ripple current and reference dc-link voltage V_{dcref} in while keeping f_{max} constant at 10 kHz, the value of L_1 comes out to be 1.375 mH. To restrict the switching frequency below 10 kHz, L_1 is taken more than the calculated value, therefore, 1.5 mH is chosen. Once L_1 is chosen to attenuate lower order harmonics, L_2 and C need to be designed for elimination of higher order harmonics.

The expression for resonance frequency will be

$$F_{res} = \frac{1}{2\pi} \sqrt{\frac{1+k}{kl1c}}$$

Where $k=L_2/L_1$

Selection of $L_2 > L_1$ (i.e., $k > 1$) will reduce the capability of L_1 to attenuate lower order harmonics. Therefore, lower order harmonics will be also attenuated by inductor L_2 to achieve satisfactory compensation performance. Usually, the magnitude of the lower order harmonics in the LCL filter is used to be more as compared with the higher order harmonics. Hence, the current through the shunt capacitor and the inductor L_1 will increase for $k > 1$. This will increase the damping power losses, the reactive power loss in inductor L_1 ,

and the inverter current. As the damping power loss is extracted from the source, the source current increases that results in more losses and cost. Therefore for less cost and losses, k should be lower. For the best choice to provide effective attenuation the value of C is chosen, C=10µF. The value of k is found to be 0.42. With this value of k, L₂ will be 0.6 mH.

The equivalent impedance of the LCL filter approaches to zero at the resonance frequency f_{res}, and the system may become unstable. However, the system can be made stable by inserting a resistance R_d in series with the capacitor. Usually, it is chosen in proportion to the capacitive reactance at f_{res}, i.e., X_{cref}, such that the damping losses are less while assuring system stability. The capacitive reactance at resonance will be

$$X_{cref} = \frac{1}{2\pi f_{res} C}$$

The power losses in the damping resistor will be

$$P_{loss} = 3 \times R_d \times \sum_{h=1}^n I_{sh} * I_{sh}$$

Where h is the harmonic order of the current flowing through R_d. In the LCL filter-based DSTATCOM topology, R_d is chosen such that the damping losses are minimized while assuring that the sufficient resonance damping is provided to the system. However, one of the major advantages of the proposed scheme is that the voltage across, and therefore the current through the shunt part of the LCL filter, is greatly reduced. This reduction in the shunt current significantly reduces the damping power losses. Therefore, sufficient resonance damping of the system is a prime concern while designing a damping resistor in the proposed method. For C = 10µF and f_{res} = 2400 Hz here, a 15-Ω resistance is chosen which provides satisfactory resonance damping.

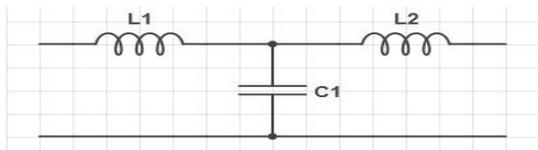


Fig.3. LCL Filter

V. RESULTS AND DISCUSSION

1) simulation parameters: The following table values are considered while designing the model of the DSTATCOM by the above considerations.

System quantities	Values
Source voltage	230v, line to neutral, 50Hz
Feeder Impedance	1+j3.14
VSI Parameters(LCL filter based)	V _{dcref} =520v, L1=1.5mH, L2=0.6mH,

	R _d =15Ω, R1= R2=0.05Ω, C=10µF, C _{dc} =3000 µF
Gain of the PI Controller	k _p = 0.1, k _i = 1
RL type non-linear load	R=50Ω,L=200mH

Table.1. Simulation Parameters

2) Proposed DSTATCOM Simulation: Fig. 4 shows the complete simulation of proposed DSTATCOM with LCL filter to compensate source current harmonics in distribution system.

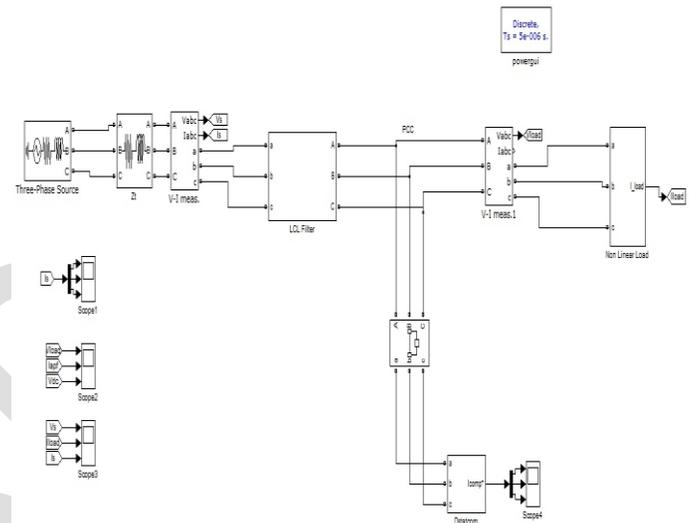


Fig.4. MATLAB/SIMULINK simulation of DSTATCOM

a) Simulation Results: Fig. 5 shows the source current waveforms without DSTATCOM. Fig. 6 shows the compensator currents. Fig. 7 shows the load currents. Fig. 8 shows the Source Currents with DSTATCOM.

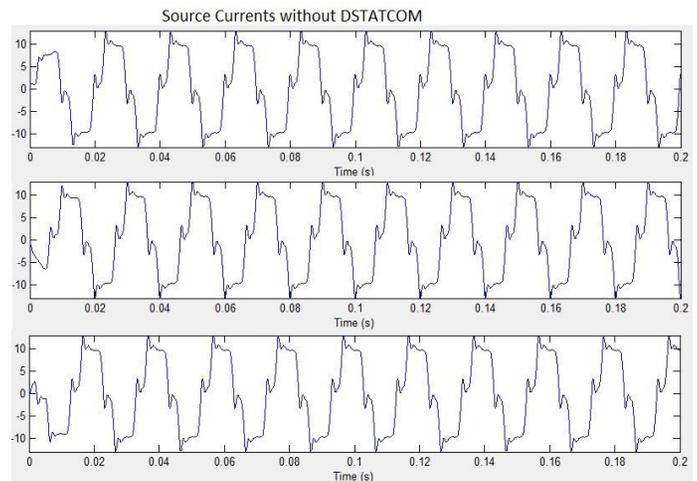


Fig.5. Source Currents without DSTATCOM

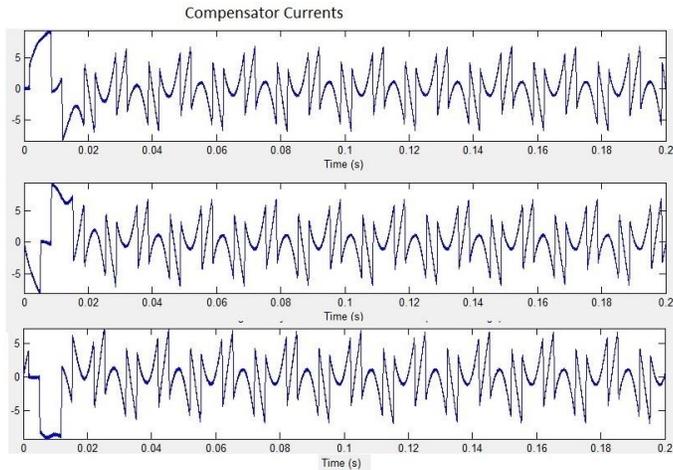


Fig.6. Compensator Currents

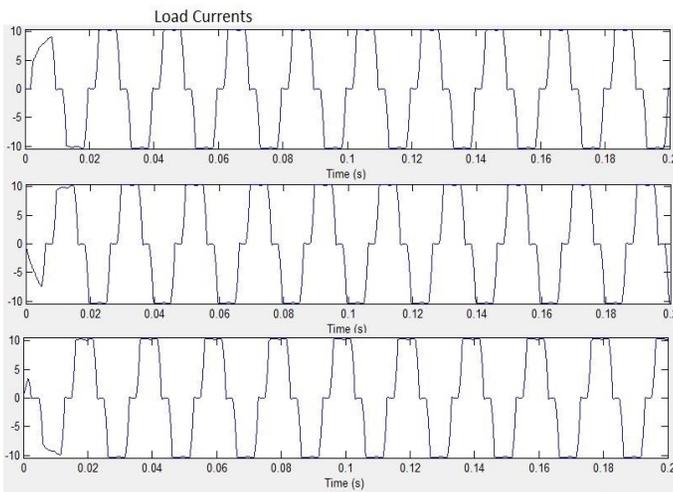


Fig.7. Load Currents

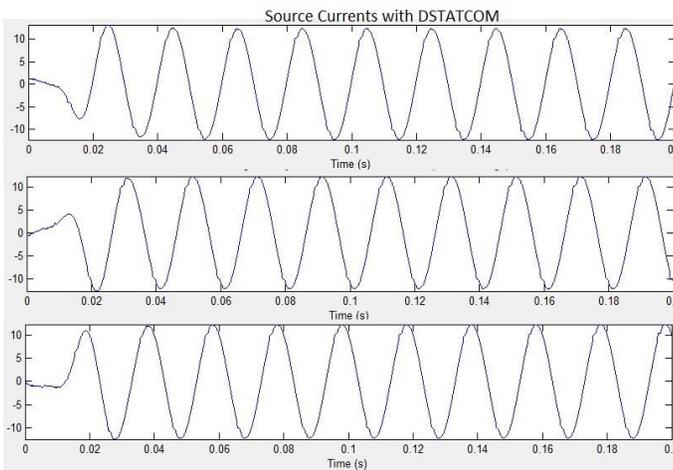


Fig.8. Source Currents with DSTATCOM

3) THD Analysis: Fig. 9 shows Total Harmonic Distortion (THD) of system without DSTATCOM. Fig. 10 shows THD of system with DSTATCOM compensation.

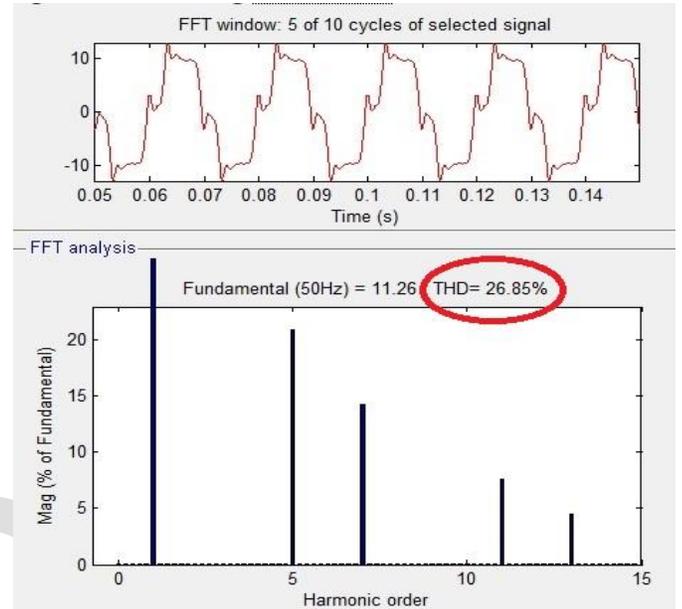


Fig.9. THD percentage without DSTATCOM

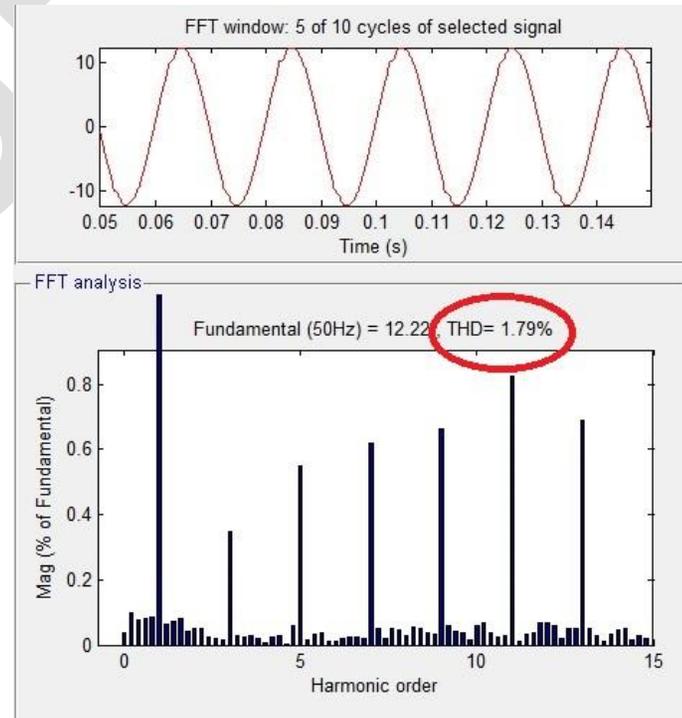


Fig.10. THD percentage with DSTATCOM

Table 2 shows the percentage of total harmonic distortion of source currents without and with compensation.

Source Current	THD in percentage
Without Compensation (DSTATCOM)	26.85%
With Compensation (DSTATCOM)	1.79%

Table.2. Percentage THD of Source Currents

VI. CONCLUSION

Hybrid Distribution Static Compensator (DSTATCOM) topology has been planned to compensate Source current harmonics. Same has been simulated using MATLAB/SIMULINK and verified results without and with DSTATCOM Compensation by connecting non linear load. Using DSTATCOM, THD is reduced remarkably from 26.85% to 1.79% on the simulated power systems circuit.

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