Multilevel diode clamped D-Statcom for power quality improvement in distribution systems

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ABSTRACT

Power quality is one big issue in power system and a big challenge for power engineers today. Electrical consumers (or otherwise load devices) expect electrical power received power should be of first-class. Bad quality in electrical power directs to fuse blowing, machine overheating, increase in distribution losses, damage to sensitive load devices and many more. DSTATCOM is one of the FACTS controllers designed to improve the quality in electrical power and thus improving the performance of distribution system. This paper presents a multilevel DSTATCOM topology to enhance power quality in power distribution system delivering high-quality power to the customer load devices. Diode-clamped structure is employed for multi-level DSTATCOM structure. 'PQ' based control strategy generates reference signal which is further processed through level-shifted multi-carrier PWM strategy for the generation of gate pulses to multi-level DSTATCOM structure. Simulation work of proposed system is developed and the result analysis is presented using MATLAB/SIMULINK software. Performance of multi-level DSTATCOM topology is verified with fixed and variable loads.

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1. INTRODUCTION

Quality in electrical power is attaining much interest these days in modern electrical trade. Electrical consumers (or otherwise load devices) expect electrical power received power should be of first-class. The nature of load (especially non-linear loads) also affects the power system and can have impact on the quality of power. Inherently power system and load nature are concurrent and their interaction affects the power quality [1]-[4]. Bad quality in electrical power directs to fuse blowing, machine overheating, increase in distribution losses, damage to sensitive load devices and many more. Pause in production due to these power quality issues necessitates huge production loss.

Power quality issues like voltage sag, voltage swell, interruptions, harmonic pollution, and reactive power problems are to b addressed and mitigated to ensure the delivery of qualified power to the consumer durables. Interruptions in electrical power lead to heavy production loss (may be around 4% of the turn-over). Interruptions in power may cause loss of data, breakdown of machines and tumble in security.

Voltage sag or swell effects the device life as sag in voltage level reduces the efficiency and swell destroys the device. Reactive power issue in power system may raise the temperature of the connected machines which gives out additional losses in the system. Regulating the reactive power issue can control the unnecessary current flow giving out considerable advantage.

Harmonic pollution is generated in the power system mainly because of connected non-linear load sections [5]-[10]. Non-linear utilization from power electronic devices (like rectifiers, inverters) alters the wave shape of current. The solution to mitigate harmonic pollution in the system is to introduce shunt power filter like DSTATCOM [11]-[14]. Controlled DSTATCOM estimates the harmonics and ensures the distortion in current shape is well within prescribed limit. Figure 1 illustrates the DSTATCOM connected power system. This paper presents a diode clamped multilevel DSTATCOM topology to enhance power quality in power distribution system delivering high-quality power to the customer load devices. 'PQ' based control strategy [15]-[26] generates reference signal which is further processed through level-shifted multi-carrier PWM strategy for the generation of gate pulses to multi-level DSTATCOM structure.

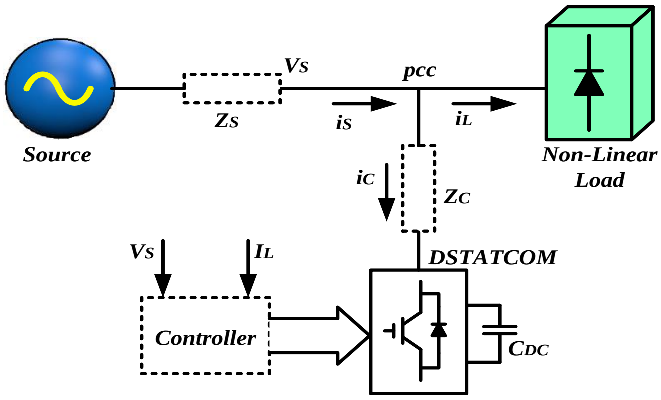

Figure 1. Block diagram of DSTATCOM in distribution system

2. MULTI-LEVEL DSTATCOM TECHNOLOGY

Multilevel structure is in good demand these days in power electronic sector. Multilevel inverter is a power electronic converter which yields multi-level structured output altering the level of voltage. Traditional two-level inverter gives out voltage with two levels (+Vdc and -Vdc). Nevertheless, the output waveform of the traditional inverter includes harmonics and the stress across the power switches of the inverter is very high.

On the other hand, modification in the output wave shape forming a stepped output other than two-level is achieved with multi-level inverter topology. As the levels in the output voltage wave shape increases, the wave-shape tends to be smoother impacting the switch with less stress achieving less distortion. Diode clamped structure is one topology among multi-level inverters. Figure 2 illustrates diode clamped multi-level DSATCOM connected to power system. DSTATCOM is a shunt controller and hence is connected in parallel to the power distribution network. To reduce the stressing of power switching devices in diode clamped and also known as neutral point clamped inverter. Output look-alike of 5-level diode clamped inverter is shown in Figure 3.

3. CONTROL OF MULTI-LEVEL DSTATCOM

The control circuit to generate gate pulses to DSTATCOM is shown in Figure 4. The reference currents to generate pulses to power switches of DSTATCOM are produced from conventional 'PQ' theory. Line voltages and currents are sensed and processed to calculate active (P) and reactive (Q) powers as in (1) where 'α' and 'β' terms are obtained through Clarke's transformation procedure.

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \qquad (1)$$

Actual DC-Link voltage is compared to reference value and the error is processed to 'PI' controller to generate power loss component. Power loss component is compared with the signal obtained from band pass filter to obtain reference current signal. Inverse transformation as in (2) gives out the compensating reference signals.

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_0^* \\ i_{s\alpha}^* \\ i_{s\beta}^* \end{bmatrix} \tag{2}$$

The reference current signal is then sent for inverse Clarke's transformation to get three-phase reference currents which are then sent to gate drive circuit for generation of pulses. Overall arrangement of multilevel diode clamped DSTATCOM in power system is illustrated in Figure 5. Table 1 illustrates the system parameters.

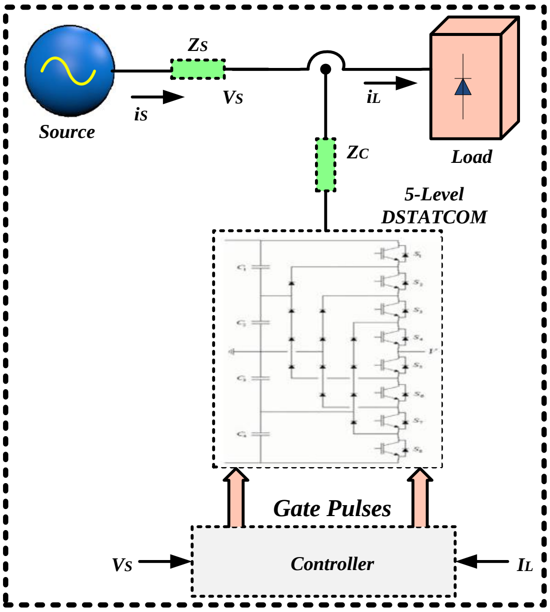

Figure 2. Multi-level diode clamped structured DSTATCOM in power distribution system

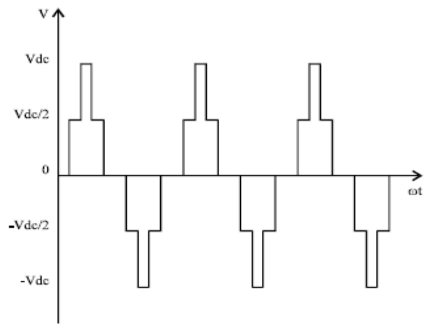

Figure 3. 5-level output from the diode clamped topology

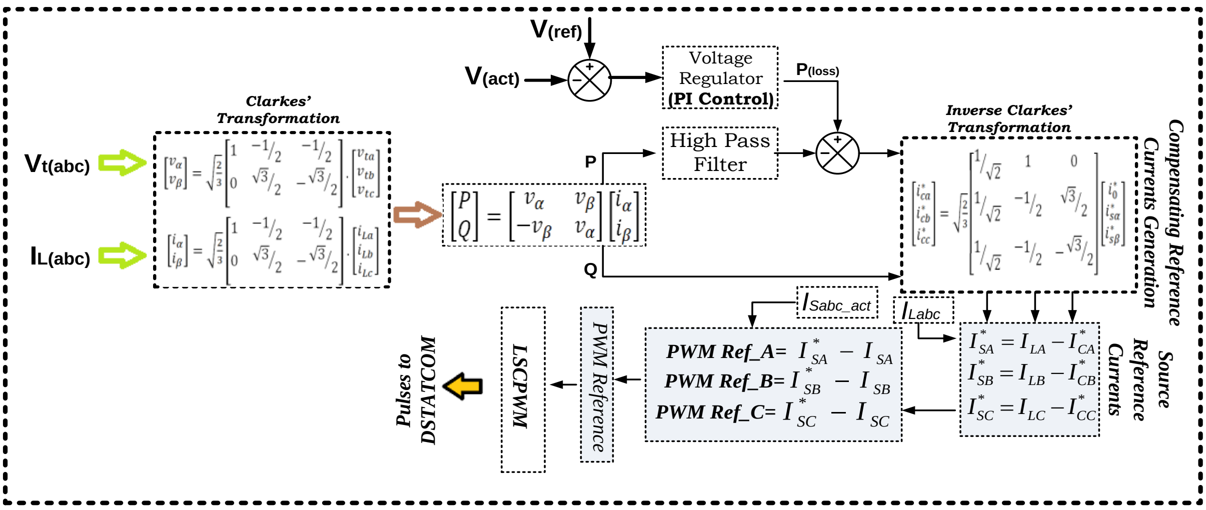

Figure 4. PI based 'PQ' control logic for Multi-level DSTATCOM

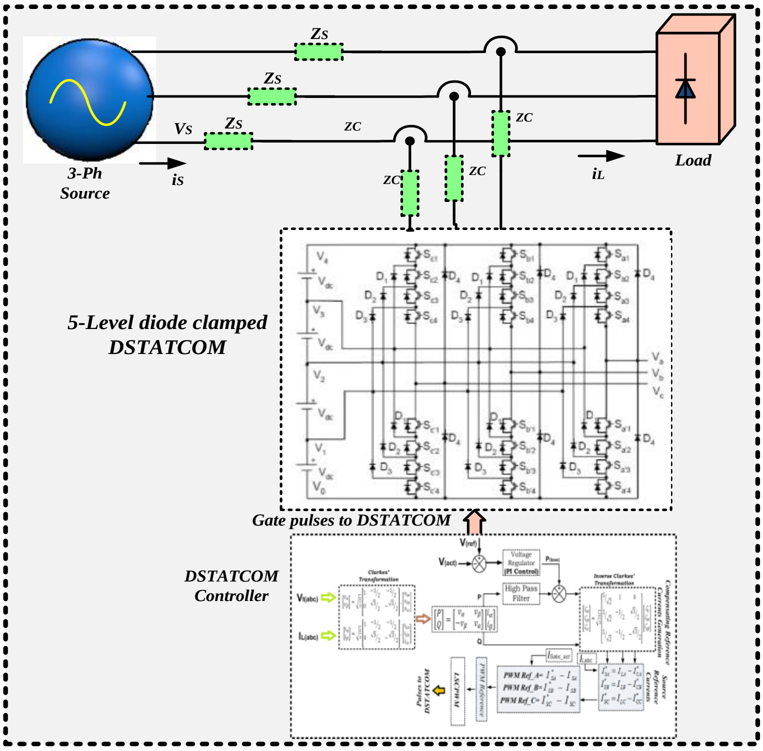

Figure 5. Overall arrangement of multilevel diode clamped DSTATCOM in power system

Table 1. System Parameters

Parameter	Value
Source Voltage (Ph-Ph RMS)	11 KV
Source Impedance	0.1+j0.282 Ω
Load Impedance	200+j37.6 Ω
DC Link Capacitance	1500 µF
Proportional Gain	0.8
Integral Gain	0.5

4. RESULT ANALYSIS AND DISCUSSION

4.1. Case 1: DSTATCOM operating in power system with fixed load

Three-phase source voltage waveform of the system is shown in Figure 6. Source voltage is sinusoidal in nature and is without distortion. Three-phase load current is shown in Figure 7. As load is non-linear in nature, the load current contains harmonics and is distorted as shown in figure. Load draws 60A peak current.

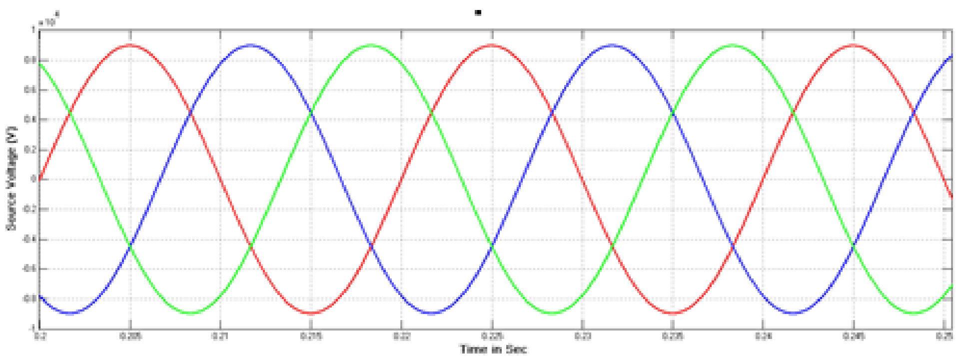

Figure 6. Source voltage

Three-phase source currents of the system are shown in Figure 8. Non-linear load causes source current to distort but the presence of DSTATCOM makes the source current to be sinusoidal removing harmonic components. Figure 9 shows the required compensating signals from the filter (DSTATCOM) to compensate for harmonics in source current at point of common coupling.

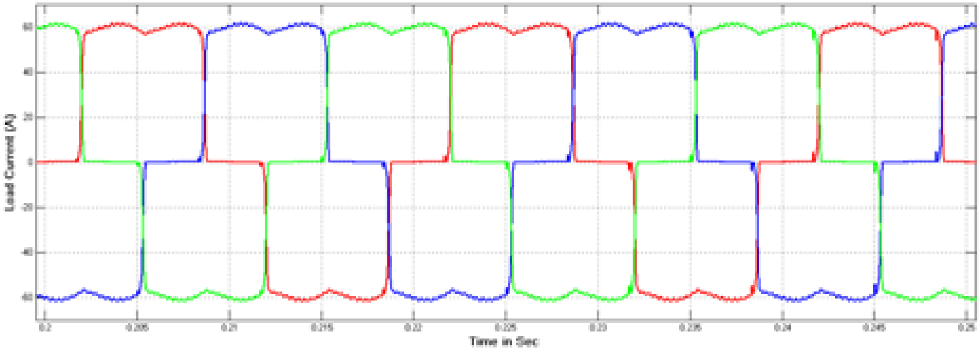

Figure 7. Load current

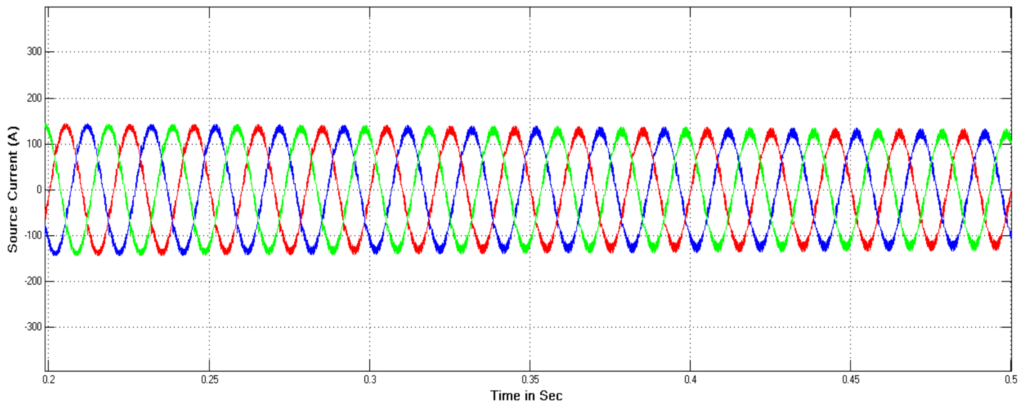

Figure 8. Source current

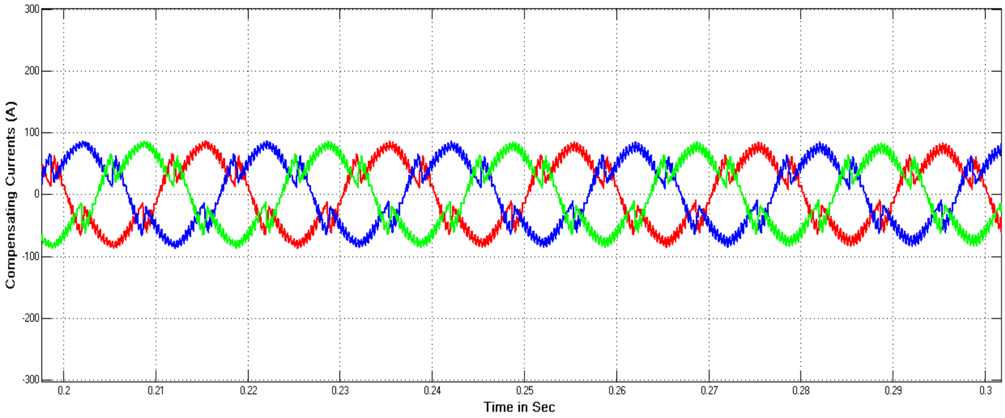

Figure 9. Compensating currents from the filter

Figure 10 shows the five-level output from the DSTATCOM. Figure 11 shows the DC-link voltage to DSTATCOM.

Figure 12 shows the active and reactive power from the source to the system. Reactive power is zero which indicates that there is no reactive power exchange in the system. Source delivers 0.6MW of active power to the system. Figure 13 shows the active and reactive power absorbed by the load. Reactive power is zero which indicates that there is no reactive power exchange in the system. Load draws 0.4MW of active power.

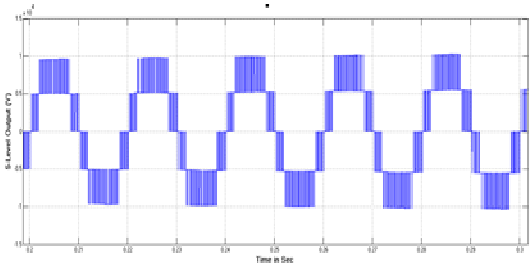

Figure 10. Five-level output from DSTATCOM

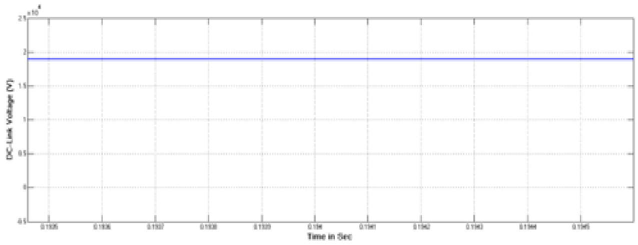

Figure 11. DC-link voltage to DSTATCOM

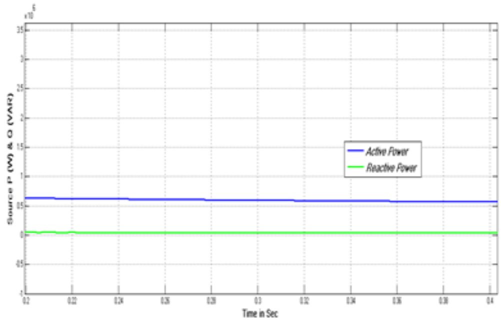

Figure 12. Source active and reactive powers

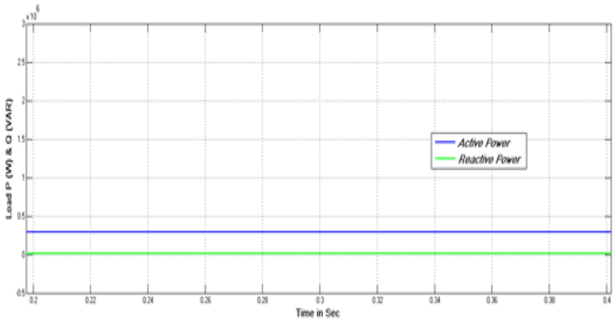

Figure 13. Load active and reactive powers

Power factor angle between the source voltage and source current is shown in Figure 14. Figure 14 illustrates that there is no phase angle difference between the source voltage and source current and source power factor is almost unity. Power factor angle between the load voltage and load current is shown in Figure 15. Figure illustrates that there is phase angle difference between the load voltage and load current and load power factor is non-unity.

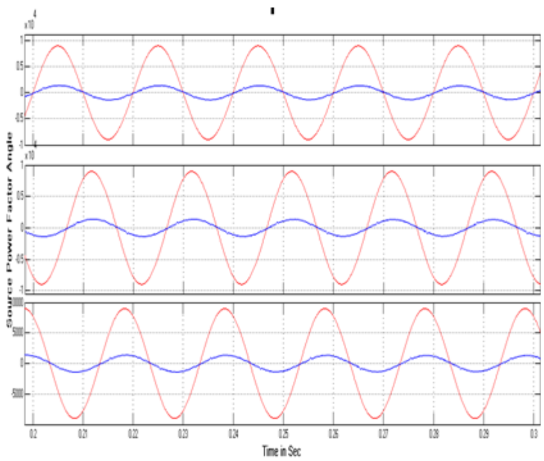

Figure 14. Source power factor

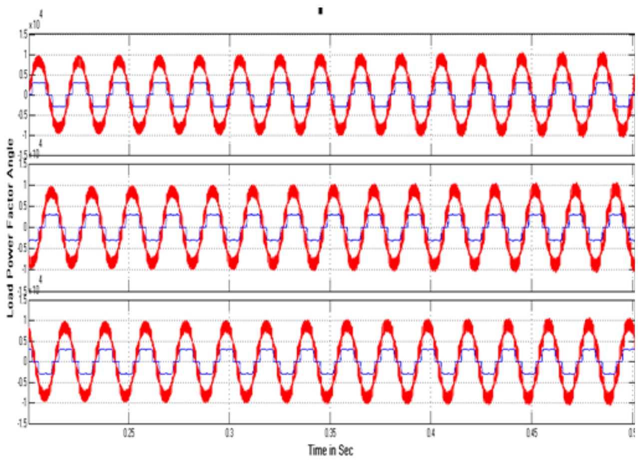

Figure 15. Source power factor

Figure 16 and Figure 17 shows the harmonic distortion analysis of source current and load current respectively. Source current contains less distortion and near to standard limits while load current is distorted by 28.92% as the load is non-linear in nature. The presence of multi-level DSTATCOM compensates the distortion in source current and maintains the distortion within limits.

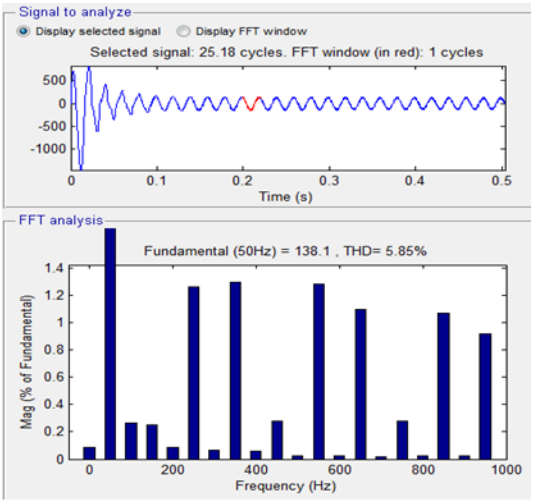

Figure 16. THD in source current

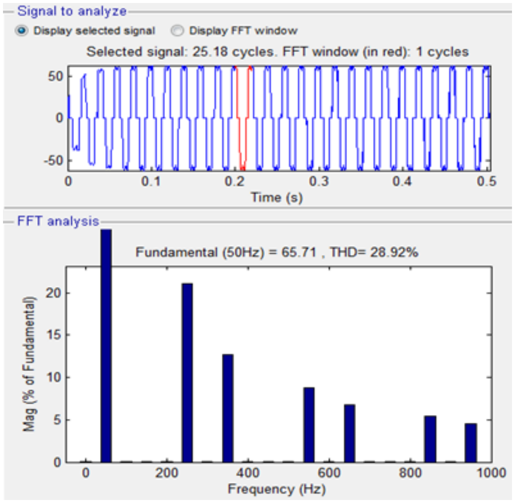

Figure 17. THD in load current

4.2. Case 2: Dstatcom operating in power system with variable load

In this case, the system is working under variable load condition. Load is varied (increased) at 0.25sec and again varied (decreased, brought back to the condition as before 0.25sec) at 0.75sec. Three-phase source voltage waveform of the system is shown in Figure 18 Source voltage is sinusoidal in nature and is without distortion.

Three-phase source currents of the system are shown in Figure 19. Non-linear load causes source current to distort but the presence of DSTATCOM makes the source current to be sinusoidal removing harmonic components. Source current is increased as the load increases from 0.25sec to 0.75sec to meet the load demand.

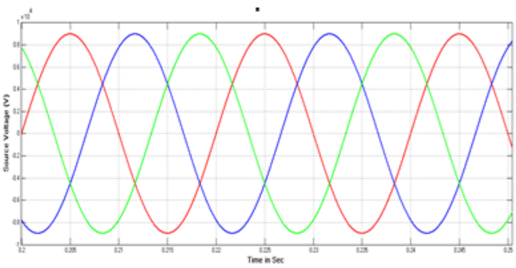

Figure 18. Source voltage

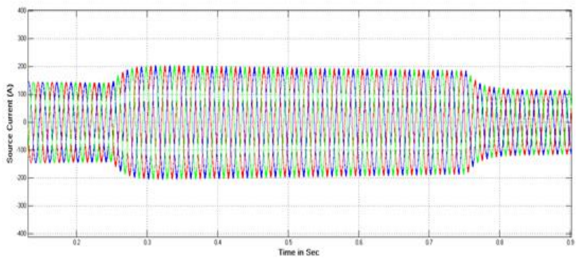

Figure 19. Source current

Three-phase load current is shown in Figure 20. As load is non-linear in nature, the load current contains harmonics and is distorted as shown in figure. Load current increases as the load increased at 0.25sec to 0.75sec. Figure 21 shows the required compensating signals from the filter (DSTATCOM) to compensate for harmonics in source current at point of common coupling.

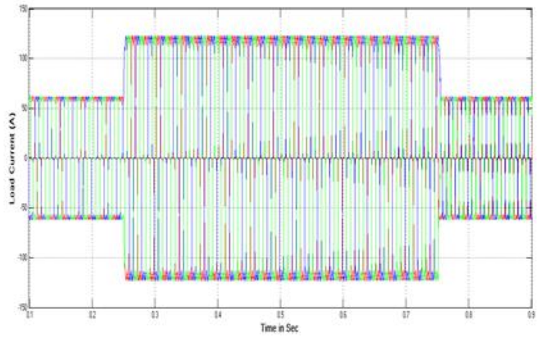

Figure 20. Load current

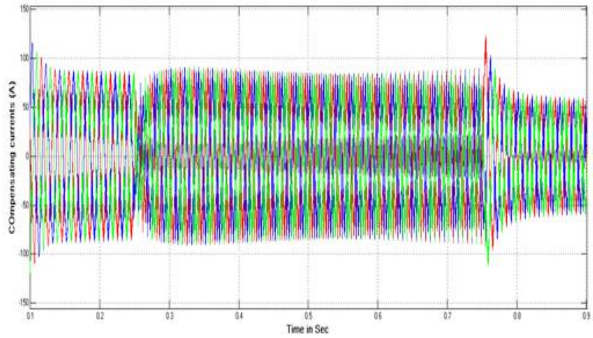

Figure 21. Compensating currents from the filter

Figure 22 shows the five-level output from the DSTATCOM. Figure 23 shows the DC-link voltage to DSTATCOM.

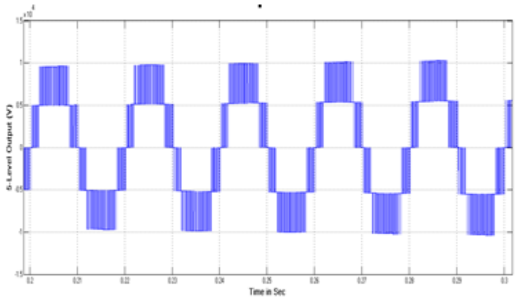

Figure 22. Five-level output from DSTATCOM

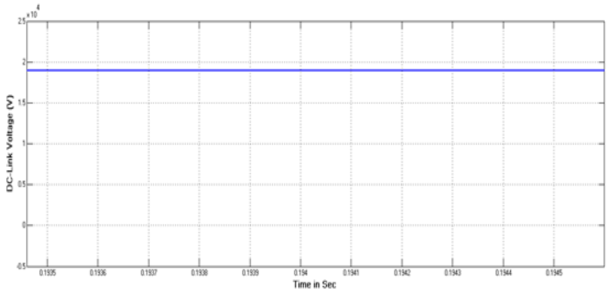

Figure 23. DC-link voltage to DSTATCOM

Figure 24 shows the active and reactive power from the source to the system. Reactive power is zero which indicates that there is no reactive power exchange in the system. Source delivers 0.6MW of active power to the system initially and as the load demand increases from 0.25sec to 0.75sec, active power delivered is 1MW.

Figure 25 shows the active and reactive power absorbed by the load. Reactive power is zero which indicates that there is no reactive power exchange in the system. Load draws 0.3MW of active power initially and as load is increased from 0.25sec to 0.75sec, active power drawn by the load is 0.6MW.

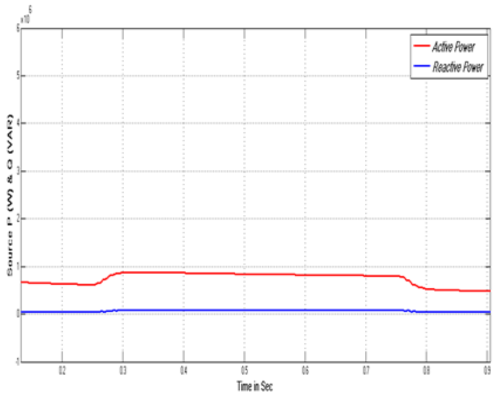

Figure 24. Source active and reactive powers

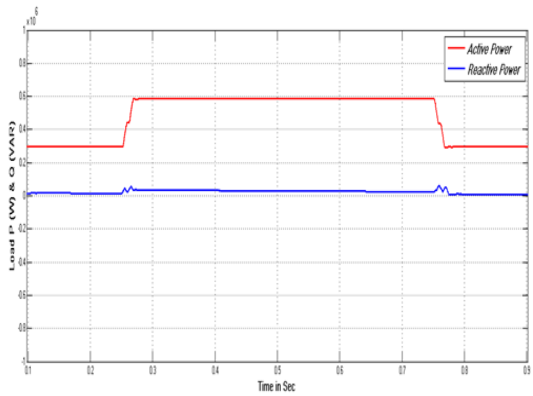

Figure 25. Load active and reactive powers

Power factor angle between the source voltage and source current is shown in Figure 26. Figure 26 illustrates that there is no phase angle difference between the source voltage and source current and source power factor is almost unity. Power factor angle between the load voltage and load current is shown in Figure 27. Figure illustrates that there is phase angle difference between the load voltage and load current and load power factor is non-unity.

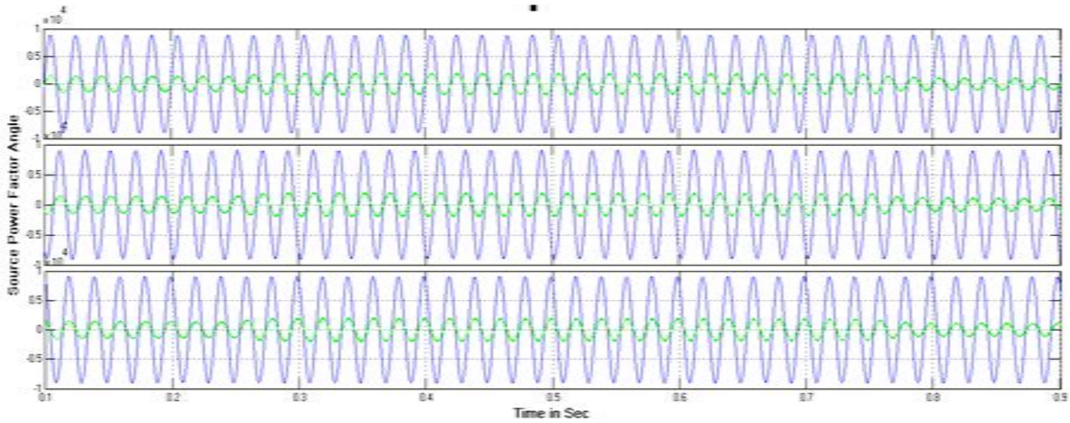

Figure 26. Source power factor

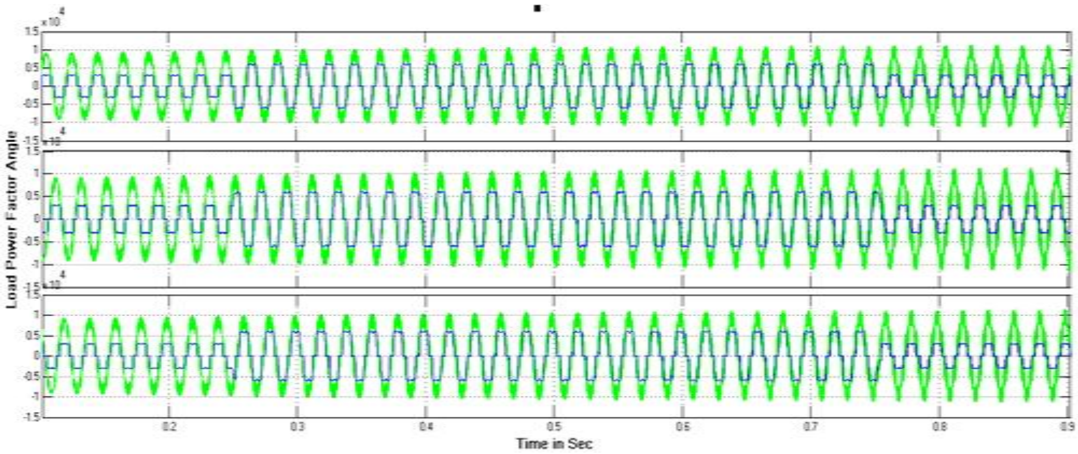

Figure 27. Source power factor

Figure 28 and Figure 29 shows the harmonic distortion analysis of source current and load current respectively. Source current contains less distortion of 4.8% and is within standard limits while load current is distorted by 27.39% as the load is non-linear in nature. The presence of multi-level DSTATCOM compensates the distortion in source current and maintains the distortion within limits. Table 2 illustrates the THD comparison analysis.

Table 2. THD comparison

THD	Source Current	Load Current
Fixed Load	5.85%	28.92%
Variable Load	4.8%	27.39%

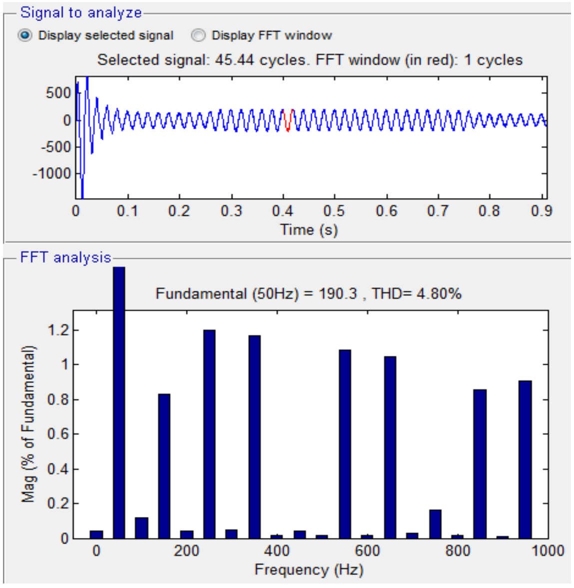

Figure 28. THD in source current

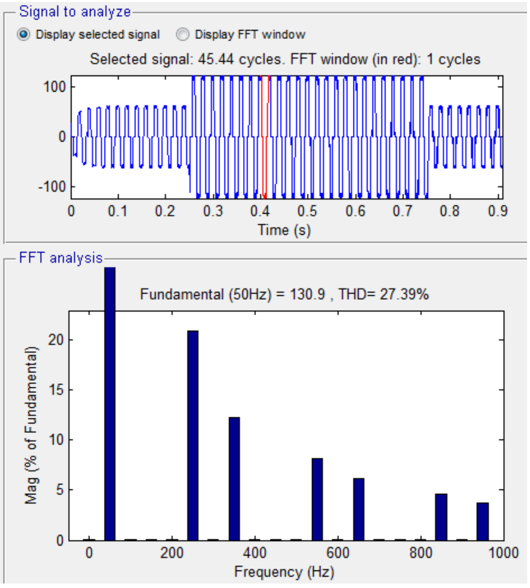

Figure 29. THD in load current

5. CONCLUSION

DSTATCOM is on among the FACTS controllers connected in parallel to the distribution system to compensate the harmonics in source current at point of common coupling. Multi-level DSTATCOM proposed in this paper injects compensating currents to point of common coupling to compensate the harmonics in source current so that no other sensitive loads are affected. Source current compensation using multilevel DSTATCOM with fixed load and variable load power system is presented in this paper. Harmonic analysis with fixed load and variable load conditions is tabulated and harmonic distortion in both the cases is well within the standard limits.

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