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A Rationalized Controller based FACTS Device for Power Quality Enhancement in the Distribution System

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Abstract: ***Providing power to the consumers without interruption and maintaining voltage, frequency and power factor within nominal values is said to be power quality. One of the major emerges for power engineers is a power quality problem such as harmonics, voltage sags, voltage swell, unbalance and many more. These power quality burdens may impact the consumer devices and even roots to damage the devices connected. FACTS devices fit for the solution for this issue, and in this paper, DSTATCOM was used to reduce the harmonics in source components. This paper presents a rationalized control to produce gate pulses to DSTATCOM for power quality improvement in the distribution system. The offered Source Current Reference Control (SCRC) algorithm for DSTATCOM is simple and eliminated complex transformations and calculations. The standardcontrol strategies sensed load currents for harmonic computations and to generate reference currents. The control strategy introduced in this paper sensesthe source current for reference in the control algorithm. The mentioned control strategy verified for fixed, variable load and linear load conditions in a power system. The considered concept developed,and results are obtained using MATLAB/SIMULINK software.***

Index Terms: ***Rationalize control, FACTS, Source Current Reference Control Algorithm, Power Quality, Harmonics.***

I. INTRODUCTION

The primary issue now worrying power engineers is power quality problems. Providing continuous supply with voltage, frequency and power factor in insignificant values is termed as power quality. Power quality subjects cost unexpected power failures, equipment overheating, damage to sensitive devices, electronic communication interference, increased system losses, declined efficiency, need for oversizing of installations and many more. A power quality problem regards harmonics, voltage variations, transients, interruptions, waveform distortions. Addressing these power quality issues is the desperately primary thing to deliver quality power to the consumers. Non-linear type of loads might originate the system to act abnormal and needs an operative and cost-efficient solution to progress the power quality. Conventional passive filters fail to address this matter effectively due to the presence of resonance. Active filters can adequately address the answer both to increase the transient and steady-state stability of the system [1-3]. A FACTS device prerequisite voltage source or current source converters for the power quality diminution [4-6]. There are different forms of FACTS controllers and shunt active filter might be thebest solution to reduce the harmonics [7-9].

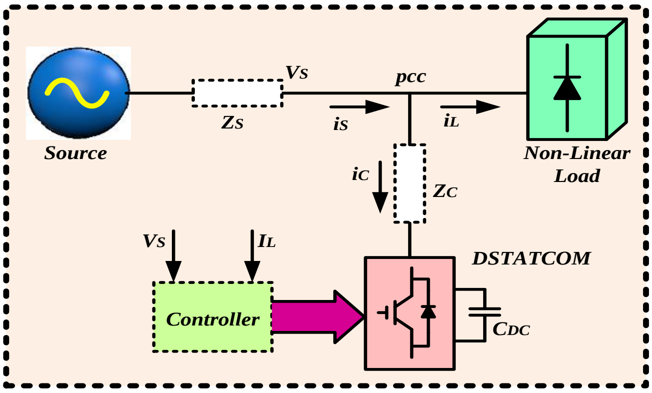

Figure 1: Block diagram of DSTATCOM

A Distribution STATicCOMpensator (DSTATCOM), a custom power device [10-11], connected in shunt with the load, reimburses for the harmonics in the distribution system. DSTATCOM comprises of a Voltage Source Converter (VSC) [12-13], a DC-Link capacitor, a coupling inductor $Z_c$and a controller as revealed in figure 1.

The enactment of the DSTATCOM [14-16] depends on the control algorithm used for extracting the current reference components [17]. This paper offers a rationalized control to produce gate pulses to DSTATCOM for power quality improvement in the distribution system. The provided control strategy for DSTATCOM is simple and eliminated complex transformations and calculations. The control available in this paper senses the source current for reference in the control algorithm. The projected control strategy verified for fixed, variable load and linear load conditions in a power system.

II. DSTATCOM IN POWER DISTRIBUTION SYSTEM

DSTATCOM is a voltage-source inverter (VSI) based shunt device [3], which is mostly used in the distribution system to advance power quality.

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The main benefit of DSTATCOM is that the current injection into the distribution bus can be regulated very capably by the intelligent power electronics-based control existent in it. Another advantage of DSTATCOM is it improves the load power factor, source power factor, reduces the harmonics present in load currents and for regulating the voltages of the distribution bus against voltage sag/swell for reimbursing the reactive power component of the load, etc. [4]. In this paper, the DSTATCOM is used to normalize the harmonics in source current and to improve power factor at the source side is offered.The schematic arrangement of DSTATCOM in power distribution system displayed in figure 2.

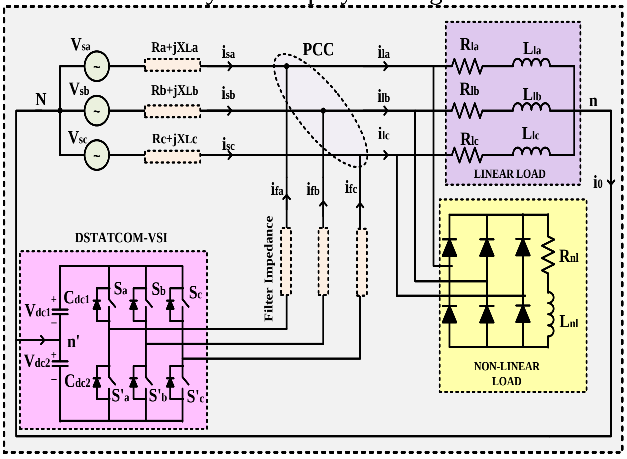

Figure 2: DSTATCOM in power distribution system

DSTATCOM generates adjusting currents and induces these origins regulated currentsinto the system, thus modifying harmonics in the system. Electrical energy is being distributed through a three phase four wire system in many of the industrial applications. Unwanted neutral currents might flow caused due to non-linear loads with uncompensated and disturbed systems. In this case, a three-phase DSTATCOM can provide compensation.

III. PROPOSED SCRC ALGORITHM FOR DSTATCOM

The shunt DSTATCOM is controlled by a controller to generate reference currents and also to generate balancing currents. The non-linear components in the load currents first sensed at the load point, and the signals fed to the standard controller. The controller conditions the signal in the system by inducing remunerate currents through proper interfacing. Sensing representative wits the load currents at the load point and fed back to the traditional controller.

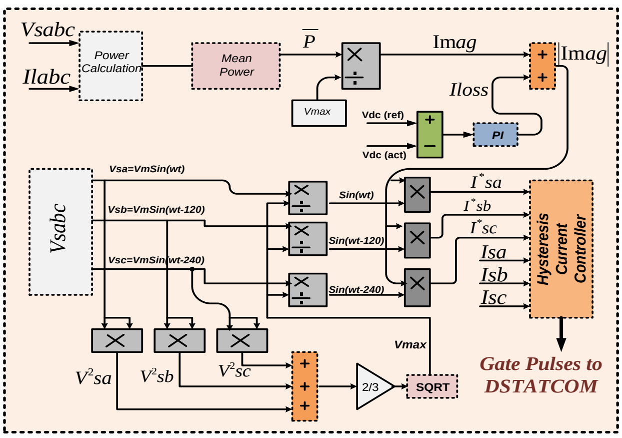

Figure 3: Source current reference control algorithm for DSTATCOM

This paper deals withan SCRC algorithm which minds the source currents for reference in the process of producing reference currents in the SCRC algorithm. Source Current Reference Control (SCRC) algorithm disclosed in figure 2 is straightforward and ignores complex transformations and calculations.

The suggested Source Current Reference Control (SCRC) algorithm creates current magnitude and phase angles for three phases before creating gate pulses to DSTATCOM. The projected Source Current Reference Control (SCRC) algorithm senses source currents and compares reference currents for the generation of gate pulses to DSTATCOM through hysteresis controller. Source voltages and load currents primarily gathered for power calculation. Mean power measured from the calculated power, and the mean measured power is divided by the maximum value of the voltage to contribute a current magnitude signal. DC-Link voltage (reference) signal compared to actual DC-link voltage, and the error given to the PI controller. The output of the PI controller grants a current loss signal which is then added to the earlier attained current magnitude signal to give out the clear current magnitude signal with a positive sign. On the other hand, the three-phase source voltage is considered to obtain signals Vsa^2, Vsb^2 and Vsc^2, where:

$$V_{sa}^2 = V_{sa} * V_{sa} \quad (1)$$

$$V_{sb}^2 = V_{sb} * V_{sb} \quad (2)$$

$$V_{sc}^2 = V_{sc} * V_{sc} \quad (3)$$

Where,

$$V_{sa} = V_m Sin(wt) \quad (4)$$

$$V_{sb} = V_m Sin(wt - 120^0) \quad (5)$$

$$V_{sc} = V_m Sin(wt - 240^0) \quad (6)$$

The three signals Vsa^2, Vsb^2 and Vsc^2 are added to treat with gain of $2/3$ and then the signals obtained is employ with function 'square root' to give out maximum value of voltage signal (V_{max}). The signal V_{max} in combination to V_{sa}, $V_{sb}$and V_{sc} are operated with algebraic the operation as presented in figure 3 to give out only phase angles of a particular signal.

$$V_{max} = \sqrt{{}^2/_3\,({V_{sa}}^2 + {V_{sb}}^2 + {V_{sc}}^2)} \quad (7)$$

The phase angle of the respective phases obtained are multiplied by current magnitude (modulus) signal to generate reference current signalsI_{sa}^*, $I_{sb}^*$and I_{sc}^*.

Where,

$$I_{sa}^* = |I_{mag}| Sin\,(wt) \quad (8)$$

$$I_{sb}^* = |I_{mag}| Sin\,(wt - 120^0) \quad (9)$$

$$I_{sc}^* = |I_{mag}| Sin\,(wt - 240^0) \quad (10)$$

Where,

$$|I_{mag}| = I_{mag} + I_{loss} \quad (11)$$

$$I_{mag} = \frac{\bar{P}}{V_{max}} \quad (12)$$

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Where,

$\bar{P}$is mean power

$$I_{sa} = I_m \sin wt \quad (13)$$

$$I_{sb} = I_m \sin(wt - 120^0) \quad (14)$$

$$I_{sc} = I_m \sin(wt - 240^0) \quad (15)$$

$$PI_{controller} = V_{dc(ref)} - V_{dc(act)} = I_{loss} \quad (16)$$

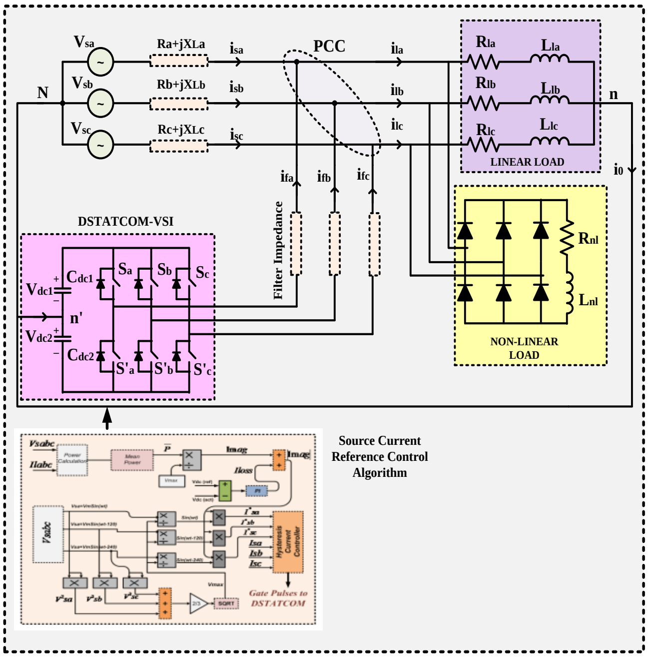

Figure 4: DSTATCOM controlled by Source Current Reference Control (SCRC) algorithm in a power distribution system.

The mention current signals generated in equations (8-10) are equated to actual source current signals and treated with hysteresis current controller to attain the gate pulses to DSTATCOM. Standard control techniques depend on load component of current to manage reference currents in the hysteresis current controller, but the projected Source Current Reference Control (SCRC) algorithm use source current signals in hysteresis current control along with reference currents obtained through control algorithm.

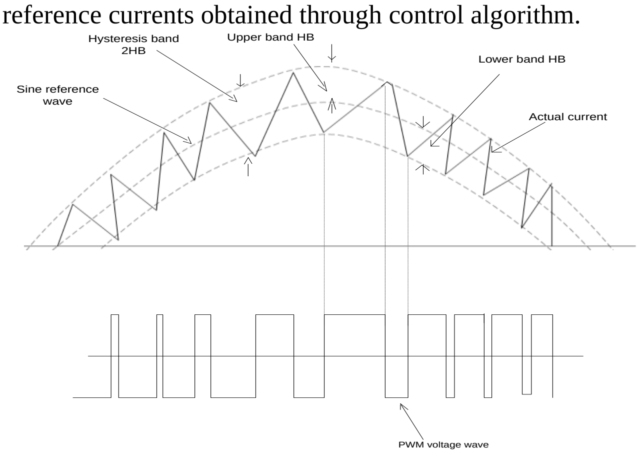

Figure.5: Hysteresis Band Current control

Hysteresis current control shown in figure 5. It is an instantaneous feedback current control method in which the actual current continuously tracks the command current within a pre-assigned hysteresis band. If the actual current exceeds the HB, the upper device of the half-bridge is turned off, andthe lowerdevice is turned on. As the current falloffs and crosses the lower band, the lowerdevice is turned off and the upper device is turned on. If the HB reduced, theharmonic quality of the wave would recuperate, but the switching frequency will increase, which will conclusively cause higher switching losses. An error signal is employed to manage the switches during voltage supply electrical converter. This error is that the distinction between the specified current and the current being injected by the electrical converter. If the error outstrips the higher limit of the physical phenomenon band, the more upper switch of the inverter arm is turned off and also the lower switch is turned on. As a result, the present starts decaying.The extensive schematic of DSTATCOM controlled by Source Current Reference Control (SCRC) algorithm in a power distribution system shown in figure 4.

IV. RESULT ANALYSIS

The considered Source Current Reference Control (SCRC) algorithm developed,and results are plotted using MATLAB/SIMULINK software. Table I describes the test system parameters used for the simulation study.

Parameters	Value
Source Voltage	$415\ Vp - p\ (avg)$, $50\ Hz$
Source Inductance	$0.05mH$
Load Impedance	$(8 + j3.77)$ Ohms
DC-Link Capacitance	$3000\mu F$

Table I: Test system parameters

A. Test Case 1: Power system without DSTATCOM

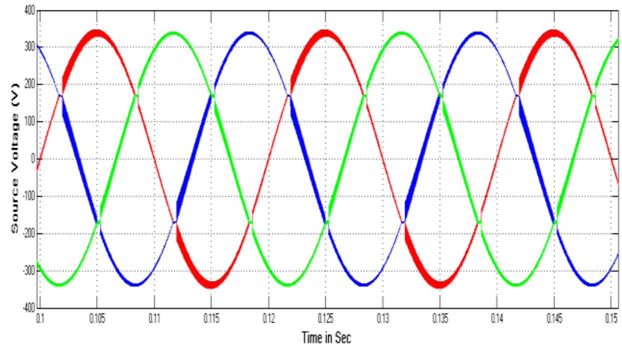

Figure 6: Source voltage

The three-phase source RMS voltages are visible in picture 6. The source voltages are with perpetual peak and are sinusoidal in shape, no distortions in the source voltages and obtained wave shape are within specified limits.

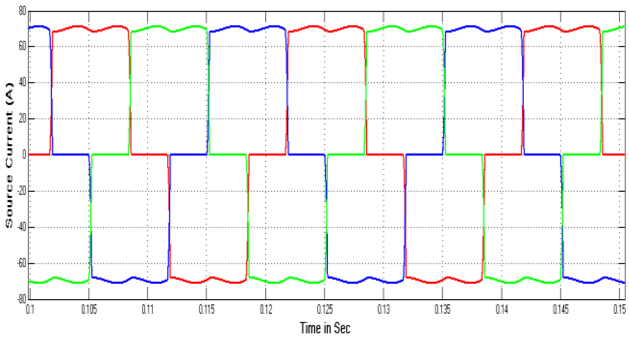

Figure 7: Source currents

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Three-phase source currents arranged in figure 7. Non-linear loads affect source currents and make them distort, and the system is without compensator (DSTATCOM) and hence source currents are distorted. The wave shape is not sinusoidal, but the magnitude of currents is nearly 70A in nature.

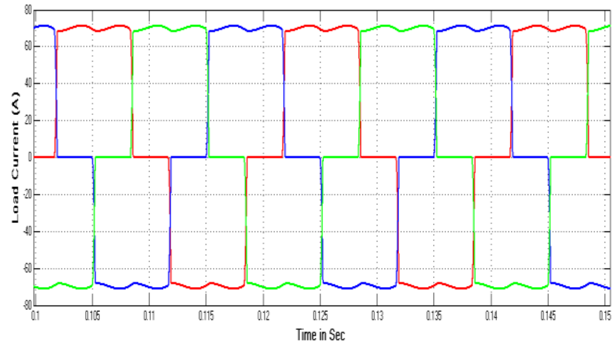

Figure 8: Load currents

Figure 8 illustrates three-phase load currents with peak 70A. Load draws 70A current from the source. The load is by inexact nature, and hence load waveform is deformed. This nonlinear loads will affect the source currents.

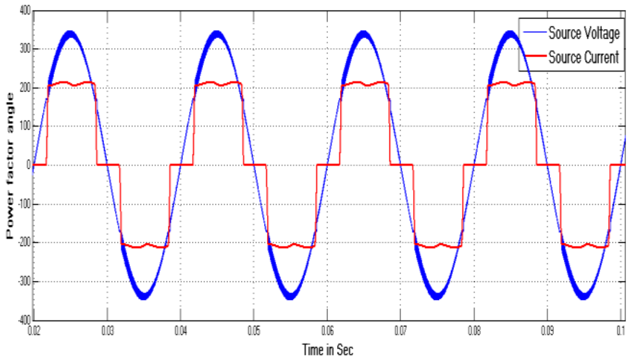

Figure 9: Source Power factor angle

Figure 9 expresses the source power factor of the power system without DSTATCOM allied. The power factor angle difference between the source voltage and source current is not zero as the source current is deformed. Hence source power factor is not maintained unity in the case power system without DSTATCOM connected. The current signal gained for the most graphic illustration.

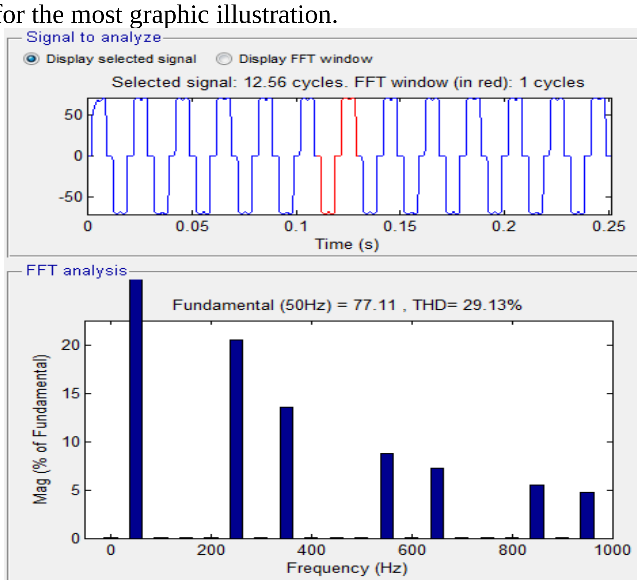

Figure 10: Source current THD

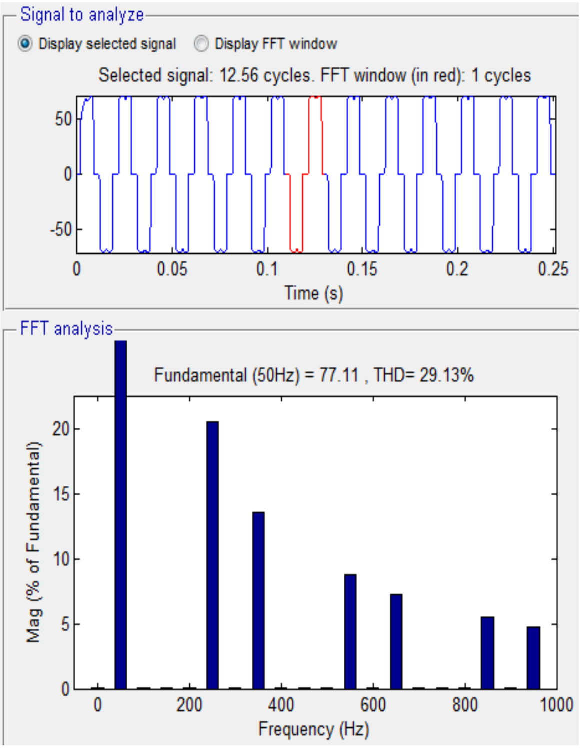

Figure 11: Load current THD

Figure 10 expounds the FFT window of harmonic distortion analysis in source current. FFT analysis decorates 29.13% perverts the source current. Figure 11 reveals the FFT window of harmonic distortion analysis in load current. FFT analysis portrays 29.13% deforms the load current. The presented THD values are not acceptable in the range [2].

B. Test Case 2: Power system with DSTATCOM and fixed loads

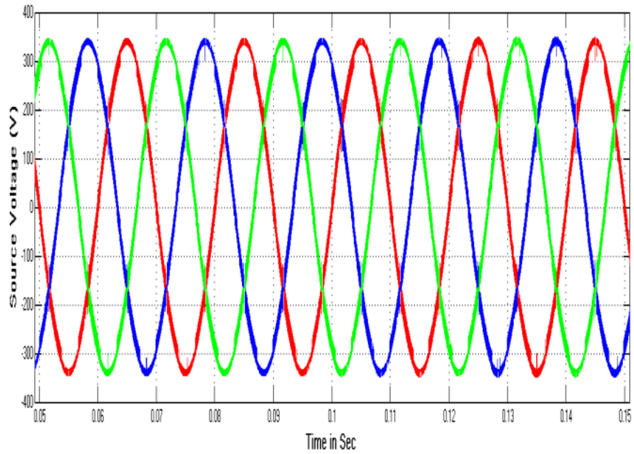

Figure 12: Source voltage

The three-phase source RMS voltages displayed in figure 12. The source voltages are within constant peak and are sinusoidal in a wave shape. Even thoughnonlinear loads are injected harmonics in the system, theobtained wave shape is in sinusoidal. DSTATCOM compensates the harmonics present in the system and normalizes the source voltages.

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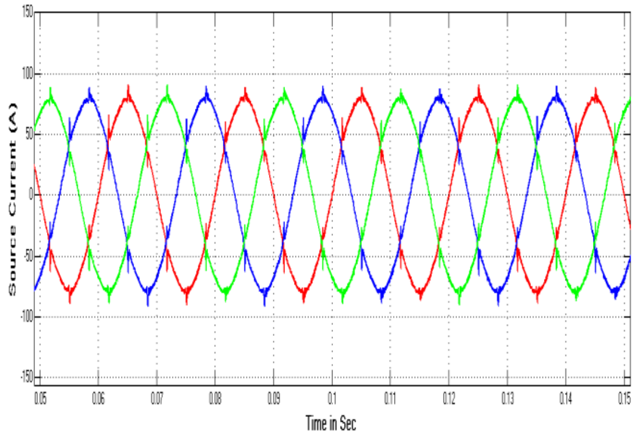

Figure 13: Source currents

Three-phase source currents exposed in figure 13. Non-linear loads affect source currents and make them alter, and here the system is with compensator (DSTATCOM), and hence source currents are non-distorted and are sinusoidal. DSTATCOM compensates harmonics and makes source current to be sinusoidal. The presented source currents are 70A current, and the wave shape is within the specified limits.

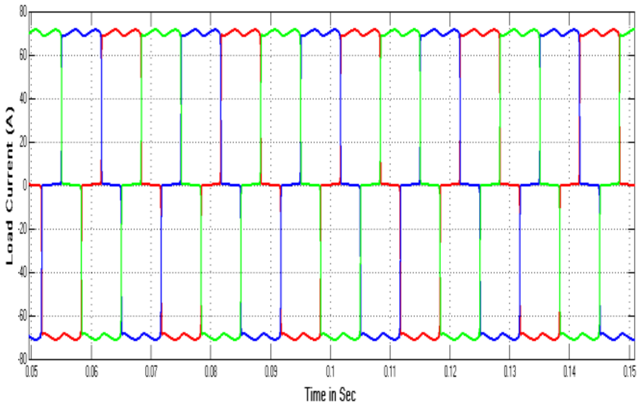

Figure 14: Load currents

Figure 14 layout three-phase load currents with peak 70A. Load draws 70A current from the source. The load is of an imprecise nature, and hence load waveform is malformed. The load currentscause the harmonics in the system. By using DSTATCOM, loadcurrent distortion minimized.

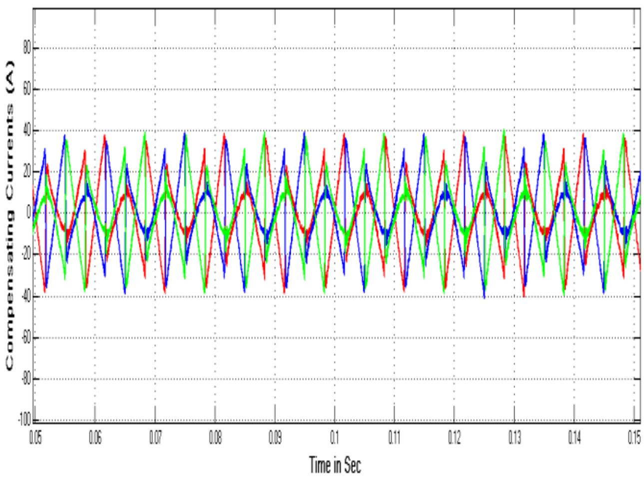

Figure 15: Compensating Currents from DSTATCOM

Figure 15 target three-phase readdressing signals from DSTATCOM. DSTATCOM compensates the harmonics and makes source components to be sinusoidal. DSTATCOM injects the compensating currents and makes source currents nondistorted. The enhanced current is nearly 40A.

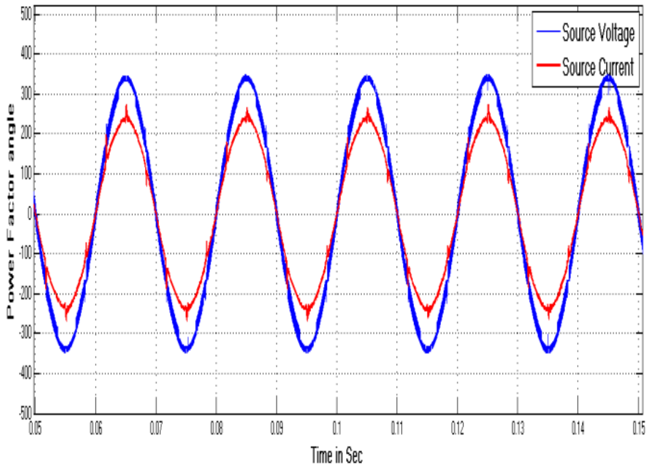

Figure 16: Source Power factor angle

Picture 16 points up the source power factor of the power system with DSTATCOM connected. The power factor angle difference between the source voltage and source current is close to zero as source current not altered. Hence source power factor is maintained nearby units in the case power system with DSTATCOM connected and with a fixed load condition. The current signal gained for the most explicit illustration.

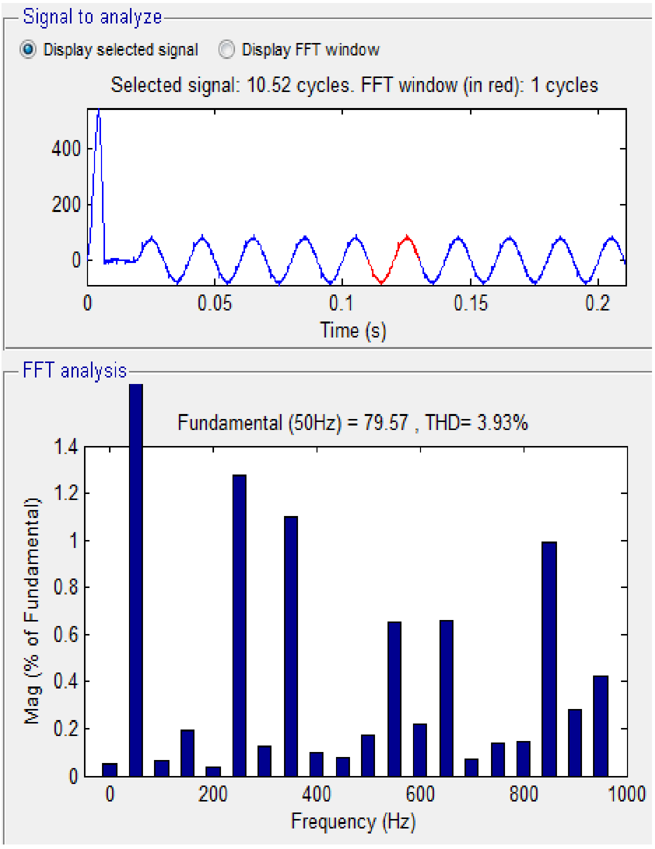

Figure 17: Source current THD

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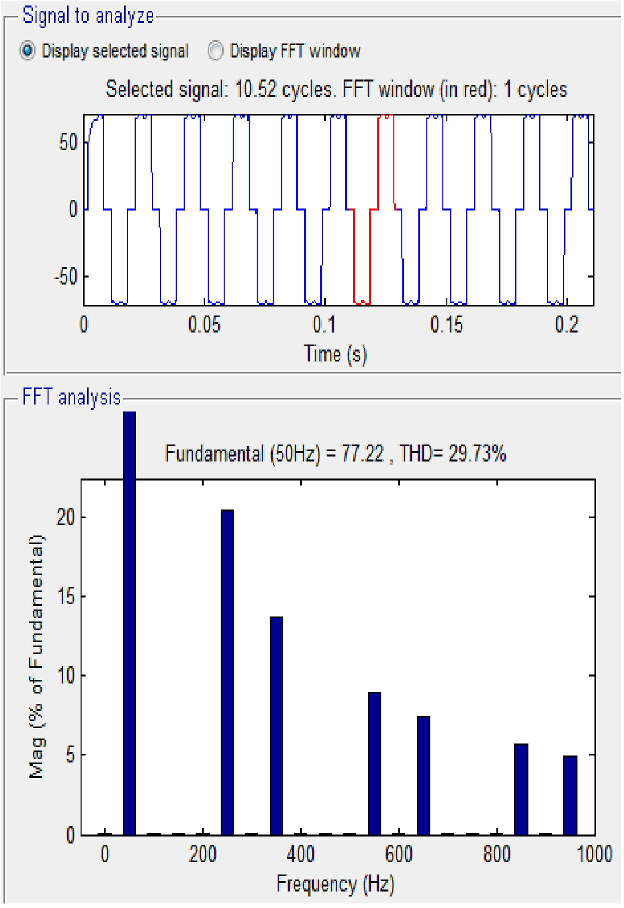

Figure 18: Load current THD

Figure 17 proves the FFT window of harmonic distortion analysis in source current. FFT analysis exemplifies thesource current is diminishing by 3.93%. The inclusion of DSTATCOM in power distribution system the THD values reduced. Source current alteration is within theoretical limits. Figure 18 exposes the FFT window of harmonic distortion analysis in load current. FFT analysis, the layout of theload current is aberrantly 29.73%.

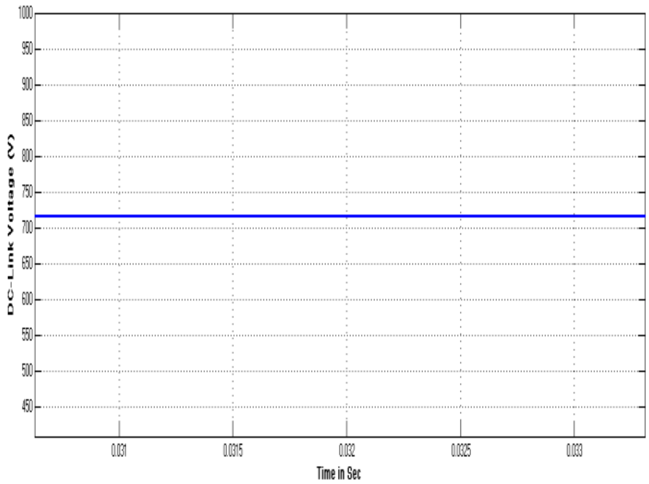

Figure 19: The DC-Link voltage of DSTATCOM

Figure 19 shows the DC-Link voltage waveform of DSTATCOM. DC-Link voltage is constant with 720V magnitude when DSTATCOM is under operating mode.

C. Test Case 3: Power system with DSTATCOM and variable loads

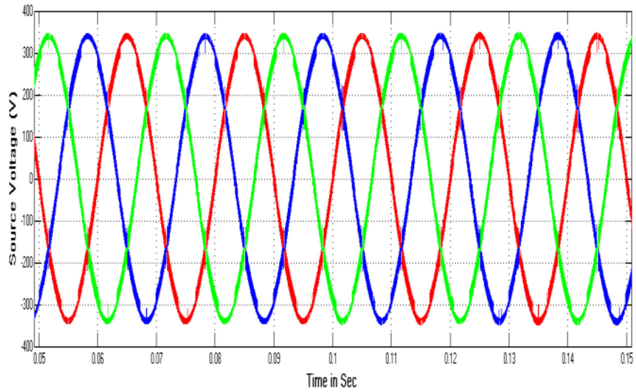

Figure 20: Source voltage

The three-phase source RMS voltages appear in picture 20. The source voltages are with constant peak and are sinusoidal in a wave shape, andmaintaining required voltage levels. In this case, source voltages not distorted by the addition of DSTATCOM in the power distribution system.

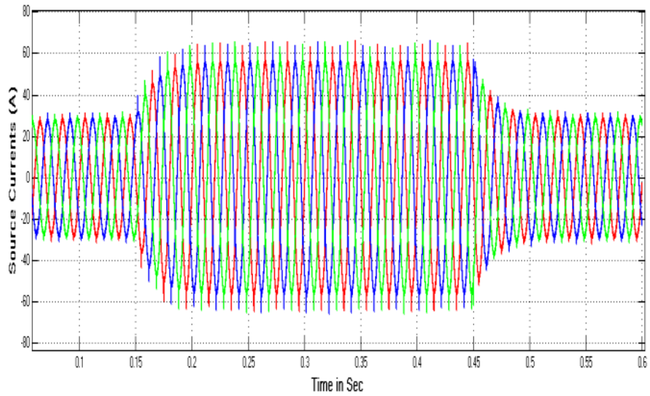

Figure 21: Source currents

Three-phase source currents exhibited in figure 21. Non-linear loads affect source currents and make them pulled,and here the system is with compensator (DSTATCOM), and hence source currents are non-distorted and are sinusoidal. DSTATCOM recoup harmonics and makes source current to be sinusoidal. The loadincreased from period 0.15 sec to 0.45 sec. During this load increase duration, source current grew to meet the load demand and provided the satisfactory operation of the loads.

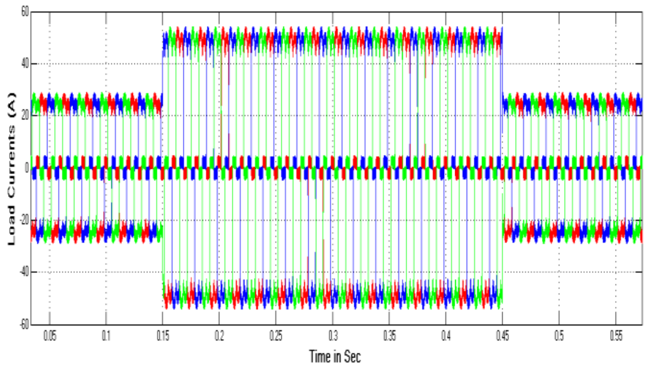

Figure 22: Load currents

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Figure 22 enhances three-phase load currents. The load isof non-linear and hence load waveform strained. The load is expanding from extent 0.15 sec to 0.45 sec. During this load increase duration, load current rises to meet the load demand. The presence of DSTATCOM in the distribution system with variable loads, the load curve in an acceptable range to encounter the nonlinearities present in the load currents.

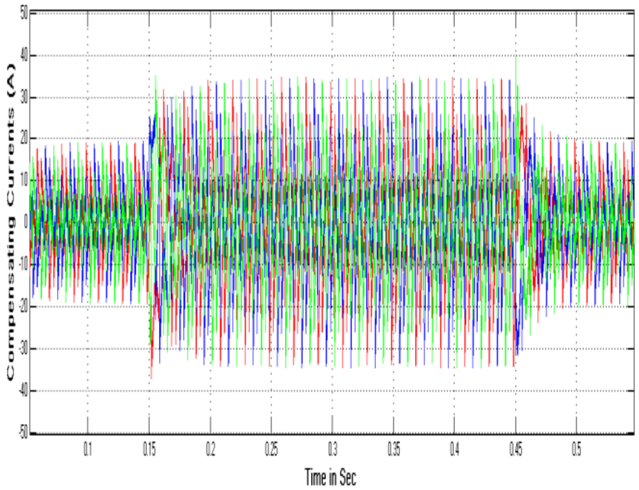

Figure 23: Compensating Currents from DSTATCOM

Figure 23 instances three-phase acclimate signals from DSTATCOM. DSTATCOM accommodate the harmonics and makes source components to be sinusoidal. The loadincreased from extent 0.15 sec to 0.45 sec. During this load development period, reimburse currents also extended. The injected compensating currents around 20A up to 0.15 sec, and the enhanced currents are increased around 30A from 0.15 sec to 0.45 sec and settle down to 20A. The compensating currents are raised in the range 0.15 sec to 0.45 sec to meet the variable load requirements.

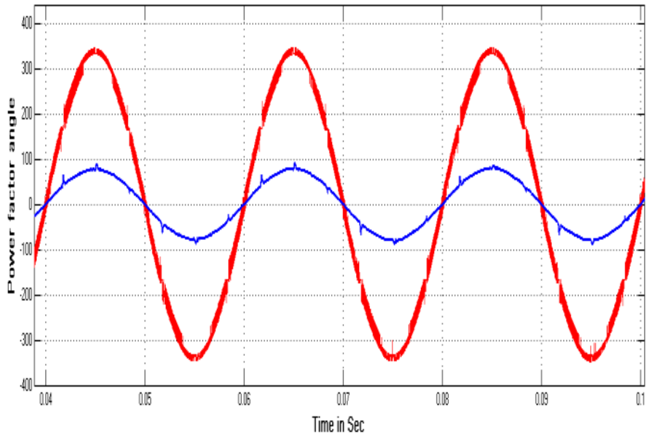

Figure 24: Source Power factor angle

Figure 24 manifest the source power factor of the power system with DSTATCOM connected. The power factor angle difference between the source voltage and source current is more approximate to zero as source current not distorted. Hence source power factor is maintained nearer unity in the case power system with DSTATCOM connected and with variable load condition. The current signal gained for the most graphic illustration.

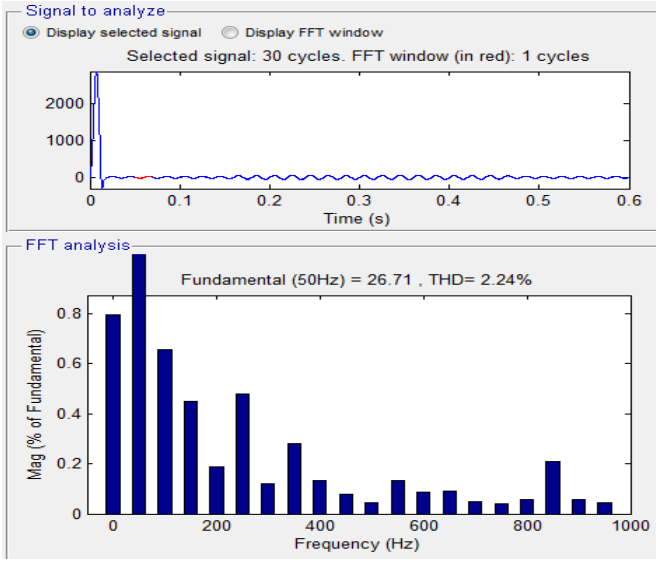

Figure 25: Source current THD

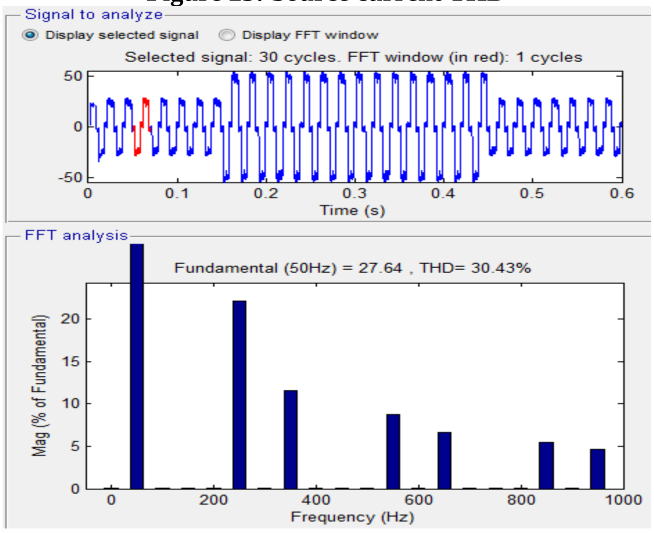

Figure 26: Load current THD

Figure 25 demonstrates the FFT window of harmonic distortion analysis in source current. FFT analysis graphic the source current is deformation by 2.24%. Source current departure is within standard limits. The attachment of DSTATCOM in the distributionsystem with variable load condition, the Total Harmonic Distortion (THD) values maintained within the specified limits. Figure 26 describes the FFT window of harmonic distortion analysis in load current. FFT analysis exemplifies 30.43% alters the load current.

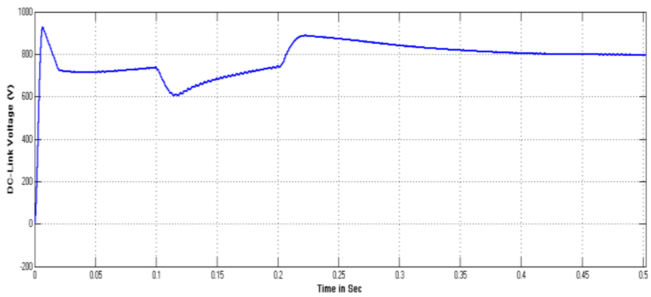

Figure 27: DC-Link voltage

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Figure 27 proves the DC-Link voltage across DSTATCOM with power system operating under variable load condition. The load is diverse at 0.15 sec to 0.45 sec, and DC-Link voltage drives DSTATCOM accordingly to support DSTATCOM generating compensating signals. After the loadrestored at 0.45 sec, the DC-link voltage settled to 800V.

D. Test Case 4: Power system with DSTATCOM and Linear loads

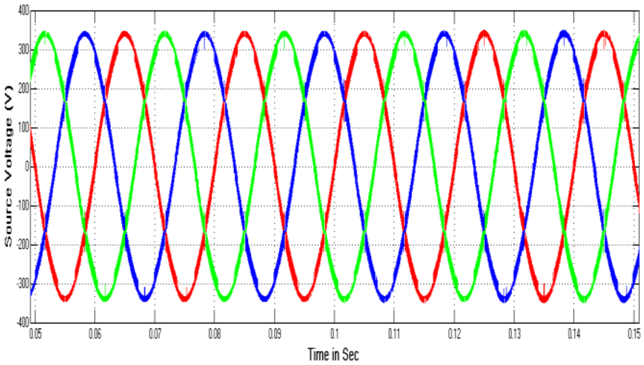

Figure 28. Source Voltage

The three-phase source RMS voltages are presented in figure 28. The source voltages are with constant peak and are sinusoidal waveshape. The presence of DSTATCOM brings the source voltages are in the acceptable range and eliminates the harmonics present in the system.

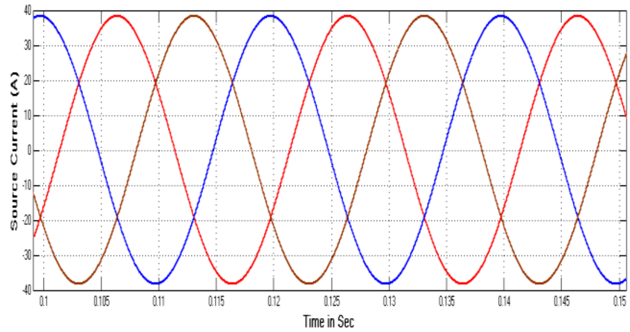

Figure 29. Source Currents

The three-phase source currents are illustrated in figure 29. The considered loads are of linear loads,so there are no nonlinearities present in the system. The SCRC algorithm based DSTATCOM also compensates the linear loads.

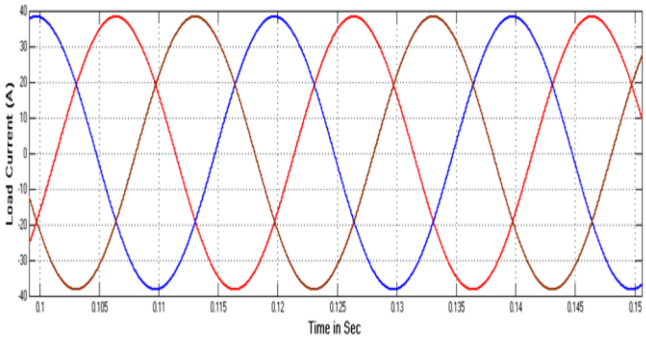

Figure 30. Load Currents

Figure 30 layouts the three-phase load currents present in the linear loads. The addition of DSTATCOM brings the load currents are in sinusoidal in a wave shape. The load draws the nearly 40A from the source side.

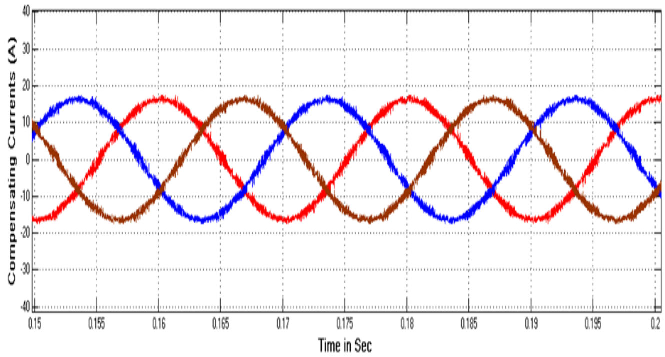

Figure 31. Compensating Currents from DSTATCOM

Figure 31 points the compensating currents produced by the DSTATCOM. The injected currents are of sinusoidal waveshape and added around 18A compensating currents to the distribution to improve the power quality.

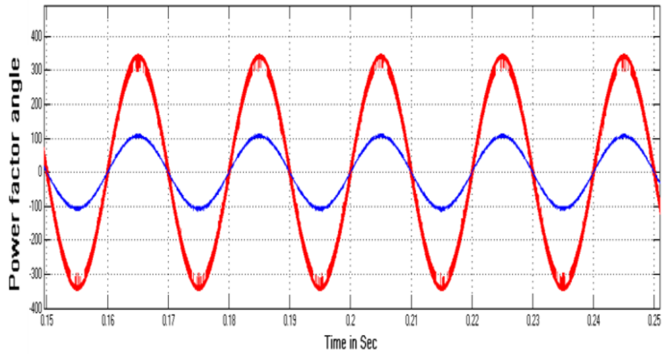

Figure 32. Source Power Factor angle

Figure 32 illustrates the source power factor angle of the system with DSTATCOM connected in the distribution system. The power factor angle variance between the source voltage and source current is approximately estimated to zero and source current is not distorted. Soenclosure of DSTATCOM in the distributionsystem with linear loads maintaina near unity power factor.

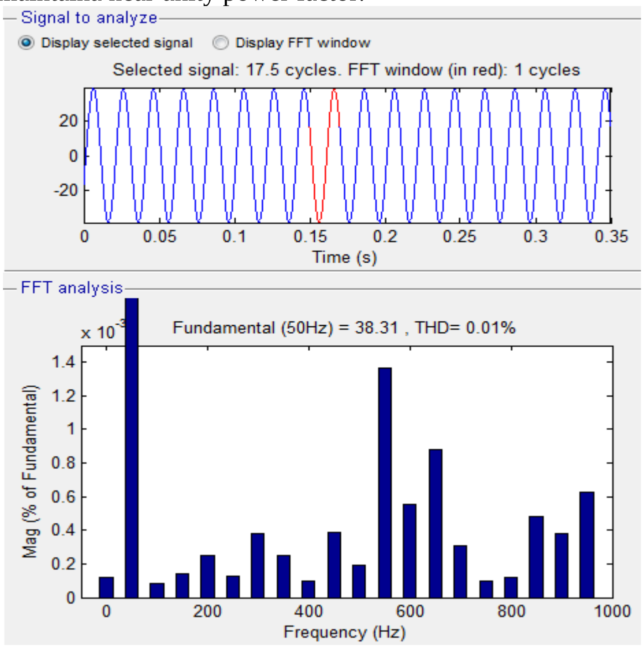

Figure 33. Source current THD

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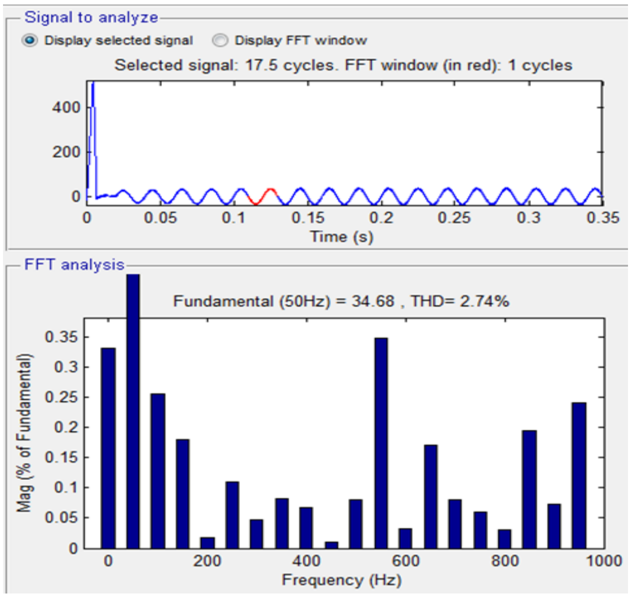

Figure 34. Load current THD

Figure 33 shows the FFT window of harmonic distortion analysis in source current. FFT window analysis proves the source current is distortion by 0.01 %. Source current adjustment is within limits. The connection of DSTATCOM in the distributionsystem with a linear load condition, the Total Harmonic Distortion (THD) values maintained within the identified limits. Figure 34 illustrates the FFT window of harmonic distortion analysis in load current. FFT investigation the load current is altered by 2.74%.

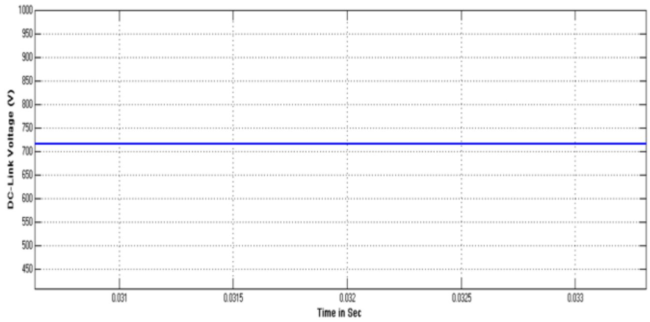

Figure 35. DC-link Voltage

Figure 35 proves that DC-Link voltage waveform of DSTATCOM. DC-Link voltage is constant with the 720V magnitude.

S.no	Test Case	THD	
		IEEE Std 519-2014 [18], [1]	Source Current
1	Without DSTATCOM	-	29.13 %
2	With DSTATCOM_ Fixed Loads	5%	3.93 %
3	With DSTATCOM_ Variable Loads	5%	2.24 %
4	With DSTATCOM_ Linear Loads	5%	0.01%

Table II: Total Harmonic Distortion (THD) Comparison table

Table II clarifies the harmonic distortion analysis with different conditions of the power system. With DSTATCOM harmonic malformation is maintained within competitive values and the suggested control works well for different power system conditions with DSTATCOM.

V. CONCLUSION

In this paper, a simplified control strategy to produce control signals to DSTATCOM is proposed. The source currents are taken as reference currents to generate gate pulses using Source Current Reference Control (SCRC) algorithm. By using this proposed technique, a DSTATCOM is designed and applied for the power quality enhancement of a distribution system consisting of fixed, variable (generally total load will be changing depending upon the requirement of the consumer, under these conditions also these method controls power quality) and linear loads in the power distribution system. The Total Harmonic Distortion (THD) analysis of the test system is performed with fixed, variable and linear loads in the power distribution system. The results indicate a significant improvement concerning the Total Harmonic Distortion (THD), which is confirmed after comparing these results with IEEE Std 519-2014 values. By use of this SCRC algorithm, the source side and load side voltages and current values are mentionedwithin limits.The suggested SCRC algorithm technique can be applied to different other FACTS devices for enhancing power quality. The proposed control strategy withstands to maintain the constant DC link voltage. An SCRC algorithm with DSTATCOM in power distribution system improves the power factor in the source side because the THD is reduced. The offered SCRC algorithm based DSTATCOM successfully improves the power quality in the distribution system by injecting the compensation currents into the power distribution system.

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