Improving Voltage Profile of Distribution System using DSTATCOM

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***Abstract*—DSTATCOM (Distribution Static Synchronous Compensator) is used for improving Power Quality. This paper presents the improving voltage profile using DSTATCOM for voltage sag mitigation, harmonic distortion and power factor improvement using LCL passive filter with DSTATCOM in distribution system. DSTATCOM injects a current into the system to mitigate the voltage sag. LCL passive filter is connecting with DSTATCOM to improve harmonic distortion and lagging power factor. A new PWM based control scheme is only required for voltage measurement, this model is based on the Voltage Source Converter (VSC) principle. The simulation of control method for DSTATCOM is done in MATLAB SIMULINK R2010b.**

***Index Terms*—DSTATCOM, VSC (Voltage Source Converter), LCL Passive Filter, Total Harmonic Distortion (THD), PWM Controller, Voltage Sag.**

I. INTRODUCTION

Power system is consisting of three levels, Generation – Transmission – Distribution of power. In earlier days Power Transmission has been faced problems like voltage variation during change in load and power transmission limitation because of reactive power unbalances. Load is very dynamic in nature it keeps changing with time and customer which make it even more difficult for forecasting. This leads to a great need of improving power utilization methods now-a-days. Maintaining power system security and reliability in highly complex & interconnected power system is one of the most challenging tasks. To achieve Optimum Power Quality, it needs perfect balance between generated capacity and its demand. Power flow in the transmission line is affected due to under loading and overloading condition, as a result of this problems regarding Voltage profile and Power system stability will increase. Power quality problem is due to nonstandard voltage, current, or frequency that results in a failure of end use equipment. The most common power quality problems are voltage sag, harmonic distortion and low power factor.

Voltage sag is caused by a fault in the utility system, fault within the customer's facility or a large increase of the load current, like starting a motor or transfer energizing. Harmonic current in distribution system can cause harmonic distortion, low power factor and additional losses as well as heating in the electrical equipment. It also can cause vibration and noise in machine.

The IGBT based FACTS devices offer a fast and reliable, and increases power transfer capability control over the transmission parameter like voltage, line impedance, and phase angle between the sending end voltage and receiving end voltage. D-STATCOM is a custom power device its futures like it provides fast response, suitable for dynamic response or voltage regulation, to correct voltage surges or sags caused by reactive power demands. PWM control scheme is implemented for D-STATCOM control at the distribution level which will compensate reactive power and improve voltage profile. A DSTATCOM basically VSC based FACTS controller sharing many similar concept with that of STATCOM used at transmission level. D-STATCOM can be applied on wide range of distribution and transmission voltage, overload capability of this provides reserve energy for transients.

In this paper, the configuration and design of the D-STATCOM, VSC based PWM controller with LCL passive filter are analyzed. It is connected in shunt or parallel to the 11 kv test distribution system. Custom power device D-STATCOM can be effectively utilized to improve the quality of power supplied to the customers. The MATLAB, simlink using Simpower system tool box and to verify the result on the basis of voltage sag, performance under different faults, total harmonic distortion and low power factor.

II. DSTATCOM (DISTRIBUTION STATIC SYNCHRONOUS COMPENSATOR)

The DSTATCOM is a controlled reactive source which includes a two-level voltage source converter, a dc energy storage device, a coupling transformer connected in shunt to the distribution network through coupling transformer. Fig. shows the basic system configuration of DSTATCOM. The VSC converts the dc voltage across the storage device into a three phase output voltages. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. With suitable adjustment of the phase and magnitude of DSTATCOM output voltages allows effective control of active and reactive power exchange between the DSTATCOM and the ac system. Here the inductance L and resistance R which represents the equivalent circuit element of the step-down transformer and the inverter is the main component of DSTATCOM. The three basic operation mode of D-STATCOM is that output current I_{out} which various depending upon inverter voltage V_i. If V_i is equal to system voltage V_s, the reactive is zero and the DSTATCOM does not generate and absorb reactive power. When V_i is greater than

Vs, the DSTATCOM shows an inductive reactance connected at its terminal. The current *I* flows through the transformer reactance from the DSTATCOM to the ac system and the device generates capacitive power. If *Vs* is greater than *Vi*, the DSTACOM shows the system as a capacitive reactance. The current flows from the ac system to the DSTATCOM and the device absorbing inductive reactive power.

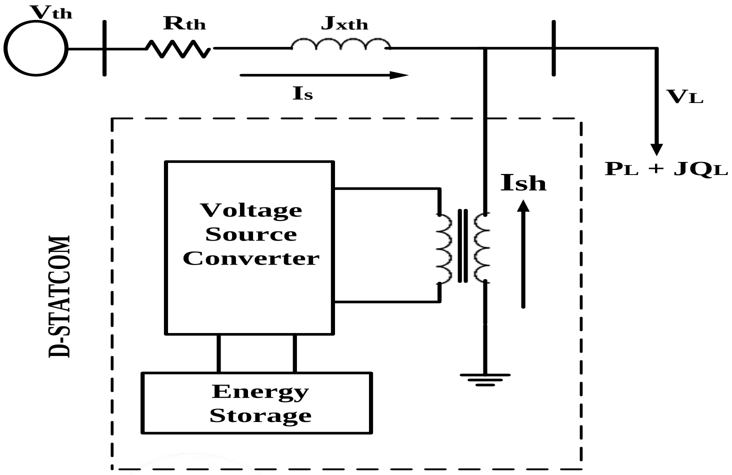

Fig. 2.1 Schematic Diagram of DSTATCOM

The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for three quite distinct purposes:[5]

1. Voltage regulation and compensation of reactive power
2. Correction of power factor
3. Elimination of current harmonics

The shunt injected current Ish can be written as,

$$Ish = IL - Is = IL - \left(\frac{Vth - VL}{Zth}\right) ------------ (2.1)$$

$$Ish\angle\eta = IL\angle(-\theta) - \left(\frac{Vth}{Zth}\right)\angle(\delta - \beta) + \left(\frac{VL}{Zth}\right)\angle(-\beta) ------ (2.2)$$

The complex power injection of the DSTATCOM can be expressed as,

$$Ssh = VL \bullet I^{*}sh ------------ (2.3)$$

According to above equation the voltage sag is corrected by current Ish which adjusting the voltage drop across the system impedance Zth. The value of the Ish can be controlled by adjusting the output voltage of converter.

III. 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. Voltage source converters are widely used in adjustable speed drive. It can 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 voltage. It also converts the DC voltage across storage devices into a set of three phase AC output voltages.[7] D-STATCOM is also capable to generate or absorbs reactive power. If the output voltage of the VSC is greater than AC bus terminal voltage, D-STATCOM is to be in capacitive mode. There for, it will compensate the reactive power through AC system and regulates missing voltages. The converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage.[4] The solid state electronic converter is switched to get desired output voltage. Normally the VSC is not only used for voltage sag mitigation, but also used for other power quality issues such as flicker, unbalance and harmonics.

IV. CONTROLLER

The main Aim of the control scheme is to maintain constant voltage magnitude at the point where a sensitive load is connected, under system is in disturbances. In this control algorithm the voltage regulation is achieved in a DSTATCOM by the measurement of the RMS voltage at the load point and no requirements of reactive power measurements. Here the sinusoidal PWM technique is used for the VSC switching strategy as sine PWM techniques offers simplicity and good response compare to other scheme.

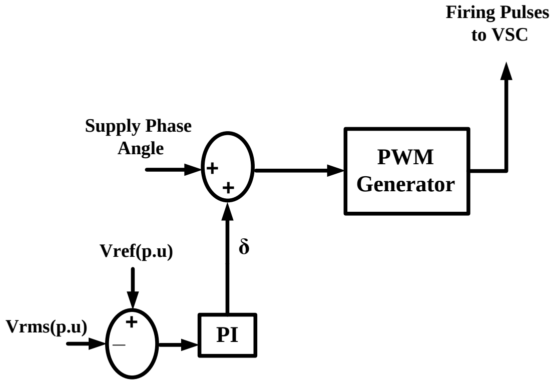

Fig. 4.1 PI Controller

In fig. 4.1 shows the input of the controller is an error signal which is obtained from the reference voltage and the value RMS of the terminal voltage measured. Now Proportional-Integral (PI) controller will process this error signal and then the output is the angle δ, which is provides to the PWM signal generator. In this case converter is exchange active and reactive power exchange with the network simultaneously. Now error signal is obtained by comparing the reference voltage with the RMS voltage measured at the load point. The error signal is processed by PI controller which in return generates the required angle to drive the error to zero, that means the load RMS voltage is brought back to the reference voltage. It is also used to control the flow of reactive power from the DC capacitor storage circuit.[9]

0The sinusoidal signal $V_{control}$ is phase-modulated by means of the angle δ.

i.e.

$VA = \sin(\omega t + \delta)$ ………………(4.1)

$VB = \sin(\omega t + \delta - 120^\circ)$ ………………(4.2)

$VC = \sin(\omega t + \delta + 120^\circ)$ ………………(4.3)

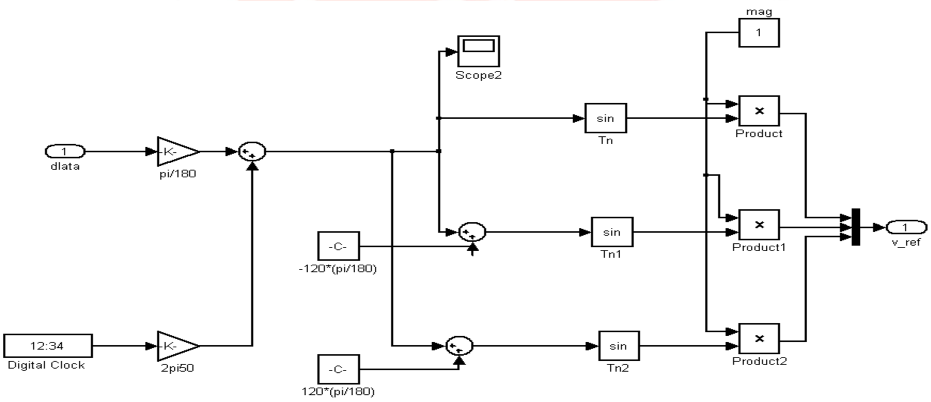

Fig.4.2 Phase-Modulation of the control angle

Now in order to generate the switching signals for the VSC valves, the modulated signal $V_{control}$ is compared with a triangular signal. The main parameters of the sinusoidal PWM scheme are the amplitude modulation index of signal and the frequency index of the triangular signal. The amplitude index is kept fixed at 1 p.u, in order to obtain the highest fundamental voltage component at the controller output.

Where; Vcontrol is the peak amplitude of the control signal; V_{tri} is the peak amplitude of the triangular signal.

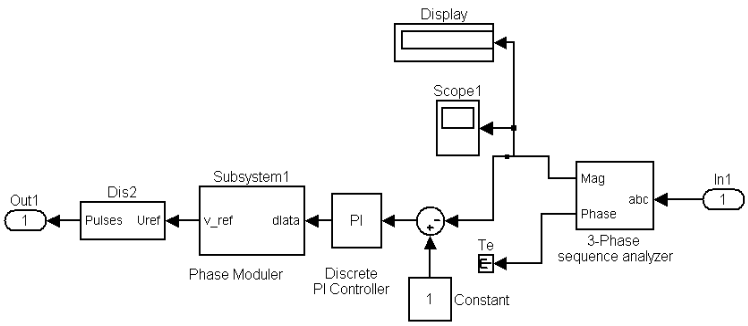

Fig.4.3 Block diagram of controller system

Proportional-integral controller (PI Controller) is a feedback controller which drives the system to be controlled with a weighted sum of the error signal and the integral of that value. 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.

V. ENERGY STORAGE CIRCUIT

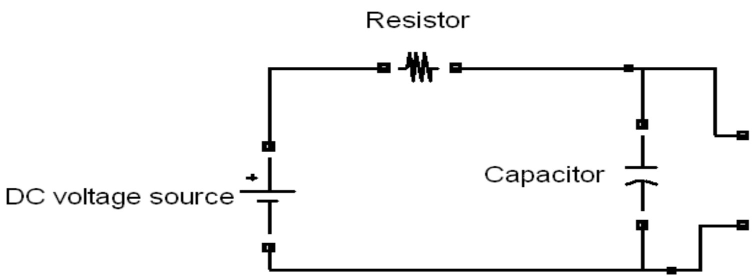

Fig. 5.1 Circuit Diagram of DC Storage

In the system for providing DC supply, then DC source is connected in parallel with the DC capacitor. It carries the input ripple current of the converter and it is the main reactive energy storage element. This DC capacitor could be charged by a battery source or could be recharged by the converter itself.

VI. LCL PASSIVE FILTER

LCL filters are very effectively use for reduction of harmonic distortion. The main drawback is that the LCL- filter will introduce a resonance frequency into the system. Harmonic components in the output voltage can lead to resonance oscillations and instability problems unless they are properly handled. One way of reducing the resonance current is by adding a passive damping circuit can be purely resistive, causing relative high losses, or a more complex solution consisting of a combination of resistors, capacitors and inductors.[7]

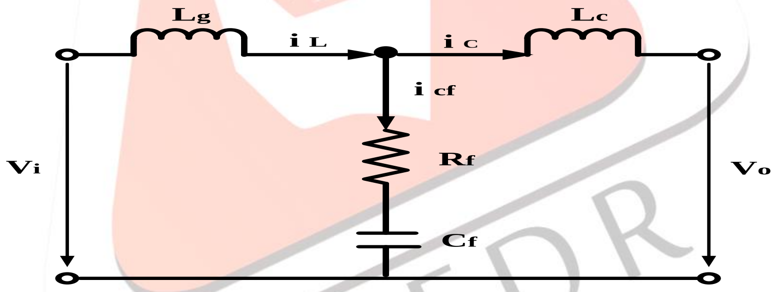

Fig. 6.1 Circuit diagram of LCL Passive filter

To design it following equation is required,

$$L_g = \frac{E_n}{2\sqrt{6 i_{ripm} f_{sw}}} \text{-------------}(6.1)$$

$$L_c = \frac{L_g}{2} \text{---------------}(6.2)$$

$$C_f = \frac{L + L_g}{L L_g (2\pi f_{res})^2} \text{-------------}(6.3)$$

Where; E_n = RMS value of grid voltage, L_g = Grid side filter inductance, L_c = Converter side filter inductance, C_f = Filter capacitance, i_{ripm} =Peak value fundamental harmonic current, f_{sw} = Switching frequency, f_{res} = Resonance frequency.

VII. TOTAL HARMONIC DISTORTION (THD)

Frequency is said as the alternating behavior of the parameters like current, voltage, flux etc with respect to time (in India fundamental frequency is 50 Hz). Harmonic is defined as the undesired multipliers of the fundamental frequency i.e. 3rd harmonic means 3 times the fundamental frequency (3 x 50 = 150 Hz). Total Harmonic Distortion (THD) is defined as the RMS value of the waveform after removing the fundamental part, the measured part is the distorted leftover and also undesired (which is said as THD).The use of non-linear load such as Variable Speed Drives (VSD), Compact Fluorescent Lamp (CFL), SMPS etc, draws high current having harmonic components which leads to Distortion in waveform of the Fundamental frequency. The selection of the range for the rating most of the Electrical equipment is based on the ability of heat dissipation to avoid the overheating of bus bars, circuit breakers, neutral conductors, transformer windings or generator alternators. In general, the less distorted frequency gives the more desired operation**.**

VIII. SIMULATION AND RESULTS

Here fig.8.1 shows the test system implemented in MATLAB SIMULINK. The test system consists of a 230 kv, 50 Hz transmission system which is now fed into the primary side of transformer connected in Y/Y/Y, 230/11/11 kv. A two-level DSTATCOM is connected to the 11 kv tertiary winding to provide instantaneous voltage support at the load point. A 750μF capacitor on dc side provides the DSTATCOM energy storage capability. Simulation were carried out with and without DSTATCOM connected to the system, to show the effectiveness of this controller. The DSTATCOM model which is connected in the transmission system for voltage regulation and it shows an VSC with its PWM controller.

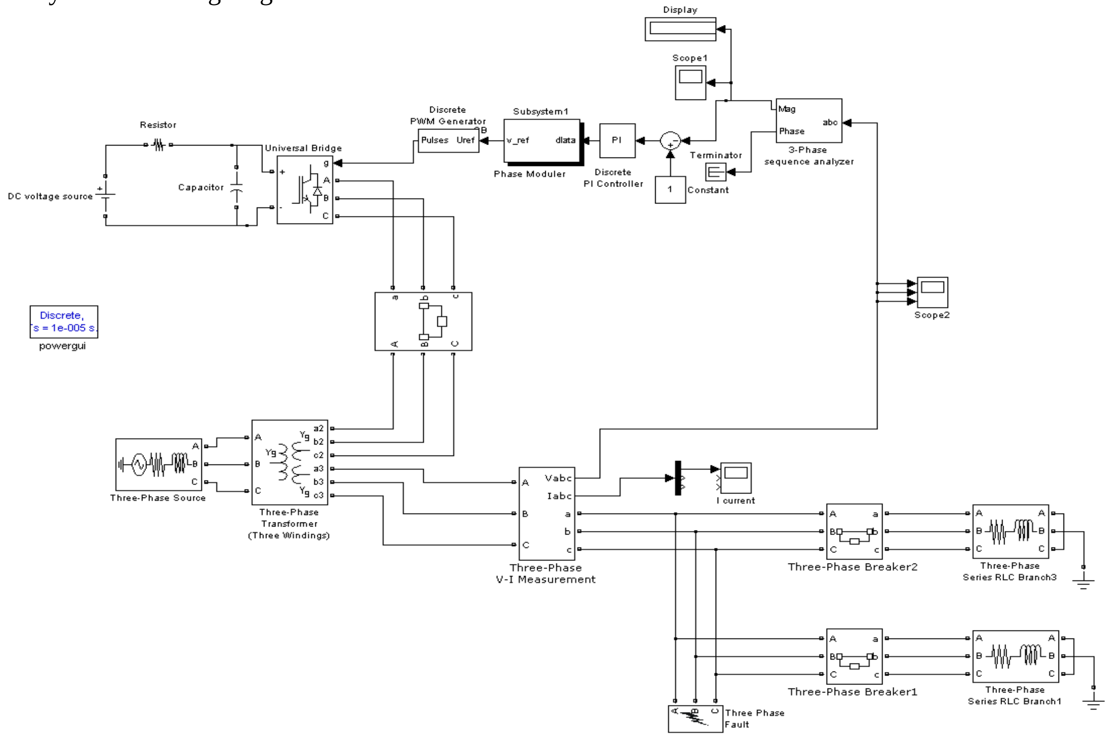

Fig.8.1 Simulation Model of DSTATCOM test system

To create distortion and unbalance in distribution system, injected different types of faults such as Three Phase to Ground (TPG), Double Line to Ground (DLG), Line to Line (LL), and Single Line to Ground (SLG).

(A) Results of Sag without DSTATCOM

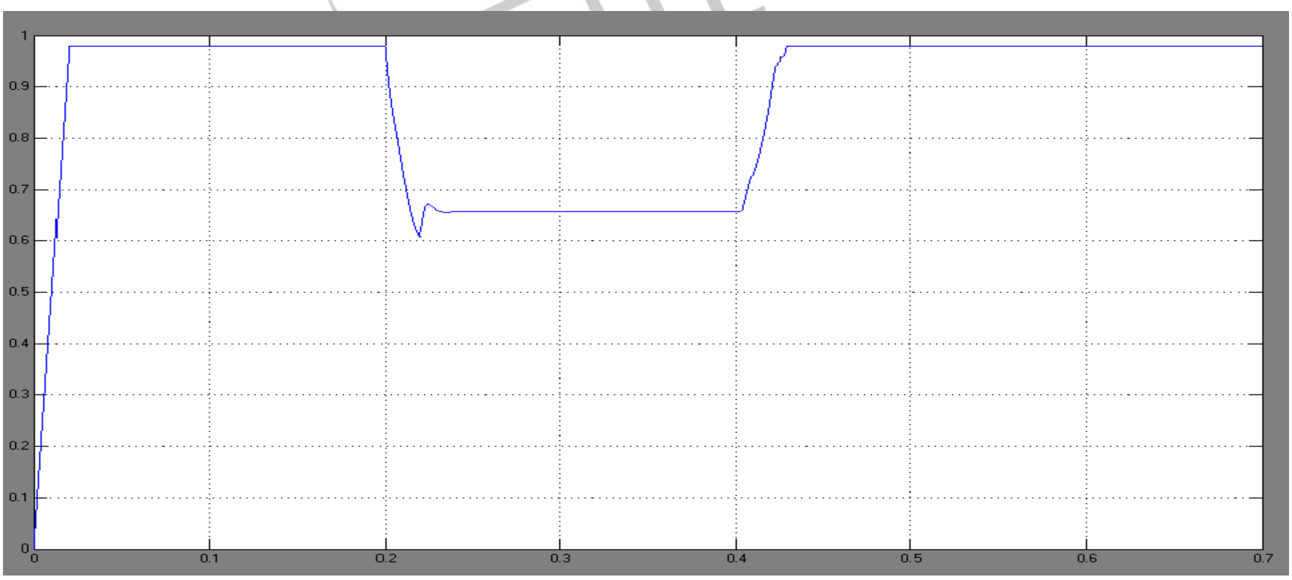

Fig. 8.2(a) Voltage sag at load point is 0.6578 p.u using TPG fault

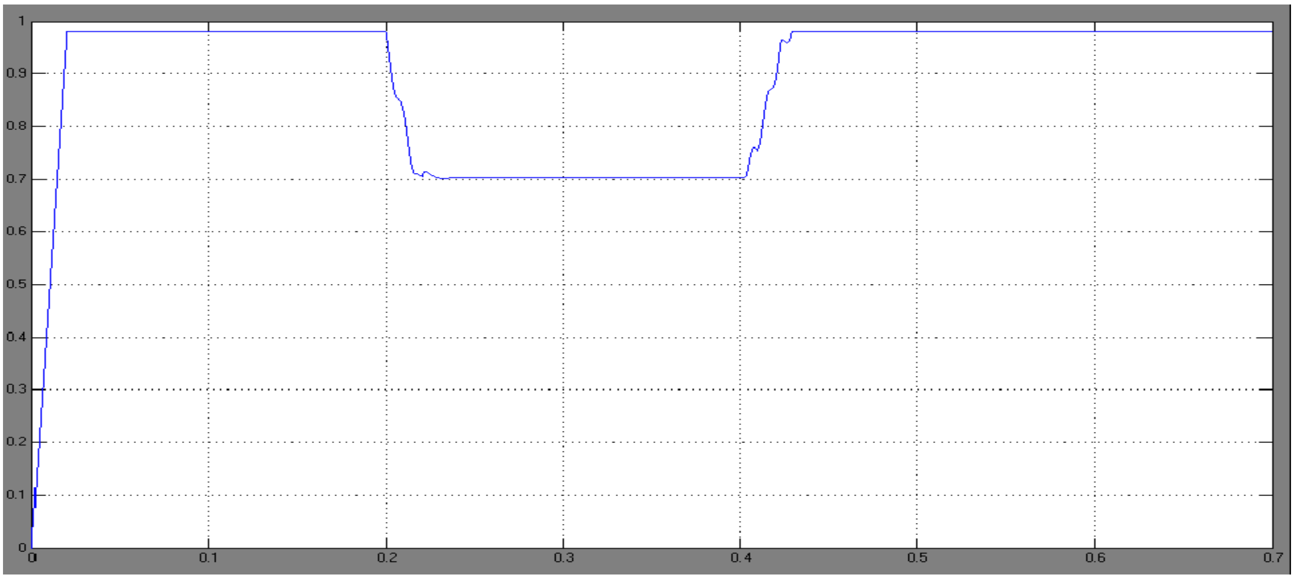

Fig. 8.2(b) Voltage sag at load point is 0.7024 p.u using DLG fault

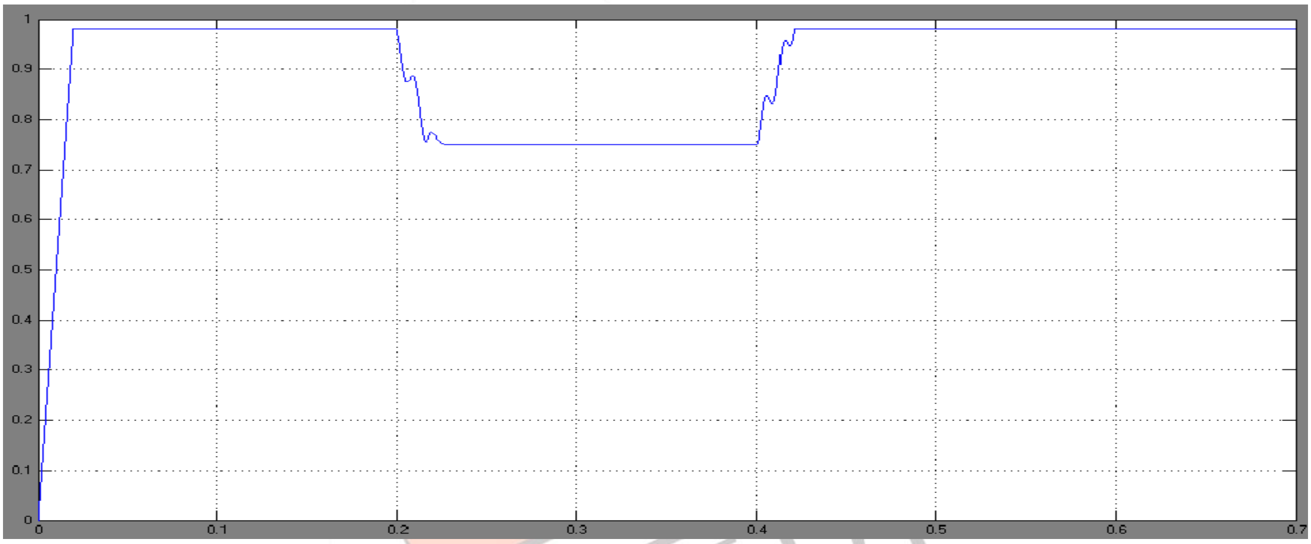

Fig. 8.2 (c) voltage sag at load point is 0.7518 p.u using LL fault

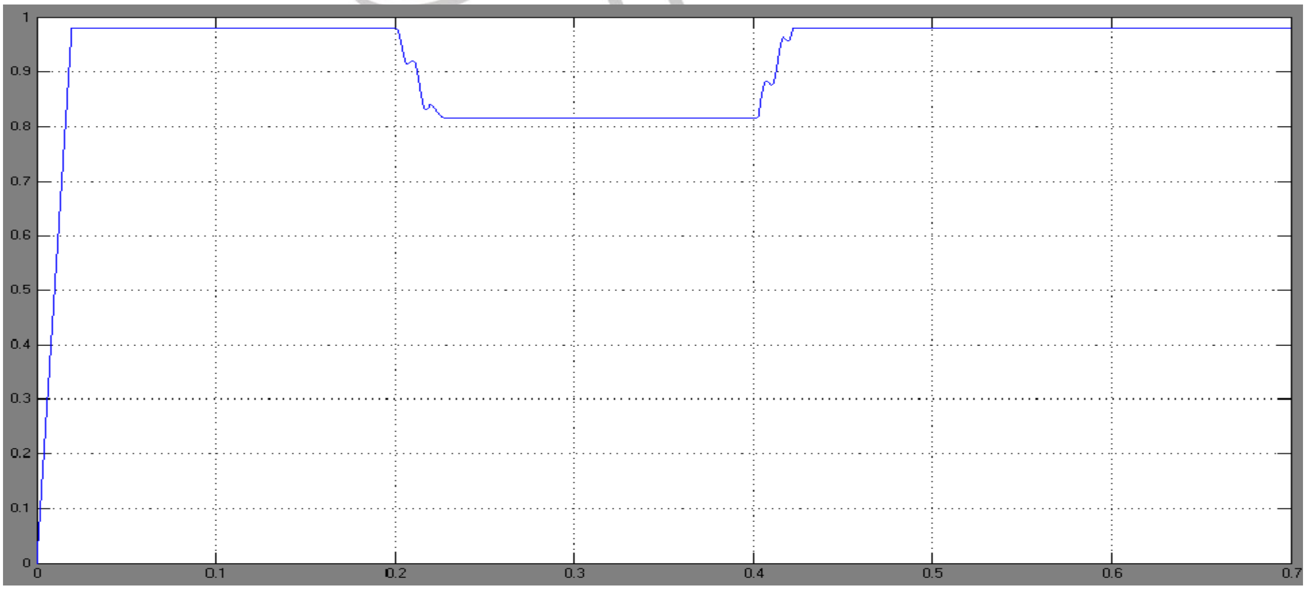

Fig. 8.2(d) voltage sag at load point is 0.8173 p.u using SLG fault

Figure 8.2(a) to 8.2(d) shows the simulation result of voltage sags of the test system for different faults without DSTATCOM with fault resistance $R_f = 0.66\Omega$.

TABLE 8.1 RESULTS OF VOLTAGE SAGS FOR DIFFERENT TYPE OF FAULTS

FAULT RESISTANCE $R_f\Omega$	VOLTAGE SAG FOR TPG FAULT	VOLTAGE SAG FOR DLG FAULT	VOLTAGE SAG FOR LL FAULT	VOLTAGE SAG FOR SLG FAULT
0.66	0.6578	0.7024	0.7518	0.8173
0.76	0.7069	0.7435	0.7846	0.8397
0.86	0.7469	0.7774	0.8119	0.8586

Table 8.1 shows the overall faults of voltage sag in p.u for different types of fault. From the table it can be observed that when fault resistance is increase, the voltage sag also will increase.

(B) Results of Sag with DSTATCOM

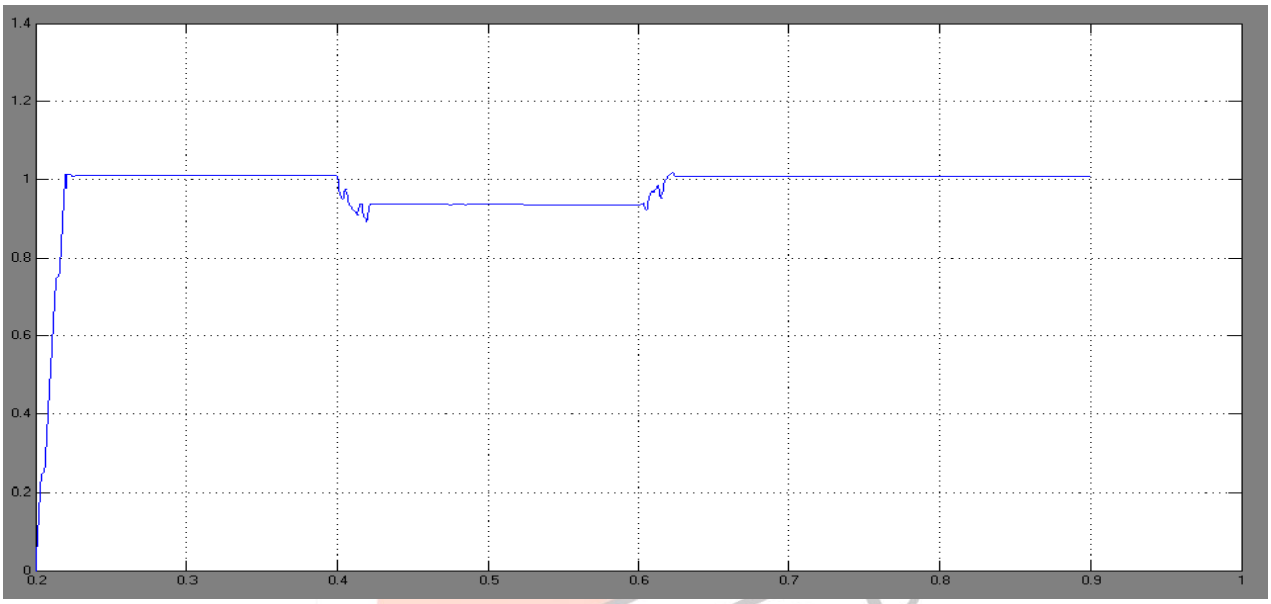

Fig. 8.3(a) Voltage sag at load point is 0.9344 p.u using TPG fault

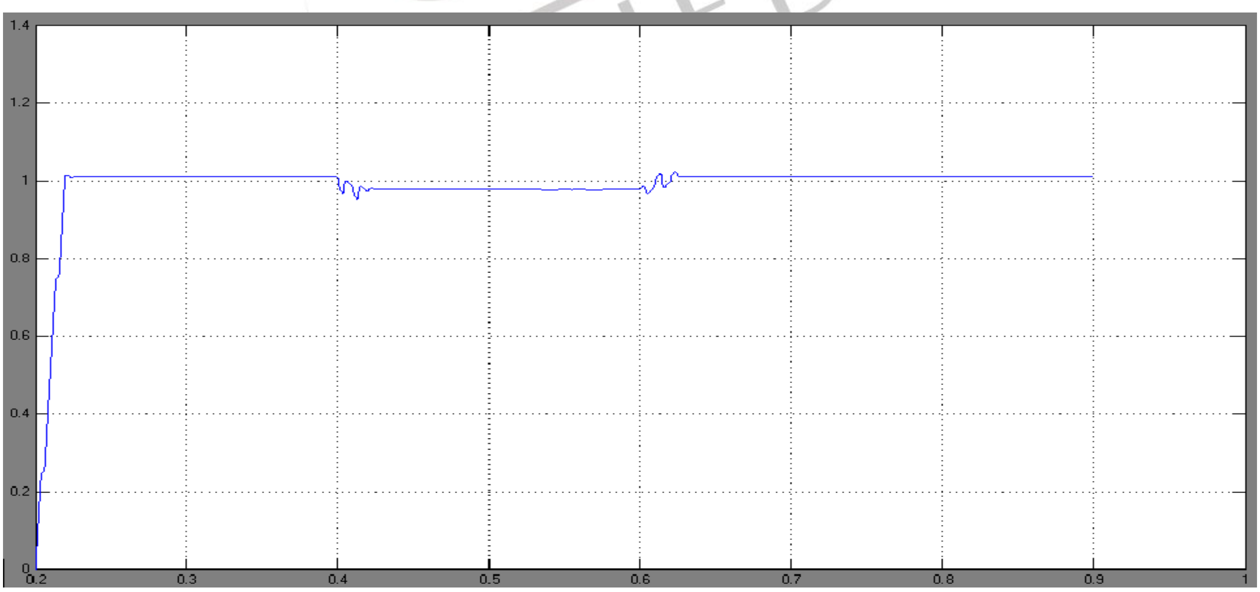

Fig 8.3(b) Voltage sag at load point is 0.9760 p.u using DLG fault

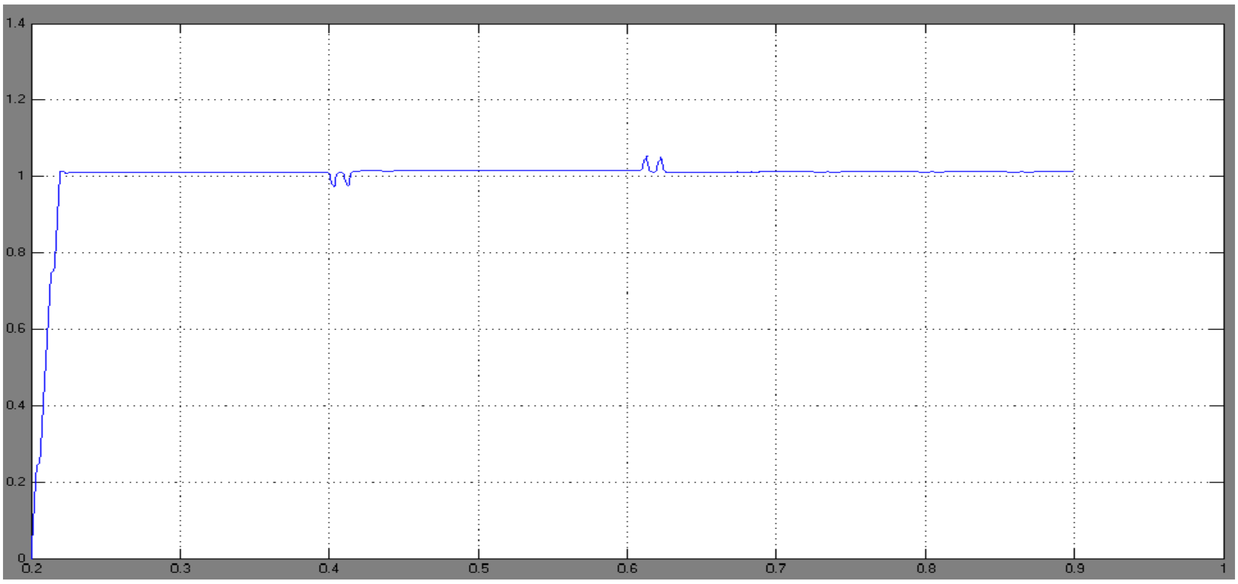

Fig. 8.3(c) Voltage sag at load point is 1.014 p.u using LL fault

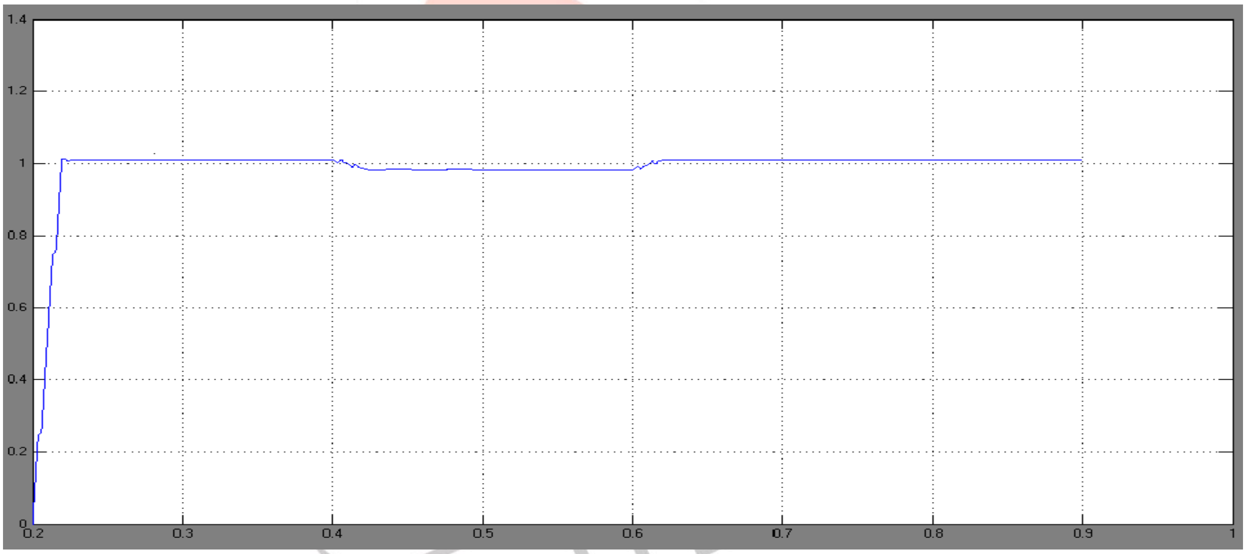

Fig. 8.3(d) Voltage sag at load point is 0.9825p.u using SLG fault

Figure 8.3(a) to 8.3(d) shows the simulation results of voltage sags of the different fault with DSTATCOM with fault resistance R_f = 0.66Ω.

TABLE 8.2 RESULTS OF VOLTAGE SAG FOR DIFFERENT TYPES OF FAULTS

FAULT RESISTANCE R_fΩ	**VOLTAGE SAG FOR TPG FAULT**	**VOLTAGE SAG FOR DLG FAULT**	**VOLTAGE SAG FOR LL FAULT**	**VOLTAGE SAG FOR SLG FAULT**
0.66	0.9344	0.9760	1.0140	0.9825
0.76	0.9490	0.9843	1.0168	0.9876
0.86	0.9576	0.9890	1.0180	0.9912

Table 8.2 shows the overall results of voltage sags in p.u with different types of fault. It can be observed that when DSTATCOM is connected in the system, voltage sag improved and the value of voltage sag is creates in between 0.9 to 1.01.

Table 8.3 Results for Different Types of Fault with and without DSTATCOM when $R_{F} = 0.66\Omega$

TYPES OF FAULT	WITHOUT DSTATCOM (p.u)	WITH DSTATCOM (p.u)	PERSENTAGE OF IMPROVEMENT (%)
TPG	0.6578	0.9344	27.66%
DLG	0.7024	0.9760	27.36%
LL	0.7518	1.0140	26.22%
SLG	0.8173	0.9825	16.52%

From table 8.3 shows the voltage sag improved in percentage for different types of fault with and without insert DSTATCOM in the system, it can be seen that with DSTATCOM the voltage sags improved close to 1.0 p.u.

Here in distribution system, the voltage regulation is achieved in DSTATCOM by using sinusoidal PWM control techniques but one major drawback is that the current harmonics are produced therefore to mitigate harmonics LCL passive filter used in the system.

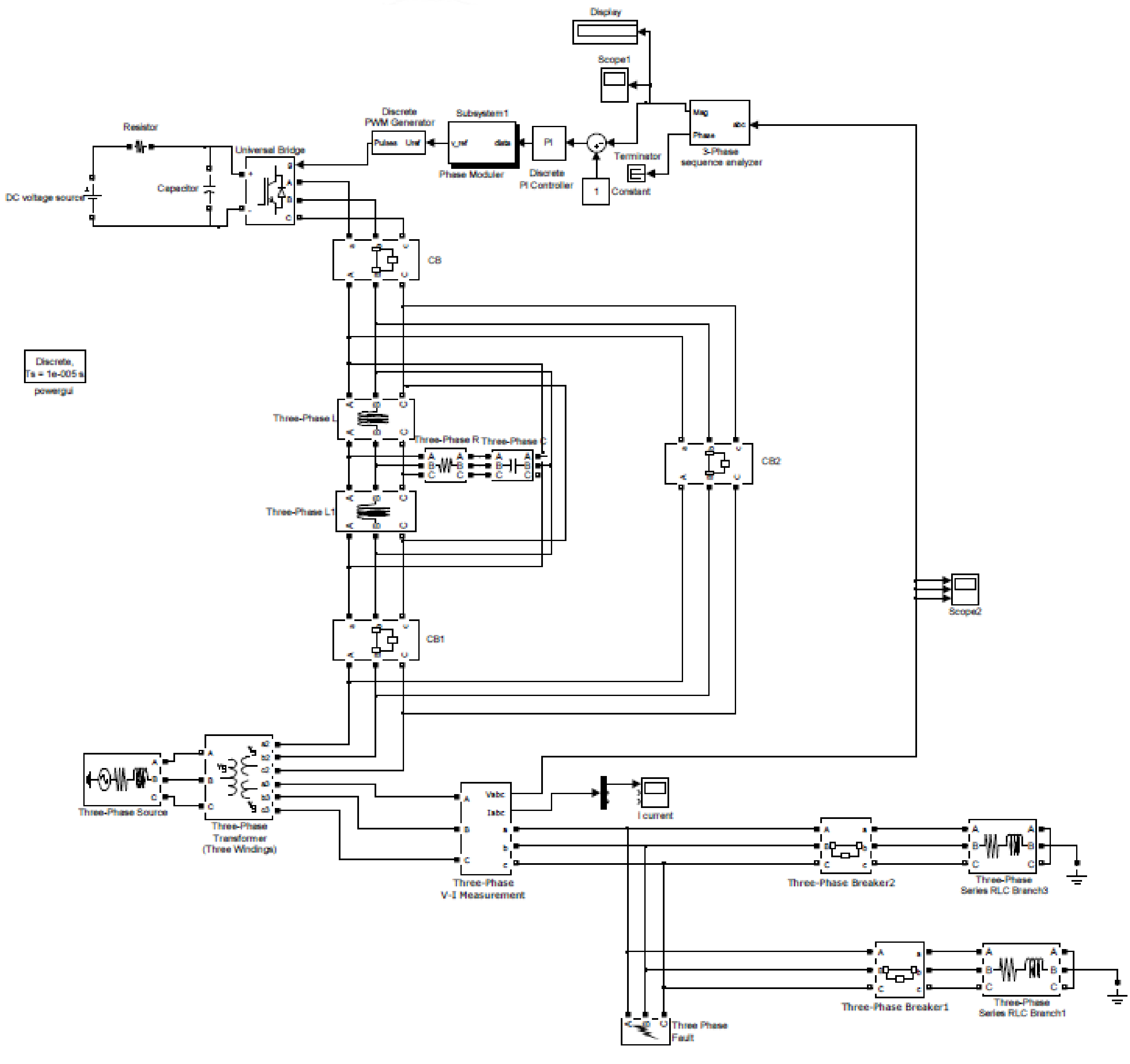

Fig. 8.4 Test system of DSTATCOM with LCL passive filter

(C) DSTATCOM without LCL passive filter

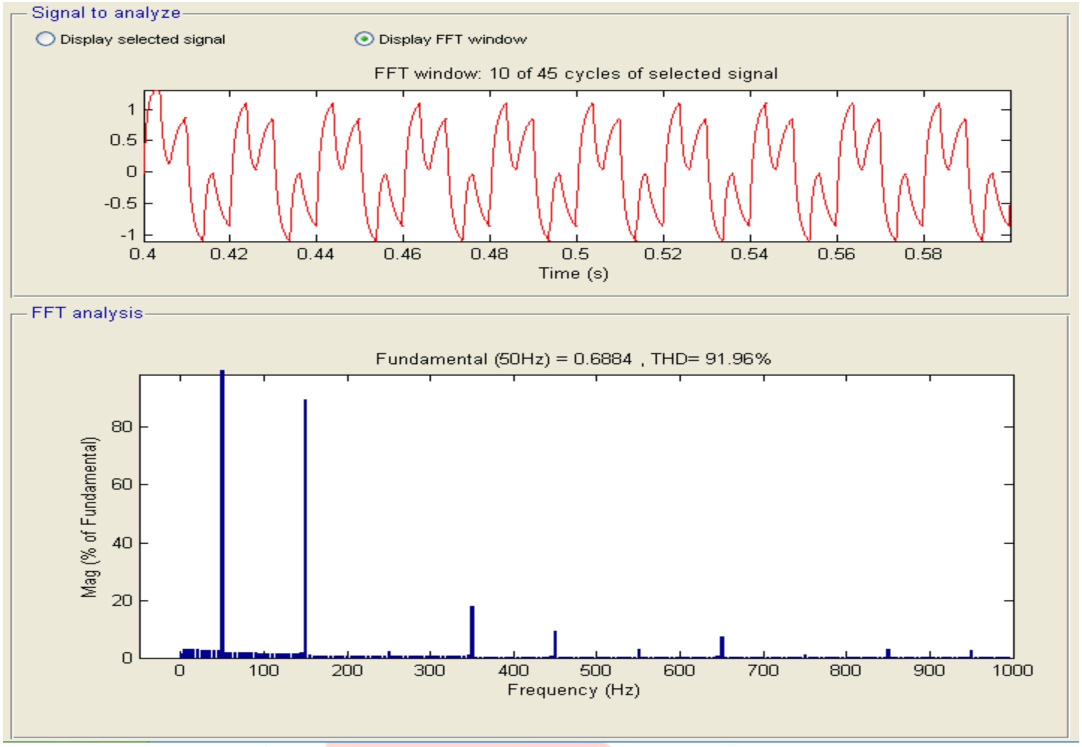

Fig. 8.5 Waveform of distortion output current without LCL passive filter and harmonic spectrum

Figure 8.5 shows the waveform of distortion output current and harmonic spectrum. The percentage of THD shows that it is not within the IEEE STD 519-1992 and percentage of power factor is low. THD produced in system without LCL passive filter is 91.96%.

(D) DSTATCOM with LCL passive filter

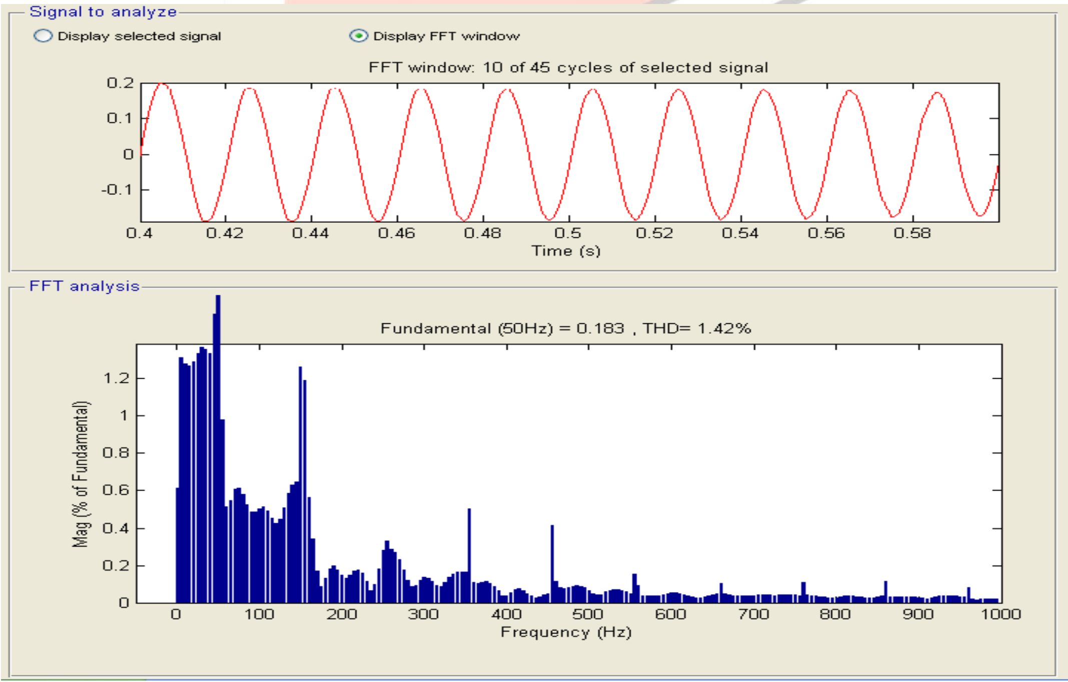

Fig. 8.6 Waveform of output current with LCL passive filter and harmonic spectrum

Figure 8.6 shows the waveform of output current and harmonic spectrum. It is sinusoidal with LCL passive filter was connected to the DSTATCOM and the percentage of THD that is reduced to the IEEE STD 519-1992 and also increase the power factor. THD produced in the system with LCL filter is 1.42.

IX. CONCLUSION

The custom power device DSTATCOM is connected in shunt with distribution system to improve the power quality. The simulation result shows that the voltage sag can be mitigated by connecting DSTATCOM to the distribution system. PWM control scheme only required for voltage measurement. By adding LCL passive filter with DSTATCOM, the THD is reduced within the IEEE STD 519-1992 and the power factor is also increased near to unity p.f. Thus, this paper can conclude that by adding DSTATCOM with LCL passive filter in system the power quality and voltage profile is improved.

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