

Enhancement of Power Quality in Distribution System Using D-Statcom

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Abstract: This paper presents the enhancement of voltage sags, Harmonic distortion and low power factor using Distribution Static Compensator (D-STATCOM) with LCL Passive Filter in Distribution system. The model is based on the Voltage Source Converter (VSC) principle. The D-STATCOM injects a current into the system to mitigate the voltage sags. LCL Passive Filter Was then added to D-STATCOM to improve harmonic distortion and low power factor. The simulations were performed using MATLAB SIMULINK.

Keywords : DSTATCOM, VSC, DVR, SMES, SC, energy storage systems (BESS), Insulated Gate Bipolar Transistors (IGBT).

I. INTRODUCTION

An increasing demand for high quality, reliable electrical power and increasing number of distorting loads may leads to an increased awareness of power quality both by customers and utilities. The most common power quality problems today are voltage sags, harmonic distortion and low power factor. Voltage sags is a short time (10 ms to 1 minute) event during which a reduction in r.m.s voltage magnitude occur. It is often set only by two parameters, depth/magnitude and duration. The voltage sags magnitude is ranged from 10% to 90% of nominal voltage and with duration from half a cycle to 1 min.

Voltage sags is caused by a fault in the utility system, a fault within the customer's facility or a large increase of the load current, like starting a motor or transformer energizing. Voltage sags are one of the most occurring power quality problems. For an industry voltage sags occur more often and cause severe problems and economical losses.. It can cause vibration and noise in machines and malfunction of the sensitive equipment. The development of power electronics devices such as Flexible AC Transmission System (FACTS) and customs power devices have introduced and emerging branch of technology providing the power system with versatile new control capabilities. There are different ways to enhance power quality problems in transmission and distribution systems. Among these, the D-STATCOM is one of the most effective devices.

In this paper, the configuration and design of the DSTATCOM with LCL Passive Filter are analysed. It is connected in shunt or parallel to the 11 kV test distribution system. It also design to enhance the power quality such as voltage sags, harmonic distortion and low power factor in distribution system.

Previous Work

DISTRIBUTION STATIC COMPENSATOR (DSTATCOM)

A D-STATCOM (Distribution Static Compensator), which is schematically depicted in Figure 1, consists of a two-level Voltage Source Converter (VSC), a dc energy storage device, a

coupling transformer connected in shunt to the distribution network through a coupling transformer. The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the D-STATCOM output voltages allows effective control of active and reactive power exchanges between the D-STATCOM and the ac system. Such configuration allows the device to absorb or generate controllable active and reactive power. The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:

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

Here, such device is employed to provide continuous voltage regulation using an indirectly controlled converter.

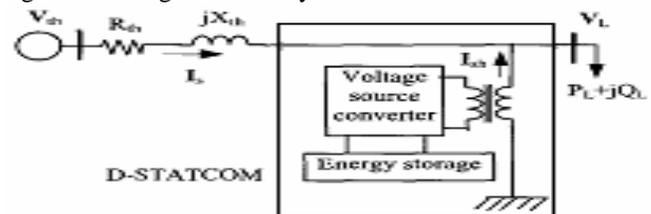


Fig 1. DSTATCOM

The shunt injected current I_{sh} corrects the voltage sag by adjusting the voltage drop across the system impedance Z_{th} . The value of I_{sh} can be controlled by adjusting the output voltage of the converter. The shunt injected current I_{sh} can be written as,

$$I_{sh} = I_L - I_s = I_L - \frac{V_{th} - V_L}{Z_{th}}$$

$$I_{sh} \angle \eta = I_L \angle -\theta - \frac{V_{th}}{Z_{th}} \angle (\delta - \beta) + \frac{V_L}{Z_{th}} \angle -\beta$$

The complex power injection of the D-STATCOM can be expressed as,

$$S_{sh} = V_L I_{sh}^*$$

It may be mentioned that the effectiveness of the D-STATCOM in correcting voltage sag depends on the value of Z_{th} or fault level of the load bus. When the shunt injected current I_{sh} is kept in quadrature with V_L , the desired voltage correction can be achieved without injecting any active power into the system. On the other hand, when the value of I_{sh} is minimized, the same voltage correction can be achieved with minimum apparent power injection into the system. The control scheme for the D-

STATCOM follows the same principle as for DVR. The **TEST SYSTEM**

Figure shows the test system used to carry out the various D-STATCOM simulations

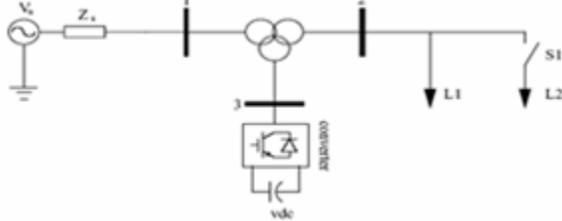


Fig. 2. Single line diagram of the test system for D-STATCOM.

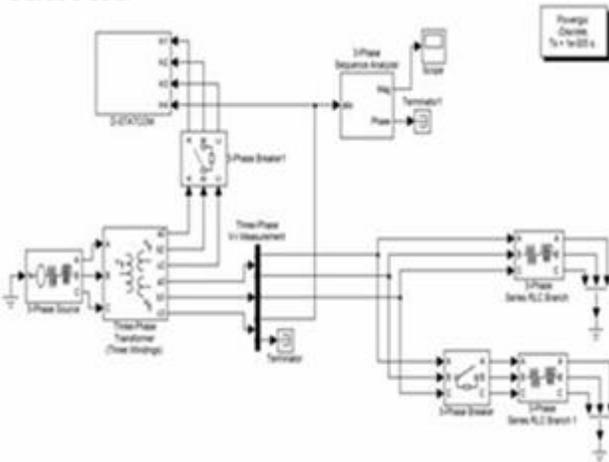


Fig 3. Simulink model of D-STATCOM test system.

MODELING OF THE DSTATCOM/ESS:

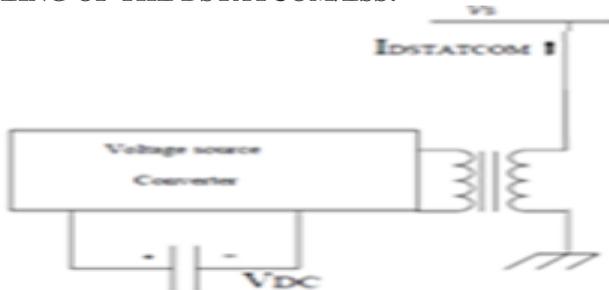


Fig 4 DSTATCOM modeling

A DSTATCOM consists of a three-phase voltage source inverter shunt-connected to the distribution network by means of a coupling transformer, as depicted in Fig 3. Its topology allows the device to generate a set of three almost sinusoidal voltages at the fundamental frequency, with controllable amplitude and phase angle. In general, the DSTATCOM can be utilized for providing voltage regulation, power factor correction, harmonics power custom device leads to a more flexible integrated controller. The ability of the DSTATCOM/ESS of supplying effectively extra active power allows expanding its compensating actions, reducing transmission losses and enhancing the operation of the electric grid. Various types of energy storage technologies can be incorporated into the dc bus of the DSTATCOM, namely superconducting magnetic energy

switching frequency is set at 475 Hz.

storage (SMES), super capacitors (SC), flywheels and battery energy storage systems (BESS), among others. However, lead-acid batteries offer a more economical solution for applications in the distribution level that require small devices for supplying power for short periods of time and intermittently. Moreover, BESS can be directly added to the dc bus of the inverter, thus avoiding the necessity of an extra coupling interface and thus reducing investment costs

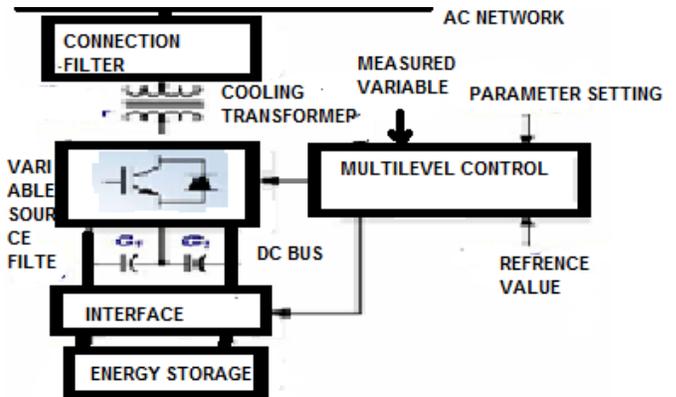


Fig 5 DSTATCOM Model with coupling Transformer

PROPOSED WORK

The integrated DSTATCOM/BESS system proposed in Fig.5 is basically composed of the inverter (indistinctly called converter), the coupling step-up transformer, the line connection filter, the dc bus capacitors, and the array of batteries. Since batteries acts as a stiff dc voltage source for the inverter, the use of a conventional voltage source inverter appears as the most cost-effective solution for this application. The presented VSI corresponds to a dc to ac switching power inverter using Insulated Gate Bipolar Transistors (IGBT). In the distribution voltage level, the switching device is generally the IGBT due to its lower switching losses and reduced size. In addition, the power rating of custom power devices is relatively low. As a result, the output voltage control of the DSTATCOM/BESS can be achieved through pulse width modulation (PWM) by using high-power fast-switched IGBTs. This topology supports the future use of PWM control even for higher power utility applications.

The VSI structure is designed to make use of a three-level pole structure, also called neutral point clamped (NPC), instead of a standard two-level six-pulse inverter structure. This three-level inverter topology generates a more sinusoidal output voltage waveform than conventional structures without increasing the switching frequency. The additional flexibility of a level in the output voltage is used to assist in the output waveform construction. In this way, the harmonic performance of the inverter is improved, also obtaining better efficiency and reliability respect to the conventional two-level inverter. In this work, the use of battery energy storage in an arrangement with neutral point (NP) permits to independently contributing to the charge of the capacitors C1 and C2, and thus to maintain the voltage balance of the dc capacitors without using additional

control techniques. The connection to the utility grid is made by using low pass sine wave filters in order to reduce the perturbation on the distribution system from high-frequency switching harmonics generated by PWM control. The total harmonic distortion (THD) of the output voltage of the inverter combined with a sine wave filter is less than 5 % at full rated unity power factor load. Typically, leakage inductances of the step-up transformer windings are high enough as to build the sine wave filter simply by adding a bank of capacitors in the PCC. In this way, an effective filter is obtained at low costs, permitting to improve the quality of the voltage waveforms introduced by the PWM control to the power utility and thus meeting the requirements of IEEE Standard 519-1992 relative to power quality.

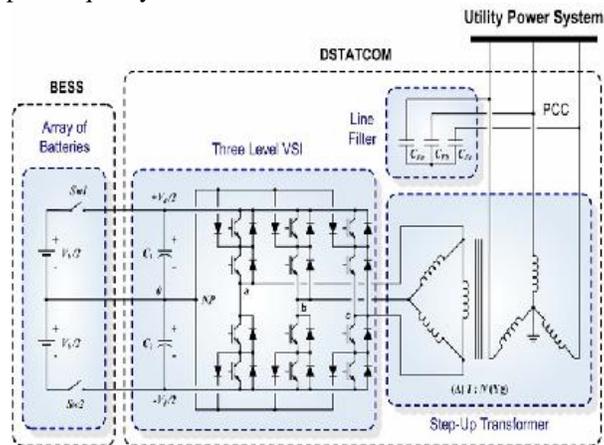


Fig 6 Detailed model of the proposed STATCOM/BESS Basic Configuration and Operation of DSTATCOM:

The D-STATCOM is a three-phase and shunt connected power electronics based device. It is connected near the load at the distribution systems. The major components of a D-STATCOM are shown in Figure 5 . It consists of a dc capacitor, three-phase inverter (IGBT, thyristor) module, ac filter, coupling transformer and a control strategy. The basic electronic block of the D-STATCOM is the voltage-sourced inverter that converts an input dc voltage a three-phase output voltage at fundamental .

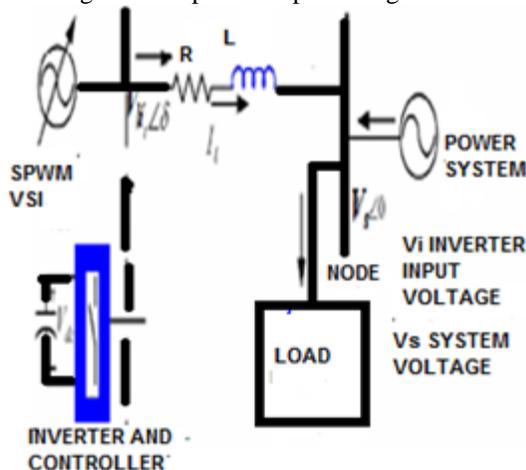


Fig 7 Basic Building Blocks of the D-STATCOM

A DSTACOM is installed in parallel with the unbalance load for on-site load compensation. The reactive power output of the DSTACOM in each phase, which is inductive or capacitive, can be independently controlled by the controller of the DSTACOM for real-time load compensation. The method of symmetrical components is used in the paper for deriving the compensation scheme of the DSTACOM.

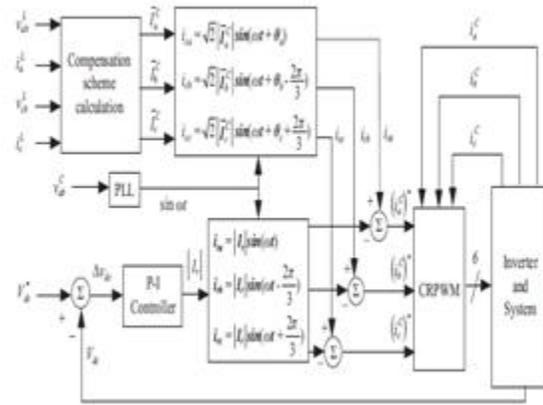


Fig 8 Block diagram of the proposed DSTATCOM controller.

Fig 8 shows the block diagram of the proposed DSTATCOM controller for the DSTATCOM. The DSTATCOM controller calculates the compensation current commands $\bar{I}_a^c, \bar{I}_b^c, \bar{I}_c^c$ by using line-to-line voltage and line current.

CONTROL OF THE DSTATCOM/BESS

The proposed multi-level control scheme for the integrated DSTATCOM/BESS device, consisting of an external, middle and internal level, is based on concepts of instantaneous power on the synchronous-rotating dq reference frame as depicted. Rotating reference frame is used because it offers higher accuracy than stationary frame-based techniques.

A. External Level Control

The proposed external level control scheme is designed for performing three major control objectives, that is the voltage control mode (VCM), which is activated when switch S1 is in position a, the power factor control mode (PFCM), activated in position b, and the active power control mode (APCM) that is always activated.

The standard control loop of the external level consists in controlling the voltage at the PCC of the DSTATCOM/BESS through the modulation of the reactive component of the output current. To this aim, the instantaneous voltage at the PCC is computed by using a synchronous-rotating orthogonal reference frame. This operation permits to design a simpler control system than using abc components, by employing PI compensators.

A voltage regulation droop (or slope) R_d is included in order to allow the terminal voltage of the DSTATCOM/BESS to vary in proportion with the compensating reactive current. In this way, a higher operation stability of the integrated device is obtained

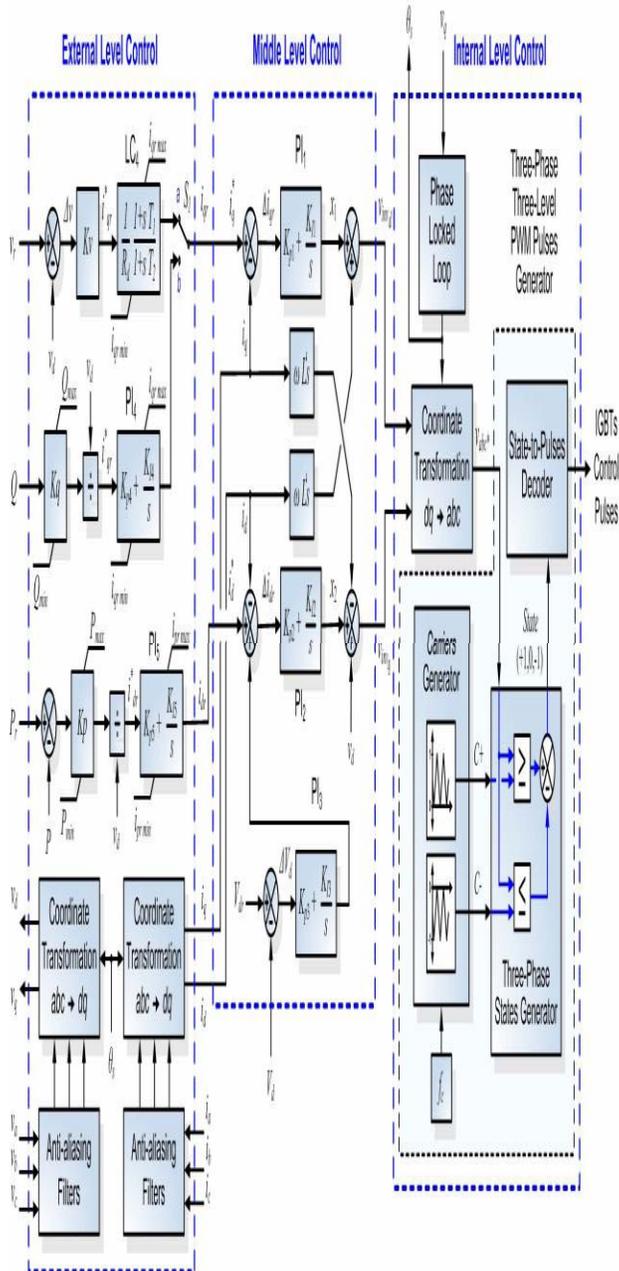


Fig 9 Multi-level control scheme for the DSTATCOM/BESS compensator

B. Middle Level Control

The middle level control makes the expected output to dynamically track the reference values set by the external level. In order to derive the control algorithm for this block, a dynamic model of the integrated DSTATCOM/BESS controller needs to be set up. For this purpose, a simplified scheme of the DSTATCOM/BESS equivalent circuit is used, that is depicted in Fig. 9. The DSTATCOM is considered as a voltage source that is shunt-connected to the network through the inductance L_s , accounting for the equivalent leakage of the step-up coupling transformer and the series resistance R_s , representing the transformers winding resistance and VSI semiconductors

conduction losses. In the dc side, the equivalent capacitance of the two dc bus capacitors is described by $C_d/2$ whereas the switching losses of the VSI and power loss in the capacitors are considered by R_p . The BESS is represented by an ideal dc voltage source V_b , and a series resistance R_b , accounting for the battery internal resistance. The self-discharge and leakage as well as the capacity of batteries are represented by a parallel combination of a resistance and a capacitor. Both values are included into R_{pand} and $C_d/2$, respectively. The dynamics equations governing the instantaneous values of the three-phase output voltages in the ac side of the DSTATCOM and the current exchanged with the utility grid are given by (1) and (2).

$$\begin{bmatrix} v_{inv_a} \\ v_{inv_b} \\ v_{inv_c} \end{bmatrix} - \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = (R_s + sL_s) \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix},$$

where:

$$s = \frac{d}{dt}, R_s = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix}, L_s = \begin{bmatrix} L_s & M & M \\ M & L_s & M \\ M & M & L_s \end{bmatrix}$$

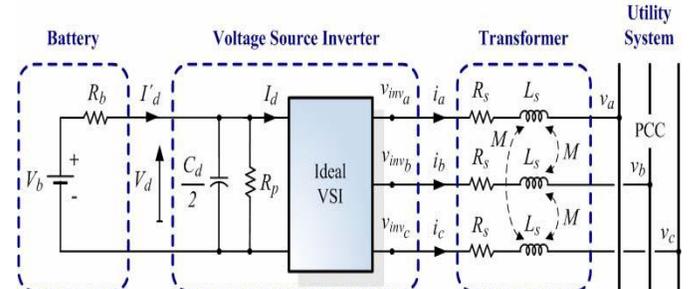


Fig 10 Simplified scheme of the DSTATCOM integrated with BESS

C. Internal Level Control:

This level is mainly composed of a line synchronization module and a three-phase three-level PWM firing pulses generator for the DSTATCOM VSI. The line synchronization module consists mainly of a phase locked loop (PLL). This circuit is a feedback control system used to automatically synchronize the DSTATCOM/BESS device switching pulses; through the phase $\square S$ of the inverse coordinate transformation from dq to abc components, with the positive sequence components of the ac voltage vector at the PCC (v_q). The design of the PLL is based on concepts of instantaneous power theory in the dq reference frame. Coordinate transformations from abc to dq components in the voltage and current measurement system are also synchronized through the PLL. The expected sinusoidal-based output voltage waveform V_{abc}^* of the DSTACOM/BESS, which is set by the middle level control, is compared to two positive and negative triangular signals generated by the carriers generator for producing three state PWM vectors (1, 0, -1). These states are decoded by the states-to-pulses decoder via a look-up-table that relates each state with the corresponding firing pulse for each IGBT of the four ones in each leg of the three-phase three-level VSI.

MODELLING OF CASE STUDY

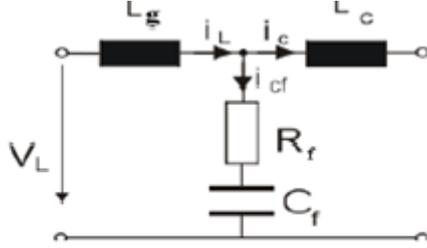


Fig 1 Circuit Diagram for single phase LCL passive Filter

METHODOLOGY

To enhance the performance of distribution system, DSTATCOM was connected to the distribution system. DSTATCOM was designed using MATLAB simulink version R2007b. Below shows the flowchart for the methodology:

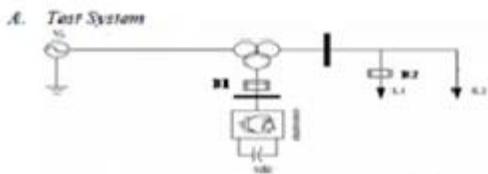
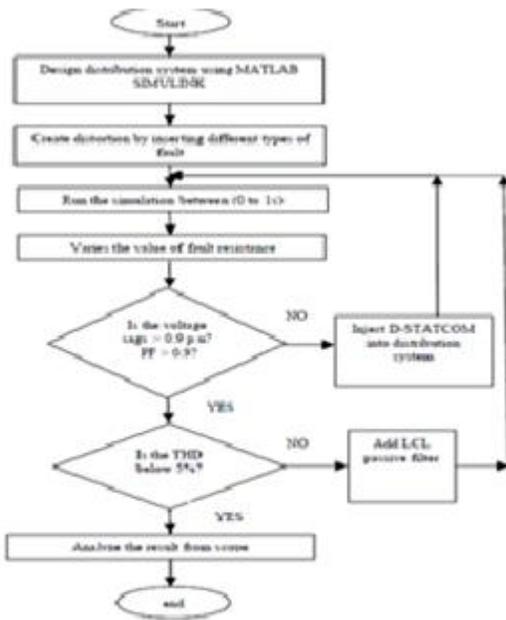


Fig.13 Flow chart Single line diagram of test system

The test system shown in figure comprises a 230kV, 50Hz transmission system, represented by a Thevenin equivalent, feeding into the primary side of a 3-winding transformer connected in Y/Y/Y, 230/11/11 kV. A varying load is connected to the 11 kV, secondary side of the transformer. A two-level D-STATCOM is connected to the 11 kV tertiary winding to provide instantaneous voltage support at the load point. A 750 μF capacitor on the dc side provides the D-STATCOM energy

storage capabilities. Breaker 1 is used to control the period of operation of the D-STATCOM and breaker 2 is used to control the connection of load 1 to the system

MATLAB DESIGN OF CASE STUDY

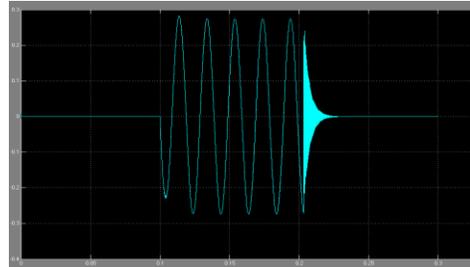


Fig 12 Three Phase Load Voltage Under Normal Condition

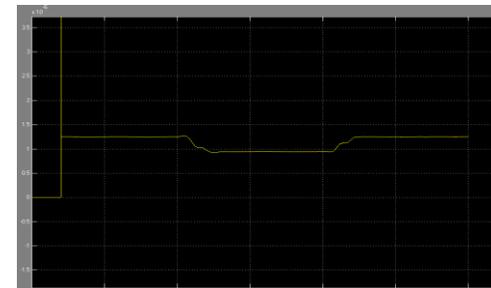
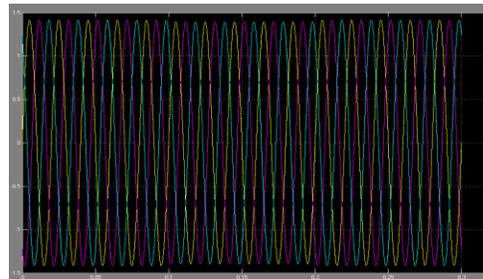


Fig14 Voltage Sag In Line Due To Fault

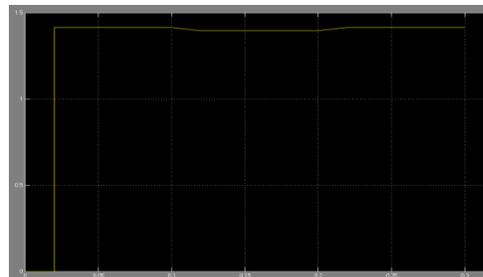


Fig 15 Clearing Of Sag With Dstatcom

CONCLUSION

The simulation results show that the voltage sags can be mitigate by inserting D-STATCOM to the distribution system. By adding LCL Passive filter to D-STATCOM, the THD reduced within the IEEE STD 519-1992. The power factors also increase close to

unity. Thus, it can be concluded that by adding D-STATCOM with LCL filter the power quality is improved.

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