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## Application of FD-STATCOM as a Distributed Generation and in Mitigation of Faults

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**Abstract** — This paper proposes a flexible D-STATCOM (Distribution Static Compensator) and its controller system, that be able to mitigate DLG fault and operate as a Distributed Generation (DG), when it supplies power to sensitive loads while the main utility source is disconnected (i.e. it is under islanded operating condition). Thus D-STATCOM operates same as a flexible DG (FDG) and consequently, it is called Flexible D-STATCOM (FD-STATCOM). This paper validates the performance of FD-STATCOM system to mitigate power quality problems and improve distribution system performance under different types of system related disturbances and system unbalanced faults, such as Double Line to Ground (DLG) fault and supplies power to sensitive loads under islanding condition. In this paper, the 12-pulse D-STATCOM configuration with IGBT is designed and the graphic based models of the D-STATCOM are developed using the MATLAB simulation program.

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**Keywords-** FD-STATCOM, Voltage Sag, Energy Storage System, Islanding Condition

### I. INTRODUCTION

Over the last decade, the implementation of Distributed Generation (DG) in distribution systems, whether by utilities or customers, has escalated. DG is defined as an electric power source connected directly to the distribution network. Utilities have recognized that DG is an imperative tool that can partially replace the need to erect new generating stations in order to meet the increasing load demand. Furthermore, customers also rely in part on DG to meet their increasing electricity needs, and reducing their costs [1].

The integration of DG with the utility distribution network offers a number of technical, environmental, and economical benefits. Moreover, such integration allows distribution utilities to improve the network performance by reducing its losses. The existing DG units are utilized to supply active power to either the network or the customers. Although DG units such as fuel cell, photo voltaic, micro turbine, and storage devices, which are linked via a nonlinear interface, represent a small portion of the installed DG capacity, they are potentially growing. Usually, this interface consists of a current controlled Voltage Source Inverter (VSI). A DG is islanded when it supplies power to some loads while the main utility source is disconnected. Islanding detection of DGs is considered as one of the most important aspects when interconnecting DGs to the distribution system [2].

Voltage sags are the most important power quality (PQ) problems that many industries and utilities face it. It contributes more than 80% of power quality problems that exist in power systems. Voltage sags are not tolerated by sensitive equipment used in modern industrial plants such as process controllers; programmable logic controllers (PLC), adjustable speed drive (ASD) and robotics. Various methods have been applied to reduce or mitigate voltage sags. The conventional methods are by using capacitor banks, introduction of new parallel feeders and by installing uninterruptible power supplies (UPS). However, the PQ problems are not solved completely due to uncontrollable reactive power compensation and high costs of new feeders and UPS. The D-STATCOM has emerged as a promising device to provide not only for voltage sag mitigation but also for a host of other power quality solutions such as voltage stabilization, flicker suppression, power factor correction, and harmonic control [3].

This paper proposes a flexible D-STATCOM system designed to operate in two different modes. Initially, it can mitigate voltage sags caused by DLG faults. Secondly, it can mitigate voltage sags caused by three-phase open-circuit fault by opening the three phases of a circuit-breaker and disconnecting the main power source (islanding condition).

### II. CONFIGURATION AND OPERATION OF FD-STATCOM

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 an interfacing inductor. 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 DSTATCOM and the ac system. Such configuration allows the device to absorb or generate controllable active and reactive power.

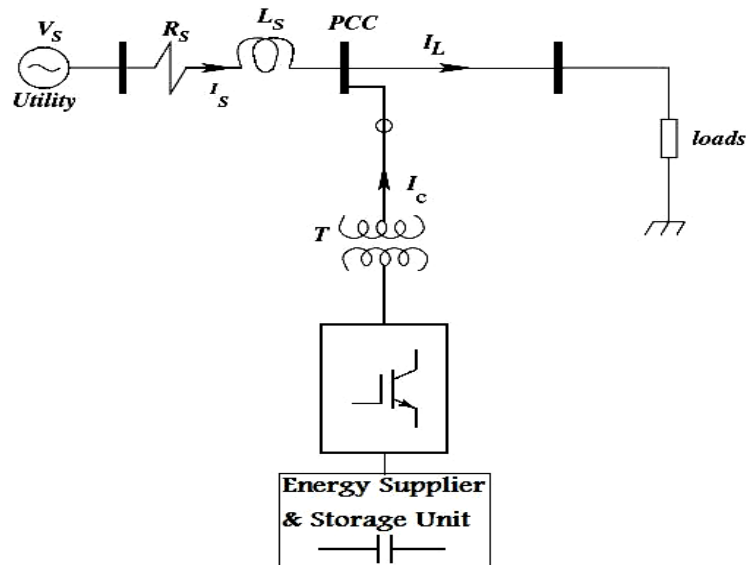


Fig.1. Schematic representation of the FD-STATCOM

The AC terminals of the VSC are connected to the Point of Common Coupling (PCC) through an inductance, which could be a filter inductance or the leakage inductance of the coupling transformer, as shown in Figure 1. The DC side of the converter is connected to a DC capacitor, which carries the input ripple current of the converter and is the main reactive energy storage element. This capacitor could be charged by a battery source, or could be precharged by the converter itself. If the output voltage of the VSC is equal to the AC terminal voltage, no reactive power is delivered to the system. If the output voltage is greater than the AC terminal voltage, the DSTATCOM is in the capacitive mode of operation and vice versa. The quantity of reactive power flow is proportional to the difference in the two voltages. It is to be noted that voltage regulation at PCC and power factor correction cannot be achieved simultaneously. For a DSTATCOM used for voltage regulation at the PCC, the compensation should be such that the supply currents should lead the supply voltages; whereas, for power factor correction, the supply current should be in phase with the supply voltages. The control strategies studied in this paper are applied with a view to studying the performance of a DSTATCOM for power factor correction and harmonic mitigation [4].

A typical 12-pulse inverter arrangement utilizing two transformers with their primaries connected in series. The first transformer is in Y-Y connection and the second transformer is in Y-Δ connection. Each inverter operates as a 6-pulse inverter, with the Y-Δ inverter being delayed by 30 degrees with respect to the Y-Y inverter. The IGBTs of the proposed 12-pulse FD-STATCOM are connected anti parallel with diodes for commutation purposes and charging of the DC capacitor. This is to give a 30 degrees phase shift between the pulses and to reduce harmonics generated from the FD-STATCOM. The FDSTATCOM is connected in shunt to the system.

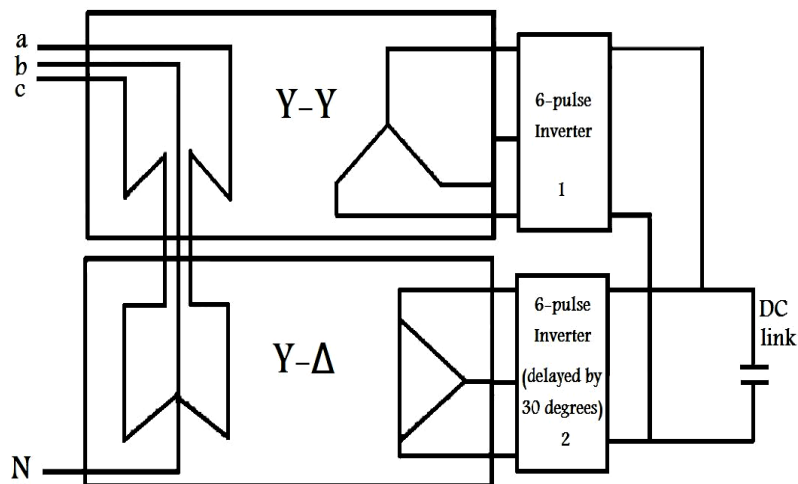


Fig.2.The 12-pulse FD-STATCOM arrangement

### III. PROPOSED CONTROL METHOD

The aim of the control scheme is to maintain constant voltage magnitude at the point where a sensitive load is connected, under system disturbances. The control system only measures the rms voltage at the load point, i.e., no reactive power measurements are required. The VSC switching strategy is based on a sinusoidal PWM technique which offers simplicity and good response. Since custom power is a relatively low-power application, PWM methods offer a more flexible option than the Fundamental Frequency Switching (FFS) methods favored in FACTS applications. Besides, high switching frequencies can be used to improve on the efficiency of the converter, without incurring significant switching losses. [5]

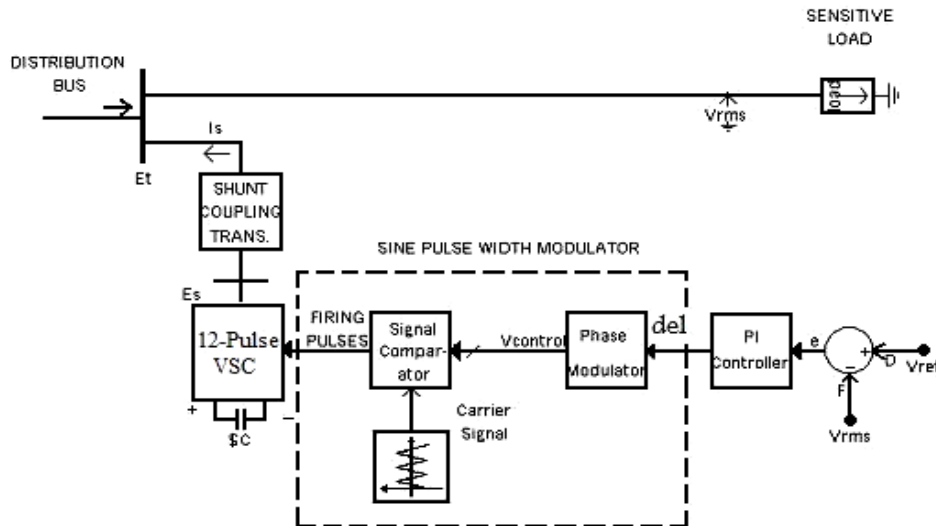


Fig.3. Control scheme designed for the FD-STATCOM

The controller input is an error signal obtained from the reference voltage and the value rms of the terminal voltage measured. Such error is processed by a PI controller the output is the angle  $\delta$ , which is provided to the PWM signal generator. It is important to note that in this case, indirectly controlled converter, there is active and reactive power exchange with the network simultaneously: an error signal is obtained by comparing the reference voltage with the rms voltage measured at the load point. The PI controller processes the error signal that generates the required angle to drive the error to zero, i.e., the load rms voltage is brought back to the reference voltage.

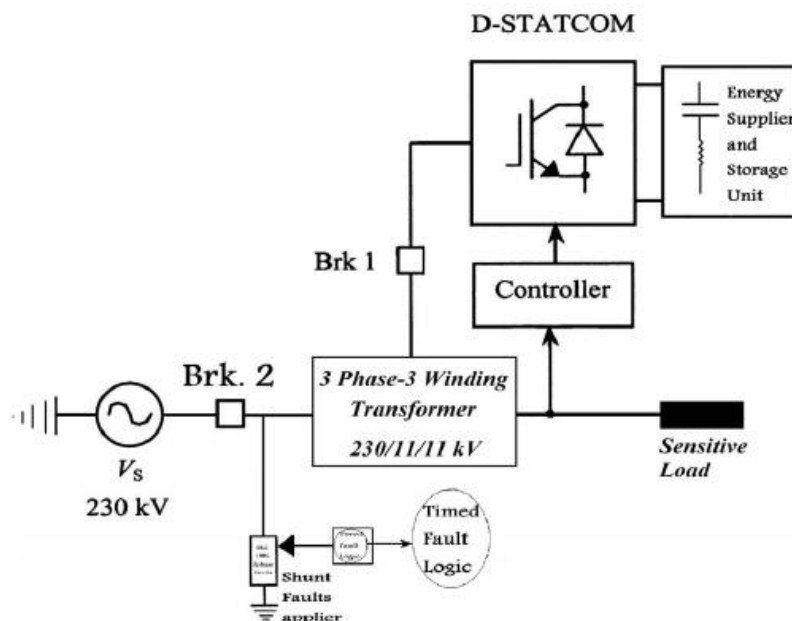


Fig.4. Distribution system with FD-STATCOM integrated with SCESS and Controller

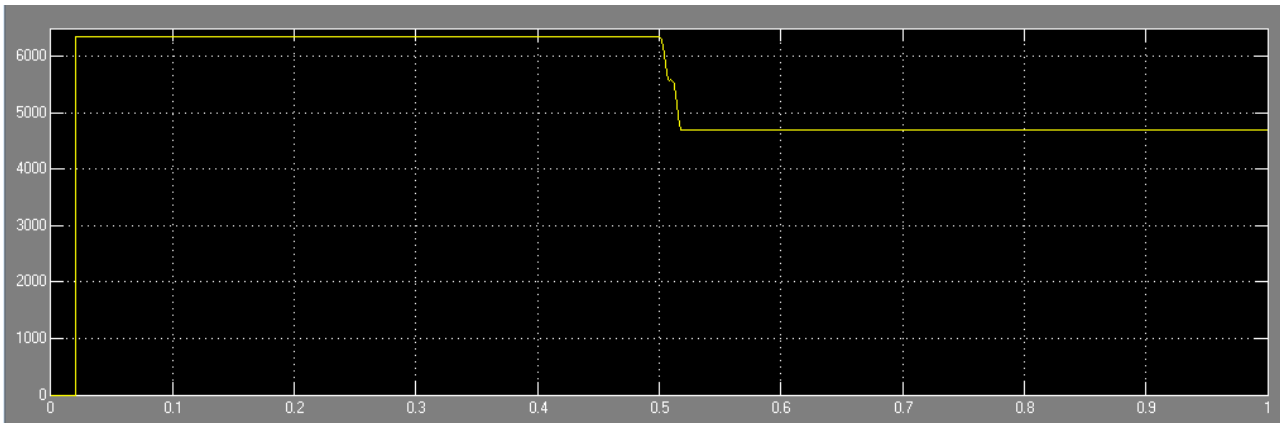
#### IV. SIMULATION RESULTS

Fig. 4 shows the test system implemented in MATLAB/SIMULINK to carry out simulations for the FD-STATCOM. The test system comprises a 230 kV transmission system. A balanced load is connected to the 11 kV, secondary side of the transformer. Brk. 1 is used to control the operation period of the FD-STATCOM. A SCESS on the dc side provide the FD-STATCOM energy storage capabilities. The simulations are carried out for both cases where the FD-STATCOM is connected to or disconnected from the system.

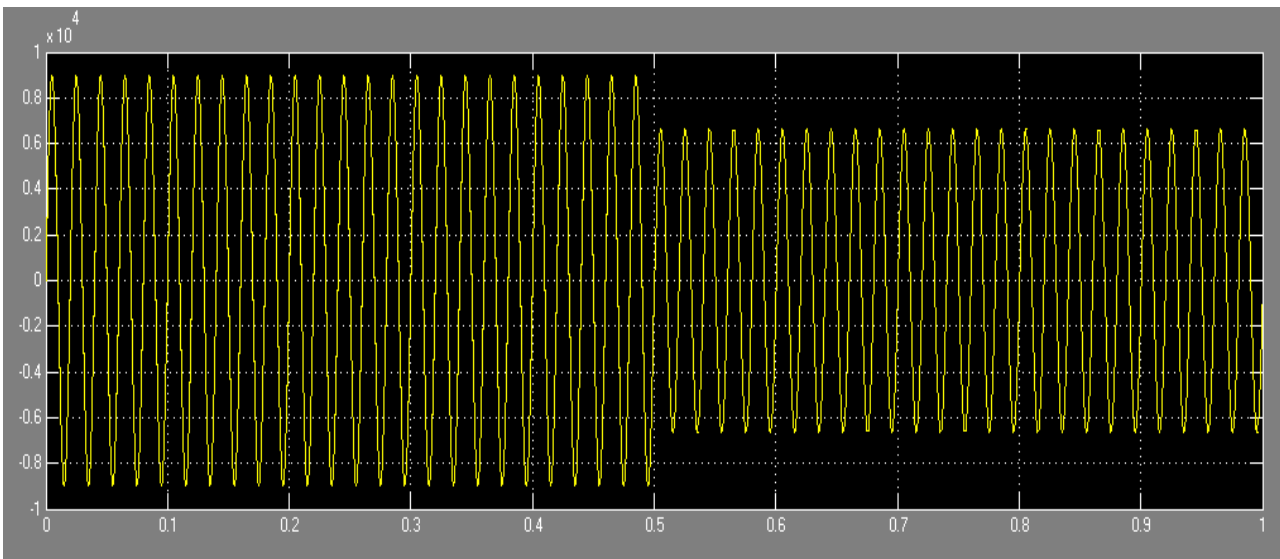
The simulations of the FD-STATCOM in fault condition are done using DLG fault and under islanded operating condition. In DLG fault the faulted phases are phases A and B while in islanded operating condition, three conductors open by Brk. 2 in 0.5 – 1 s. The duration of the islanding condition is considered for about 0.5 s and the DLG fault is considered for about 0.5 s. The faults are exerted at 0.5 s. The total simulation time is 1 s. In this paper, the FD-STATCOM uses the proposed control method to mitigate the load voltage sags due to DLG fault. The simulations are done for DLG fault introduced in the 11 kV distribution systems as follows:

##### A. Simulation results for Double line to ground fault

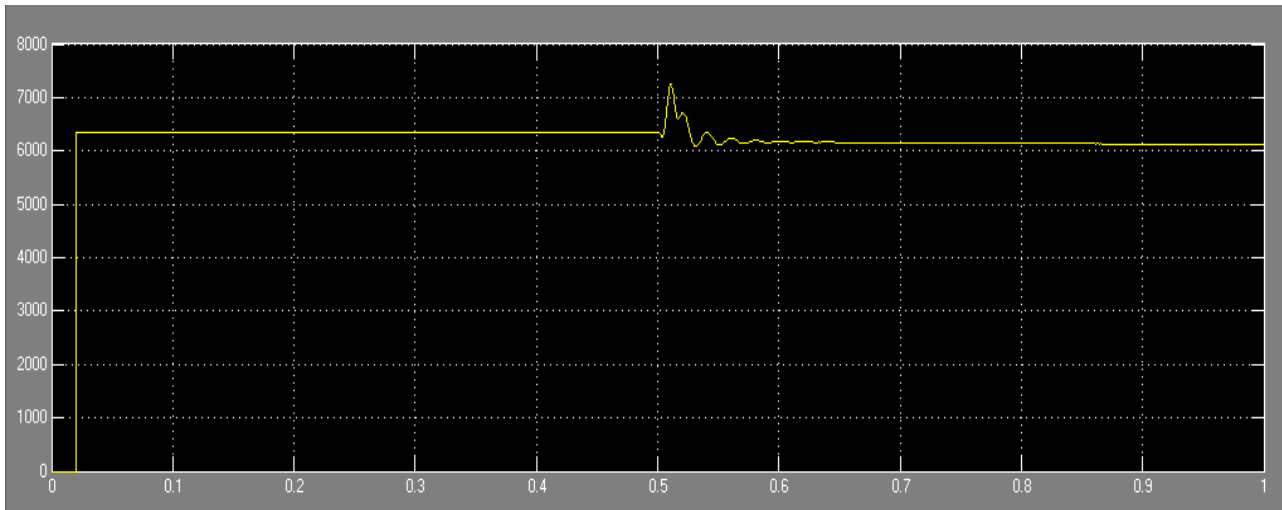
Figs. 5 and 6 show the RMS voltage and line voltage  $V_{ab}$  at the load point, respectively, for the case when the system operates without FD-STATCOM and unbalanced DLG fault is occurred. Figs. 7 and 8 show the compensated RMS voltage and mitigated voltage of  $V_{ab}$  at the load point, respectively, under DLG fault using proposed method. It is observed that the proposed method has correctly mitigated voltage sag.



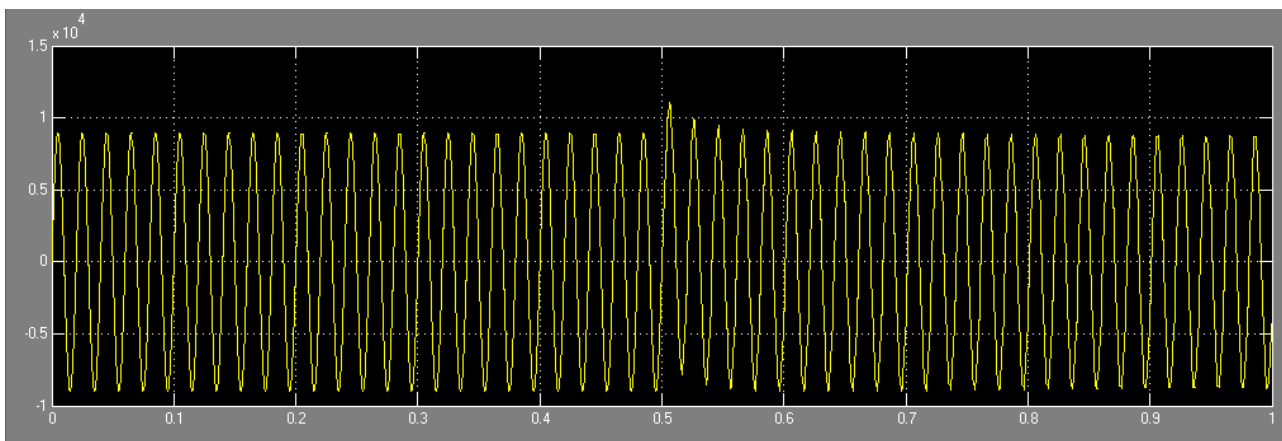
*Fig.5. RMS Voltage at PCC without FD-STATCOM*



*Fig.6. Vab Line Voltage at PCC without FD-STATCOM*



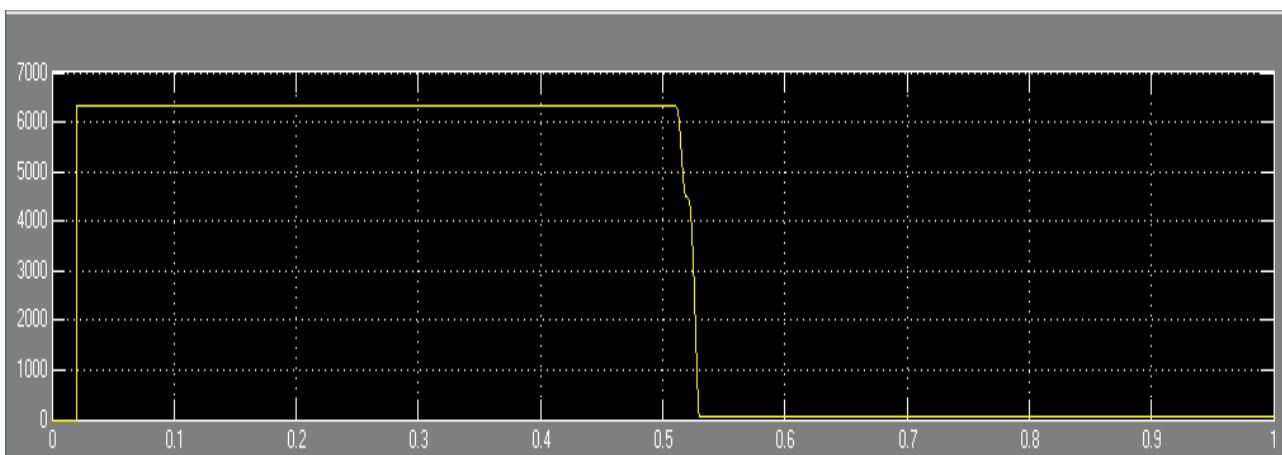
*Fig.7. Compensated RMS Voltage*



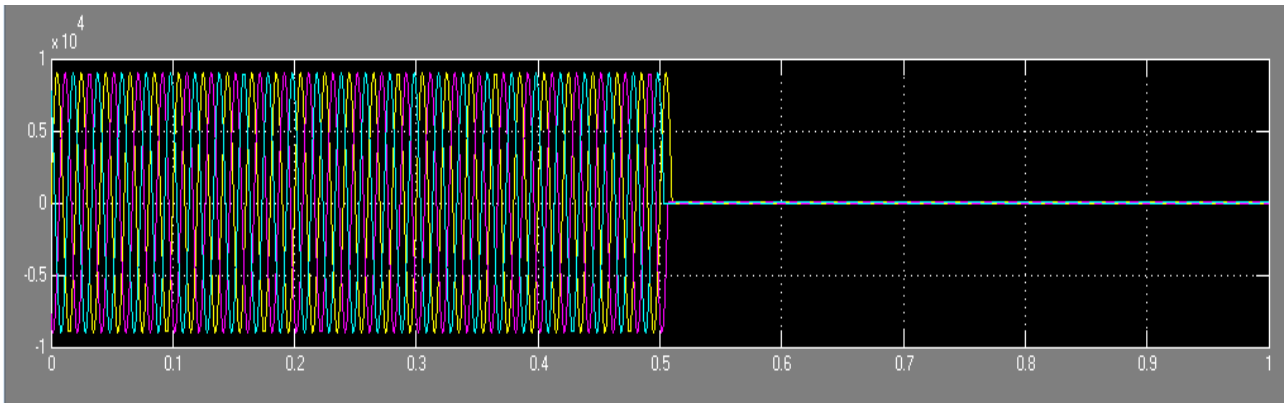
*Fig.8. Mitigated line Voltage Vab at the load point*

### **B. Simulation results under Islanded operating condition**

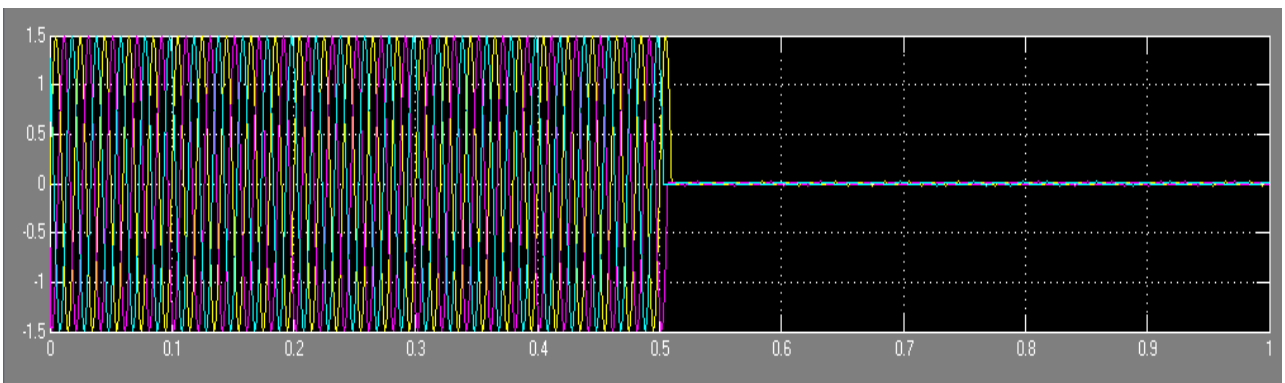
Figs. 9, 10 and 11 show the RMS voltage, line voltages and load currents at the PCC, respectively, for the case when the system operates without FD-STATCOM and under islanded operating condition.



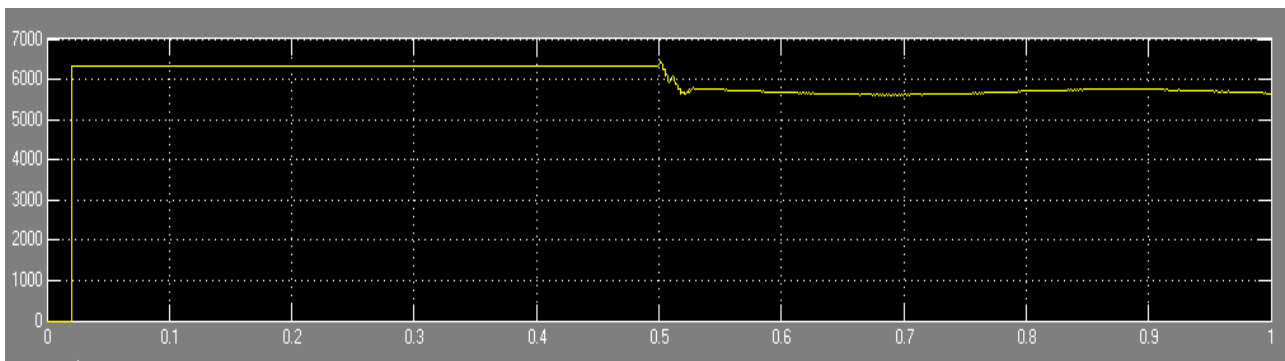
*Fig.9. VRMS at PCC without FD-STATCOM*



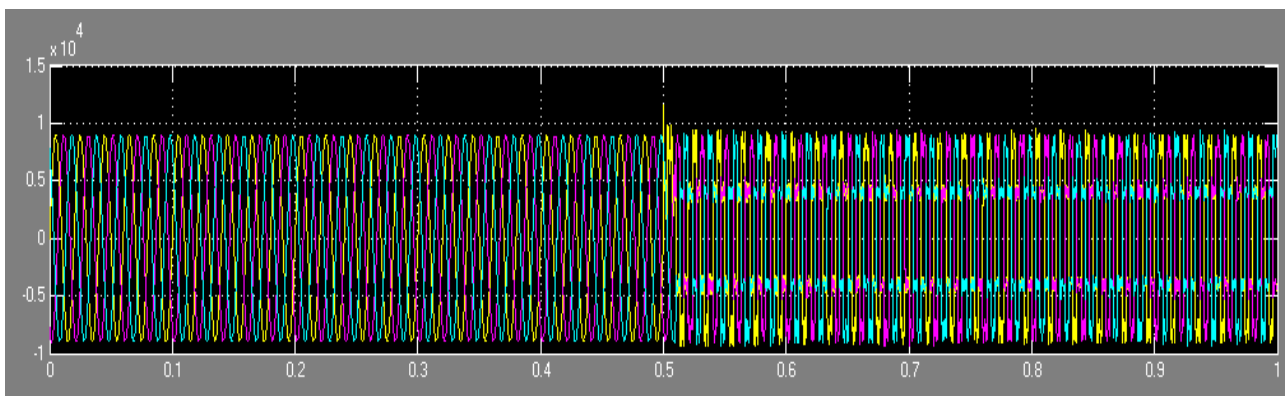
**Fig.10. Line voltages at PCC without FD-STATCOM**



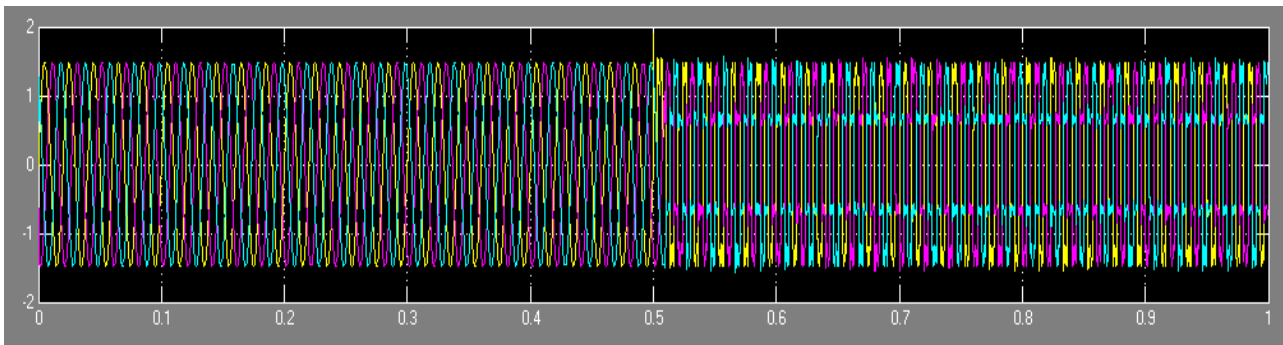
**Fig.11. Load currents without FD-SATCOM**



**Fig.12. Compensated RMS voltage**



**Fig.13. Compensated Line voltage**



**Fig.14. Mitigated load currents**

Figs. 12, 13 and 14 show the mitigated RMS voltage, line voltages at the load point and compensated load currents, respectively, using the proposed method.

## V.CONCLUSION

In this paper, a flexible D-STATCOM is proposed that could mitigate DLG fault and operate as a DG, when it supplies power to sensitive loads while the main utility source is disconnected. As a result, D-STATCOM operates same as a FDG and consequently, it is called FD-STATCOM. In addition, this paper has proposed a new control method for mitigating the voltage sags, caused by DLG fault and islanding condition, at the PCC. The proposed method is based on integrating FD-STATCOM and SCESS. This proposed control scheme was tested under a wide range of operating conditions (under DLG fault and islanded operating condition), and it was observed that the proposed method is very robust in every case. In addition, the regulated VRMS voltage showed a reasonably smooth profile. The operation of the D-STATCOM and its control system are developed in MATLAB/SIMULINK for mitigating the voltage sags and improving the power quality of the distribution system.

## VI. REFERENCES

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