

Comparison and Analysis on the Role of D-STATCOM and DVR with PI Controller to improve the power Quality in Distributed Networks

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ABSTRACT-- *In the running years and the coming era, power quality is one of major concerns in the expansion of power electronics. Whenever using a non standard voltage, current or frequency that results a failure or disoperation of end user equipments. Distribution networks, industrial loads etc., are suffered by power quality problems. A number of power quality solutions are provided by custom power electronic devices. Now, A wide range of flexible controllers, which capitalize on newly available power electronic components are utilizing for power application among them, the Distribution Static Synchronous Compensator (DSTATCOM) and Dynamic Voltage Restorer (DVR) or makes the efficient solutions for Improving power quality in Distribution Networks. DSTATCOM and DVR are utilizing with different types of controllers, to improve the power Quality. Comparison and Analysis of these devices consider in this work is DSTATCOM and DVR with PI controller to improve the power quality under different Abnormal conditions like single line to ground fault, double line to ground fault Distribution Networks with static linear and static non linear loads. The thesis modifies analyzed simulation of a DSTATCOM and DVR test systems using MATLAB.*

KEY WORDS: *Solid-State Transfer Switch, SSTS, Hybrid Switch, Thyristor, Static Voltage Compensation, Voltage Source Inverter, D-STATCOM, Power Quality, Custom Power Device (CPD), Dynamic Voltage Restorer (DVR), PI controller, Pulse Width Modulation (PWM), Voltage Sag*

I. INTRODUCTION

Now days electrical power system is AC i.e. electric power is generated, transmitted and distributed in the form of alternating current [2]. When the power is generated it possesses certain electrical properties that allow electrical system to function in their intended manner. But power travels long distances through wires. Due to various pieces of equipments or due to any abnormal conditions in the network, the quality of the power changes and thus it becomes less suitable for any further application. Voltage magnitude is one of the major factors that determine the quality of electrical power [10]. Hence it is necessary to improve the quality of power before it is used to energize any load. Though the transmission system and the distribution system are similar for man's circulatory system, in present scenario power quality irectly related to distribution system. The reason behind is that distribution system locates at the end of the power system and is directly connected to the customer. Because most of the electrical distribution network failures account for about 90% of the average customer interruptions and if any disturbance occur in the distribution system a huge amount of financial losses may happen with the consequent loss of productivity and competitiveness.

Flexible AC Transmission System (FACTS) devices like static synchronous compensator (STATCOM), static synchronous series compensator (SSSC), interline power flow controller (IPFC), unified power flow controller (UPFC) etc. were used. FACTS devices are generally designed for the transmission system.

But now-a-days these devices are modified to be used in distribution system and named as Custom Power Devices. Some of the widely used custom power devices are Distribution Static Synchronous Compensator (DSTATCOM), Dynamic Voltage Restorer (DVR), Active filter (AF), Unified power quality conditioner (UPQC).

In This paper, comparison and analysis on the role of D-STATCOM and DVR with PI controller to improve the Power quality in distribution networks investigates the performance of DVR in improving the quality of power under three phase fault and line to line fault.

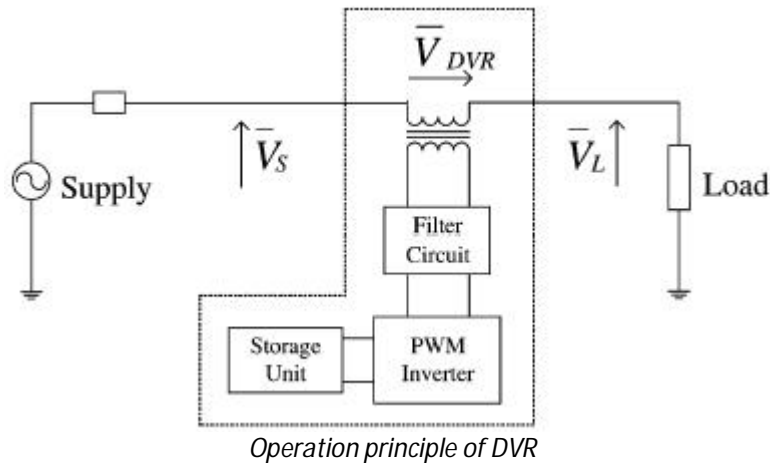
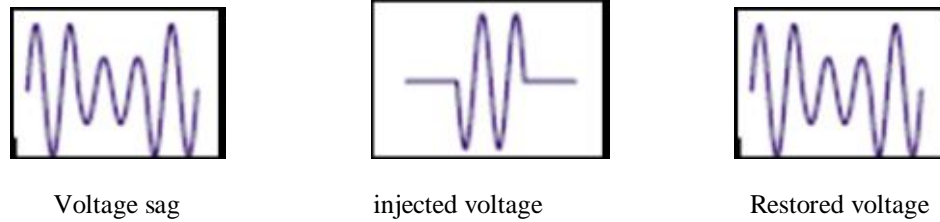
2. OPERATION OF DVR

DVR is a solid state power electronic switching device which is connected in series to the power system. It Comprises of the following components:

- [1] Energy storage device
- [2] Voltage source Inverter
- [3] Injection transformer
- [4] Control unit.

2.1. PRINCIPLE OF OPERATION

DVR is connected in between the supply and the load as shown in the Fig 1. The main function of the DVR is to boost up the load side voltage so that load is free from any power disruption. Besides voltage sag compensation DVR also carry out other functions such as line voltage harmonic compensation, reduction of Transients in voltage and fault current limitation.



1. Energy storage device: The purpose of the energy source is to supply the necessary energy to the VSI which will be converted to alternating quantity and fed to the injection transformer. Batteries are most commonly used and the capacity of the battery determine the duration of the sag which can be compensated by the DVR.
2. Voltage Source Inverter (VSI): A voltage source inverter is a power electronic device consisting of a switching device and a storage device such as battery. VSI can generate a sinusoidal voltage at any required magnitude, phase and frequency. VSI is used to temporarily generate the part of the supply voltage that is missing. IGBT is the newer compact switching device that is used with VSI for DVR operation.
3. Injection transformer: It consists of two side voltage one is high voltage side and low voltage side. The high voltage side is normally connected in series with the distribution network while the power circuit of the DVR is connected to the low voltage side [13]. The DVR transfer the voltage which is required for the compensation from DC side of the inverter to the distribution network through the injection transformer.
4. Control unit: A controller is used for proper operation of DVR system. DVR detects the presence of voltage sags and operates to mitigate the voltage dip. Pulse Width Modulation (PWM) control technique is applied for inverter switching so as to generate a three phase 50 Hz sinusoidal voltages at the load terminals.

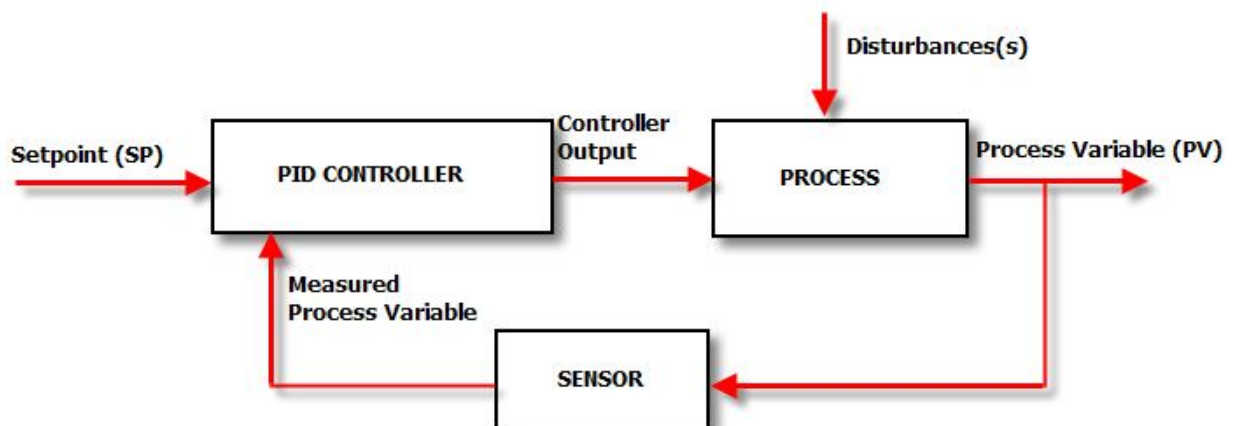


Fig 2: Schematic diagram of PI controller

In this study, the dq0 transformation or the Park's transformation is used for voltage calculation where the three phase stationary co-ordinate system is converted to the dq rotating quantity. The dq0 transformation technique is used

to give the information of the depth (d) and phase shift (q) of voltage sag with start and end time. The V_0 , V_d and V_q are obtained as

$$V_0 = (V_a + V_b + V_c) = 0$$

$$V_d = [V_a \sin \omega t + V_b \sin(\omega t -) + V_c \sin(\omega t +)] 2\pi/3$$

$$V_q = [V_a \cos \omega t + V_b \cos(\omega t -) + V_c \cos(\omega t +)] 2\pi/3$$

2.2. THEORETICAL CONCEPT OF DVR:

From the equivalent circuit of DVR given in Fig 3 the equation is found to be $V_{DVR} = V_{Load} + Z_{line} I_{load} - V_{source}$

Where V_{Load} = Desired load Voltage

Z_{line} = Line Impedance

I_{load} = Load Current

V_{source} = Supply voltage to the system

The line impedance Z_{line} depends on the fault level of the load. When a fault is occurred in the system the system Voltage drops from any specific value then the DVR injects a series voltage i.e. V_{DVR} via the injection transformer So that the load voltage V_{LOAD} can be maintained at required level.

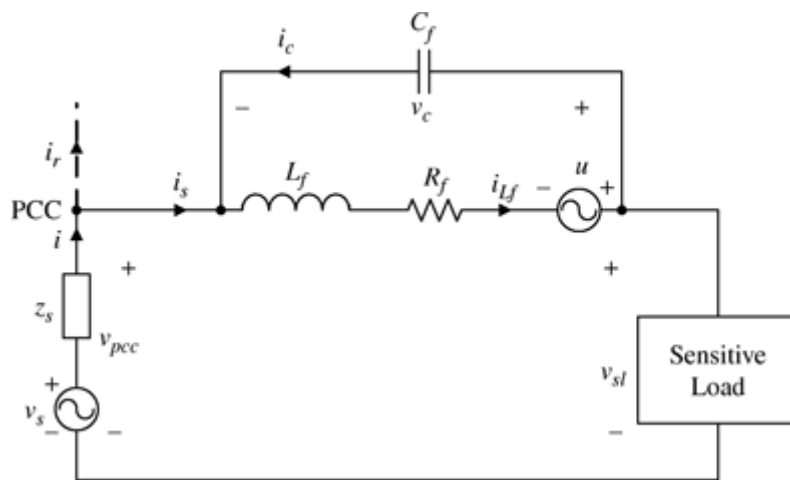
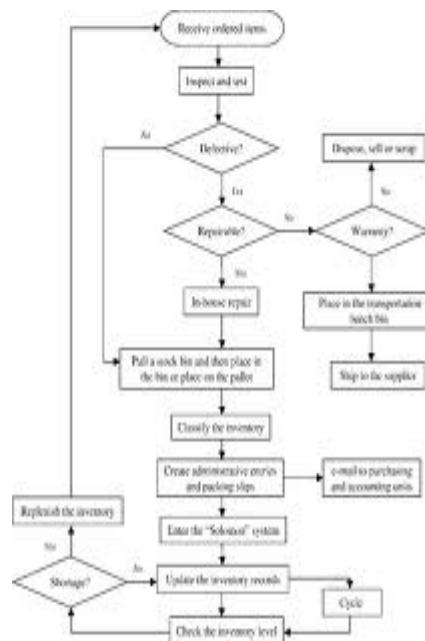


Fig3 equivalent circuit of DVR

2.3 SIMULATION



Flow chart of control scheme of dvr

The flow chart above depicts the method implemented in this paper. At the very beginning the magnitude of line voltage V and load voltage V_{load1} are measured. Both values are found to be equal. Then a fault is applied the magnitude of load voltage reduce suddenly to a great extent. The magnitude of the load voltage is measured again and it becomes V_{load2} . Then V_{load2} is compared with V_{load1} if V_{load2} is equal to V_{load1} , then DVR will not operate and no injection of voltage to the line. But if V_{load2} is less than V_{load1} then DVR will inject the sag voltage V_{sag} and if V_{load2} is greater than V_{load1} DVR will not operate. After injection the new voltage will be $V_{load2} = V_{load2} + V_{sag}$. The DVR will inject voltage till it detects the difference between the load voltage before fault and after fault, i.e. the DVR will maintain the load voltage at nominal value until the fault is removed.

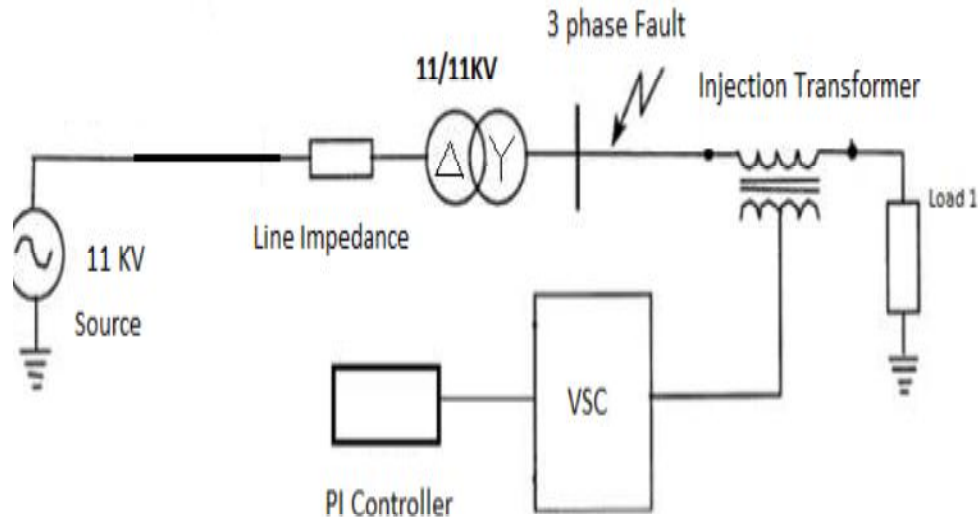


Figure: Block diagram of a DVR test model

3.0 THE DSTATCOM SYSTEM CONFIGURATION AND MODELLING

DSTATCOM [1] is a voltage source converter (VSC) that is connected in shunt with the distribution system by means of a tie reactance connected to compensate the load current. In general, a coupling transformer is installed between the distribution system and the DSTATCOM for isolating the DSTATCOM from the distribution system. In addition, the device needs to be installed as close to the sensitive load as possible to maximize the compensating capability. Being a shunt connected device, the DSTATCOM mainly injects reactive power to the system. The role of DSTATCOM is specifically appreciated in case of a weak AC system [2].

The structure of DSTATCOM along with its operating modes is shown in Figure 6. The main components of DSTATCOM are - a VSC (voltage source converter), controller, filter, and energy storage device. The system scheme of DSTATCOM is shown in Figure 2. These are briefly described as follows:

Isolation transformer: It connects the DSTATCOM to the distribution network and its main purpose is to maintain isolation between the DSTATCOM circuit and the distribution network.

Voltage source converter: A voltage source converter consists of a storage device and devices of switching, generating a sinusoidal voltage at any required frequency, magnitude and phase angle. In the DSTATCOM application, this temporarily replaces the supply voltage or generates the part of the supply voltage which is absent and injects the compensating current into the distribution network depending upon the amount of unbalance or distortion. In this work, an IGBT is used as the switching device.

DC charging unit: This unit charges the energy source after a compensation event and also maintains the dc link voltage at the nominal value.

Harmonic filters: The main function of harmonic filter is to filter out the unwanted harmonics generated by the VSC and hence, keep the harmonic level within the permissible limit. **Energy storage unit:** Energy storage units like flywheels, batteries, superconducting magnetic energy Storage (SMES) and super capacitors store energy. It serves as the real power requirements of the system when DSTATCOM is used for compensation [3].

In case, no energy source is connected to the DC bus, then the average power exchanged by the DSTATCOM is zero assuming the switches, reactors, and capacitors to be ideal. Figure 6 represents the schematic scheme of DSTATCOM in which the shunt injected current I_{sh} corrects the voltage sag by adjusting the voltage drop across the system impedance Z_{th} and value of I_{sh} can be controlled by altering the output voltage of the converter [4].

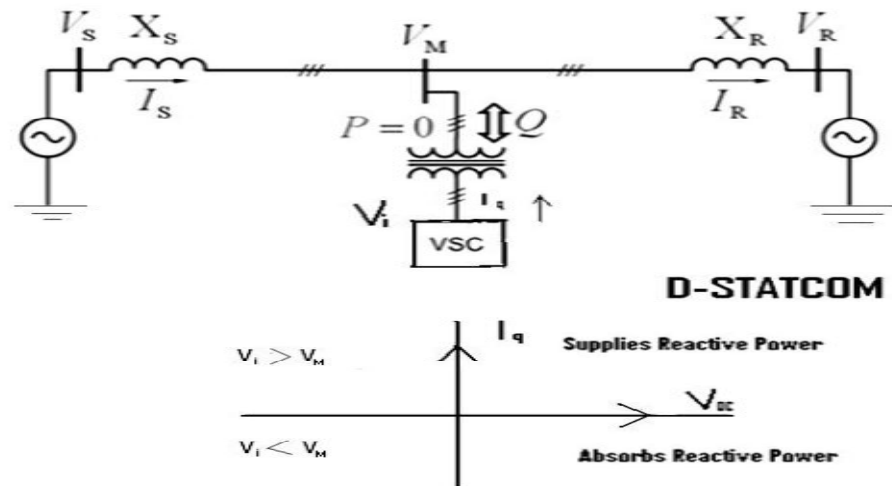
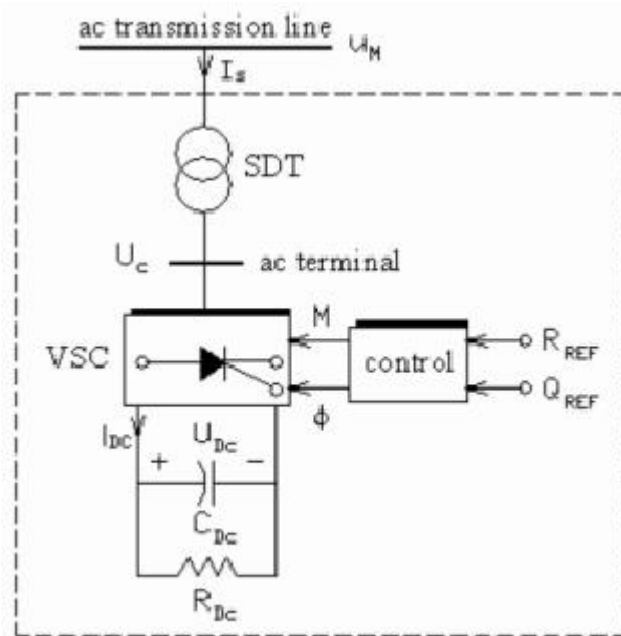


Figure 1. Structure and operating modes of DSTATCOM.



Block diagram of DSTATCOM

The effectiveness of the DSTATCOM in correcting the fault depends on the value of Z_{th} or fault level of the load bus. When the shunt supplied current I_{sh} is set in quadrature with V_L , the desired correction of voltage can be achieved without injecting any active power into the system. Alternatively, when the value of I_{sh} is decreased, the same correction of voltage can be achieved with minimum apparent power injection into the system. The contribution of the DSTATCOM to the load bus voltage equals the injected current times the impedance seen from the device also, that is the source impedance in parallel with the load impedance. The ability of the DSTATCOM to compensate the voltage dip is limited by this available parallel impedance. It helps to reduce the voltage fluctuations at the PCC (point of common coupling) [5],[6]. Voltage dips can be mitigated by DSTATCOM, which is based on a shunt connected voltage source converter. VSC with pulse-width modulation (PWM) offers fast and reliable control for voltage dips mitigation. The topology of the DSTATCOM connected at distribution level is shown in Figure 4.

In the proposed model, the application of DSTATCOM to improve the power quality in a distribution network with Single Line to Ground (SLG) fault and Double Phase to Ground (DPG) fault and three-phase fault is investigated.

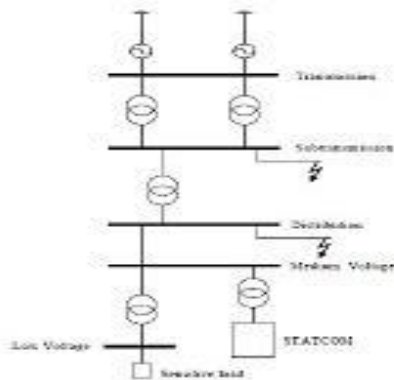
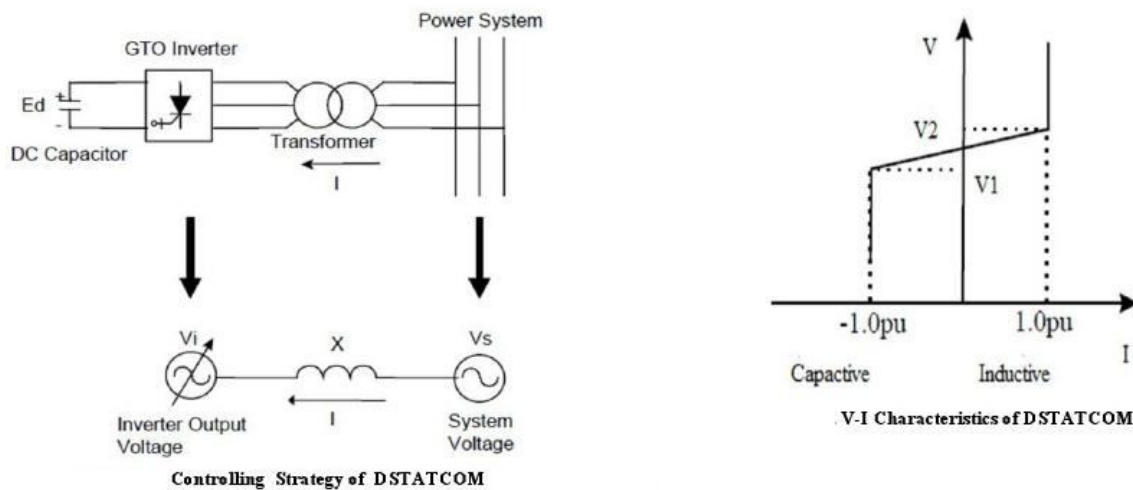


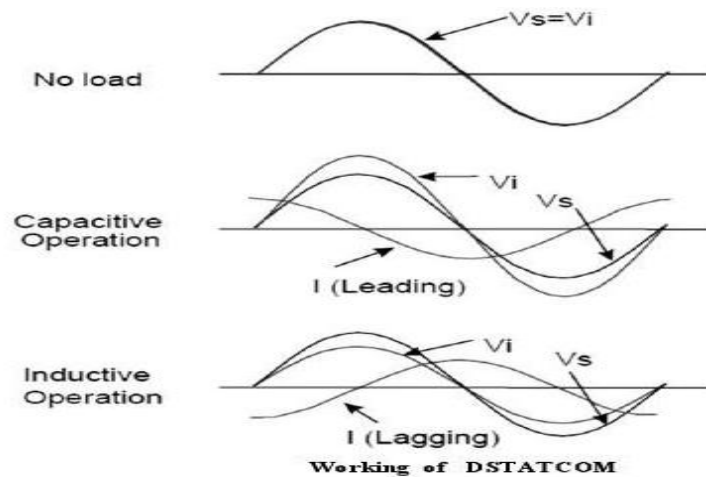
Figure 4. Topology of the power system with DSTATCOM.

CONTROLLING STRATEGY

The output voltage of the GTO converter (V_i) is controlled in phase with the system voltage (V_s), as shown in this figure, and the output current of the STATCOM (I) varies depending on V_i . If V_i is equal to V_s , then no reactive power is delivered to the power system. If V_i is higher than V_s , the phase angle of I is leading with respect to the phase angle of V_s by 90 degrees. As a result, leading reactive power flows from the STATCOM (capacitive mode). If V_i is lower than V_s , the phase angle of I is lagging with respect to V_s by 90 degrees. As a result, lagging reactive power flows into the STATCOM (inductive mode). The amount of the reactive power is proportional to the voltage difference between V_i and V_s . Note that this is the same basic operating principal as a rotating synchronous condenser. Working and V-I characteristic of the STATCOM is shown in figure of 4, 5

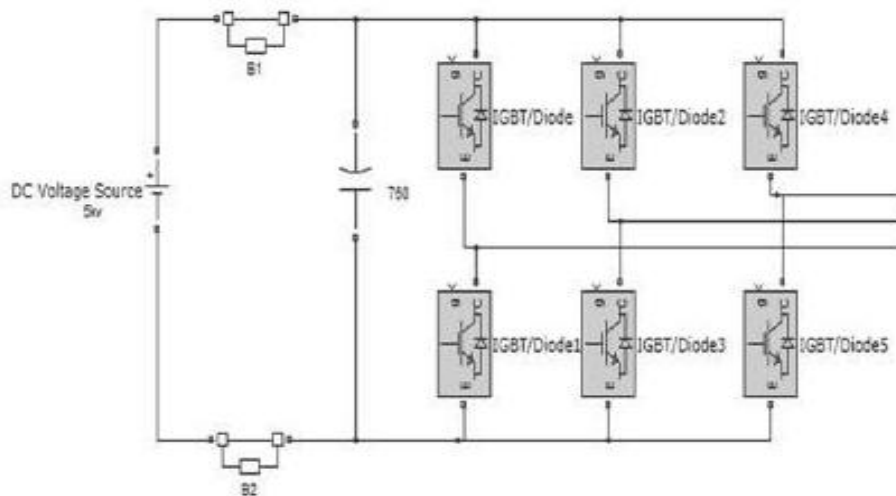


The DSTATCOM smoothly and continuously controls voltage from V_1 to V_2 . However, if the system voltage exceeds a low-voltage (V_1) or high-voltage limit (V_2), the STATCOM acts as a constant current source by controlling the converter voltage (V_i) appropriately. Thus, when operating at its limits of voltage, the quantity of reactive power compensation provided by the STATCOM is more than the most-common competing FACTS controller, namely the Static Var Compensator (SVC).



IV. PARAMETERS OF THE TEST SYSTEM

Simulation model of the test system is shown in Figure 9. System parameters of the test system are given in Table 1. In this test model two similar loads with different feeders have been considered, in which one of the feeder is connected to DSTATCOM and the other is kept as it is. This test system is analyzed with non linear load under different fault conditions. The technique of control implements a PI controller which starts from the difference between the injected current (DSTATCOM current) and reference current (identified current)



. Basic inverter structure.

SYSTEM PARAMETERS OF DSTATCOM

S.no	System quantities	Standards
1	Source	Yn, 3-phase, 25 kV, 50 Hz
2	Inverter parameters	3 arms, 6 Pulse, IGBT based ,Carrier frequency = 475 Hz
3	PI controller	$K_p = 0.5$, $K_i = 50$, Sample time = 50 s
4	Three winding Trans former	250MVA,50Hz

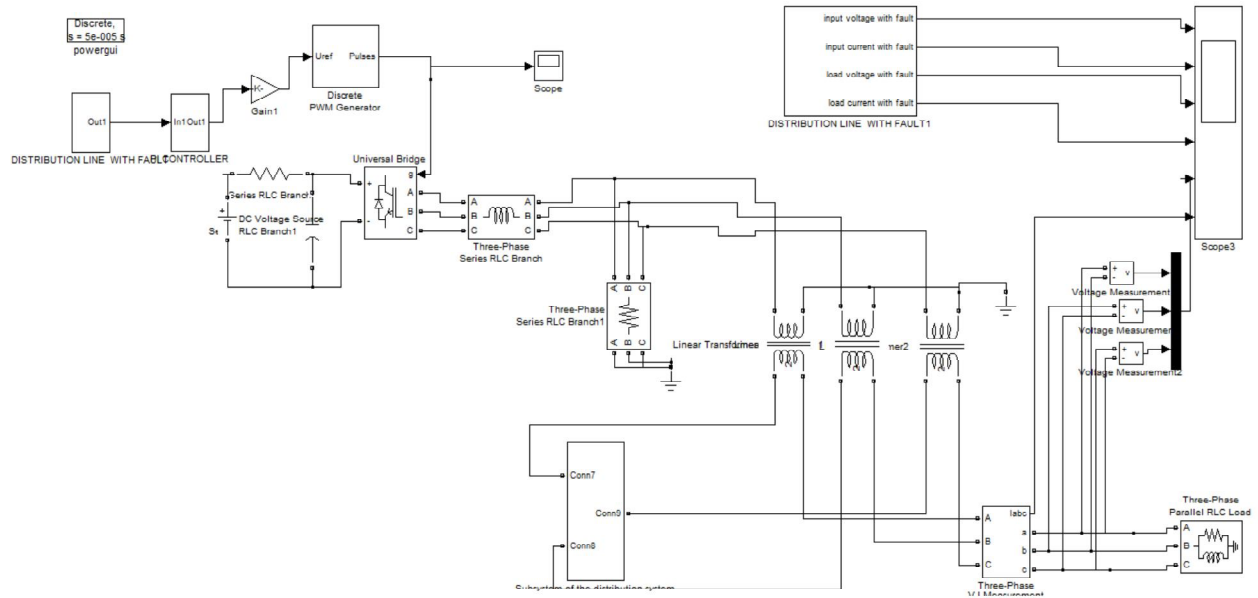
SYSTEM PARAMETERS OF DVR

Sr. No	System Quantities	Standards
1	Source	3 phase, 11 KV, 50 Hz
2	Inverter Parameters	IGBT based, 3 arms, 6 pulse, Carrier frequency= 1080 Hz , Sample time = 50 μ s
3	PI Controller (2)	$K_{p1}=20, K_{i1}=154, \text{Sample time} = 50 \mu\text{s}$ $K_{p2}=25, K_{i2}=260, \text{Sample time} = 50 \mu\text{s}$
4	RL load	Active power= 1KW, Inductive Reactive power= 500 VAR
5	Two winding transformer	Yg/ Δ , 11/11KV

The components required for constructing the DVR test model is shown in the Fig 5 and Table1 shows the parameters of DVR test system consisting of 11KV, 50 Hz source feeding one distribution line through a two winding transformer

RESULTS AND ANALYSIS OF THE DVR TEST MODELS

In this section the various results obtained after simulation are analysed and discussed. The simulink test model of DVR is shown in Fig. 6. The test system comprises of 11KV distribution network and the system has been examined under different fault conditions such as three phase to ground fault and line to line fault.



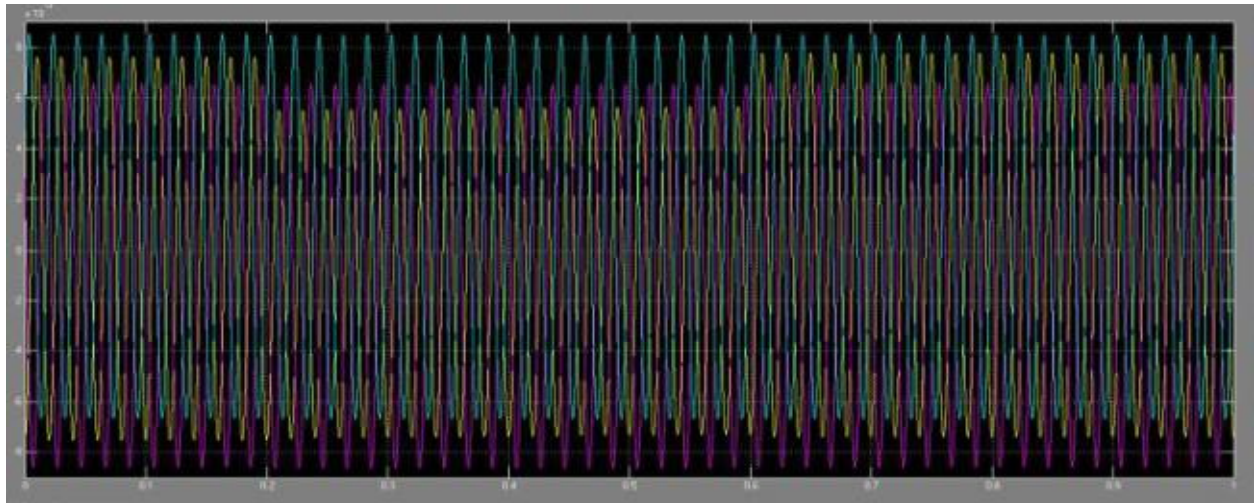
TEST MODEL OF DVR

V. SIMULATION RESULTS

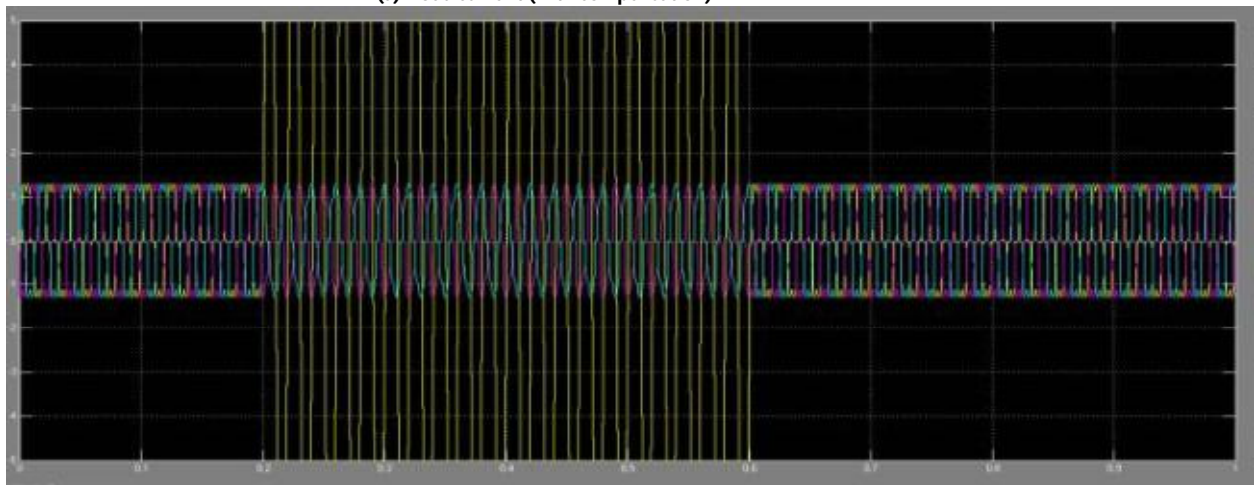
Fig.7 shows the test system implemented in MATLAB/SIMULINK to carry out simulations for the DSTATCOM. The test system comprises a 250 (kV) transmission system. The system consists of two parallel feeders with similar loads of similar ratings and static non linear load is taken. One line is connected to DSTATCOM while other one is kept as it is. The system has been analyzed under different fault conditions. The simulations of the D-STATCOM in fault condition are done using unbalanced and balanced faults. In SLG fault analysis, phase A is the faulted phase, while in DPG fault the faulted phases are phases A and B. In addition, in three-phase fault, the faulted phases are phases A, B, and phase C.

A. Simulation results for SLG fault

In this case a single line to ground fault is considered for both the feeders and the fault resistance is 0.001 ohm and the resistance to ground is 0.001 ohm. The fault is created for the period of 0.2s to 0.6s. Output waveforms of the load current with compensation and without compensation is shown in Figure-10(a) and Figure-10(b) respectively



(a). Load current (with compensation)

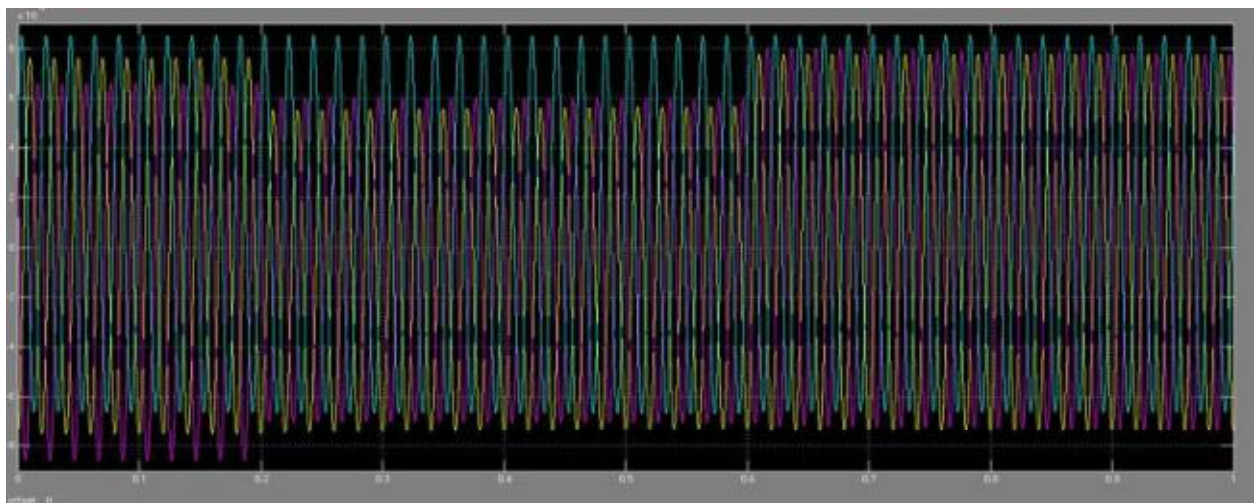


(b). Load current (without compensation)

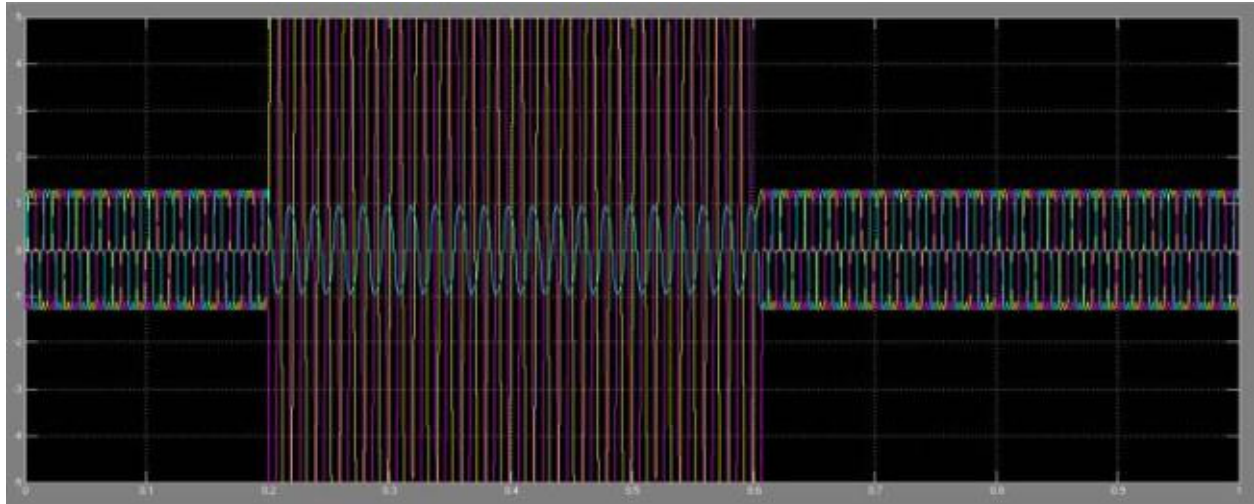
Figure10(a-b). Output wave for the load current

B. Simulation results for DPG fault

In this case a Double line to ground fault is considered for both the feeders and the fault resistance is 0.001 ohm and the resistance to ground is 0.001 ohm. The fault is created for the period of 0.2s to 0.6s. Output waveforms for the load current with compensation and without compensation is shown in Figure-11(a) and Figure-11(b) respectively.



(a (w). Load current with compensation)



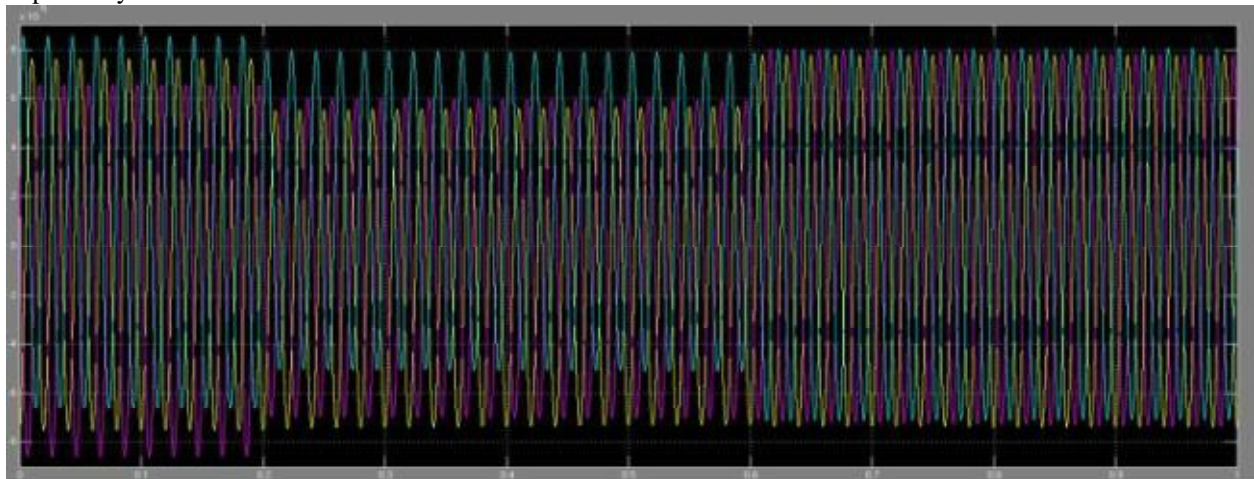
(b). Load current (without compensation)

Figure11(a-b). Output wave for the load current

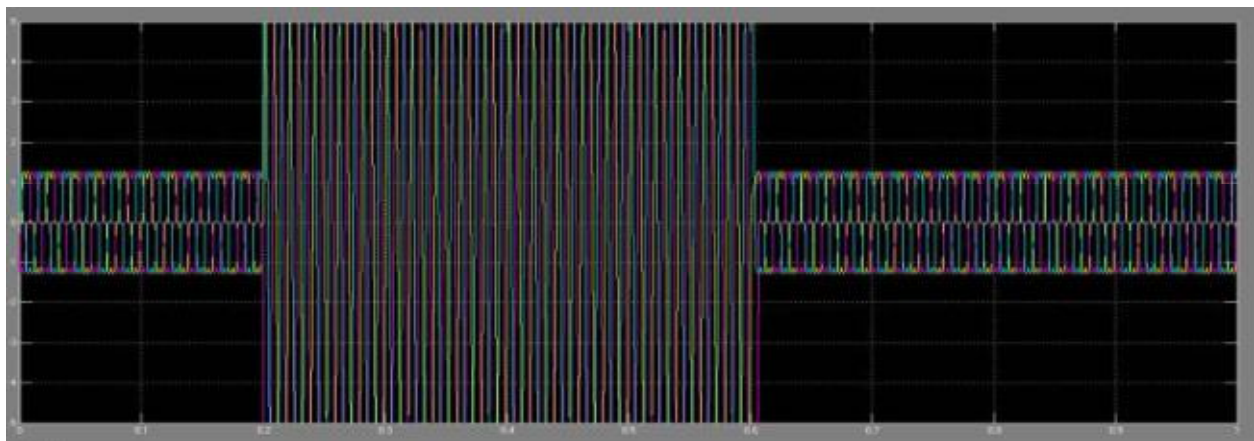
The Figure-10 and Figure-11 respectively, shows the wave shapes that the current in the phase where fault is created is increasing during the fault duration in the uncompensated feeder. And the system where DSTATCOM is connected unbalancing is reduced.

C. Simulation results for three-phase fault

In this case a three phase line to ground fault is considered for both the feeders and the fault resistance is 0.001 ohm and the resistance to ground is 0.001 ohm. The fault is created for the duration of 0.2s to 0.6s. Output wave for the load current with compensation and without compensation is shown in Figure-12(a) and Figure-12(b) respectively.

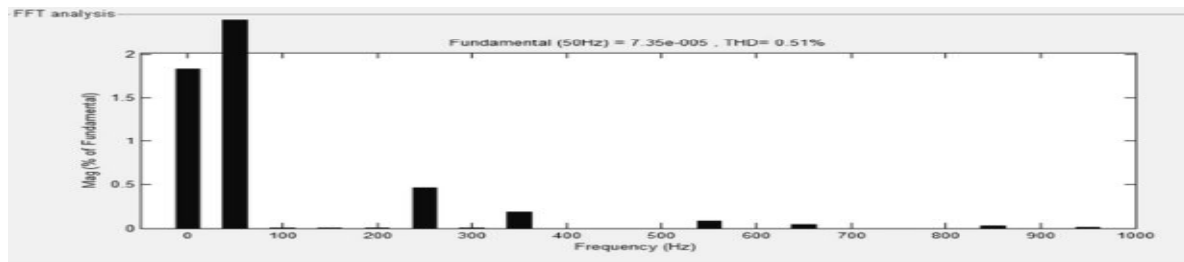


b). Load current (with compensation)

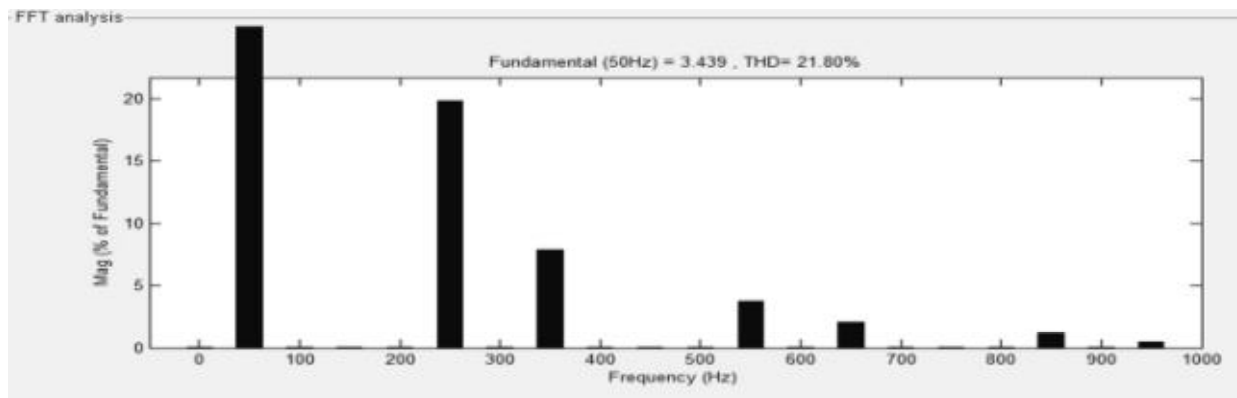


b). Load current (without compensation)

Here it is clear from the output wave shapes that the current in the phase where fault is created is increasing during the fault duration in the uncompensated feeder, that is why here the unbalancing in the system where DSTATCOM is connected is reduced clearly. However these results become clear from the total harmonic distortion graphs, taken one by one for compensated and non compensated feeders with non linear loads



THD (without compensation)



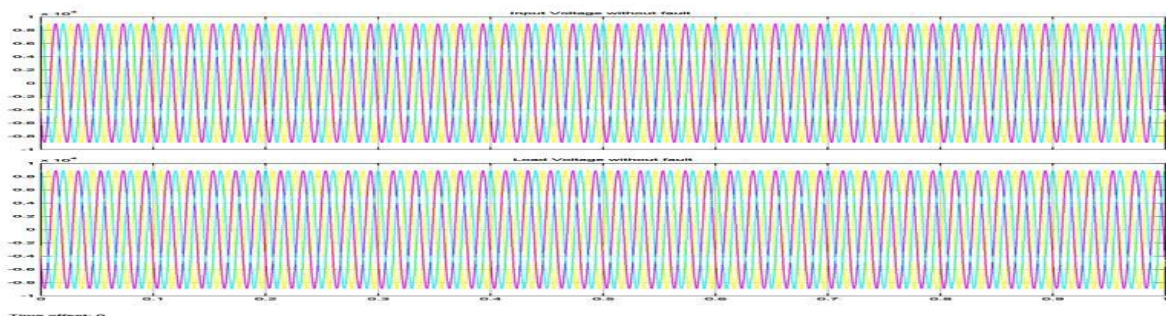
(b). THD (without compensation)

Figure13(a-b). THD of the load current

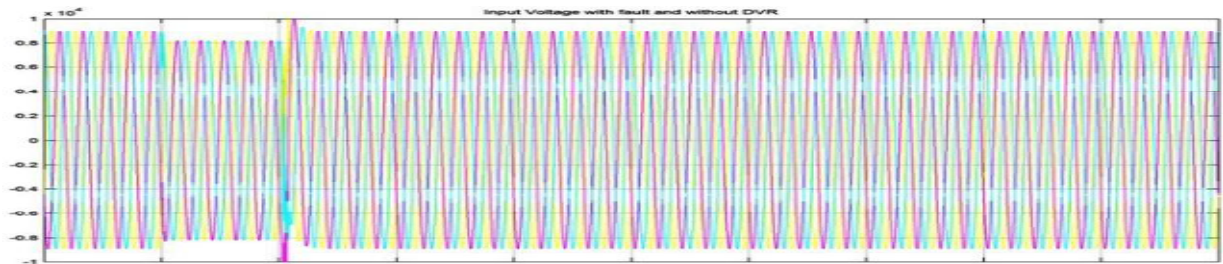
The THD graphs with compensation and without compensation are given in Figure-13(a-b). The total harmonic distortion without compensation is 21.80%, which is reduced to 0.51% where DSTATCOM is connected.

TEST RESULTS FOR THREE PHASE TO GROUND FAULT.

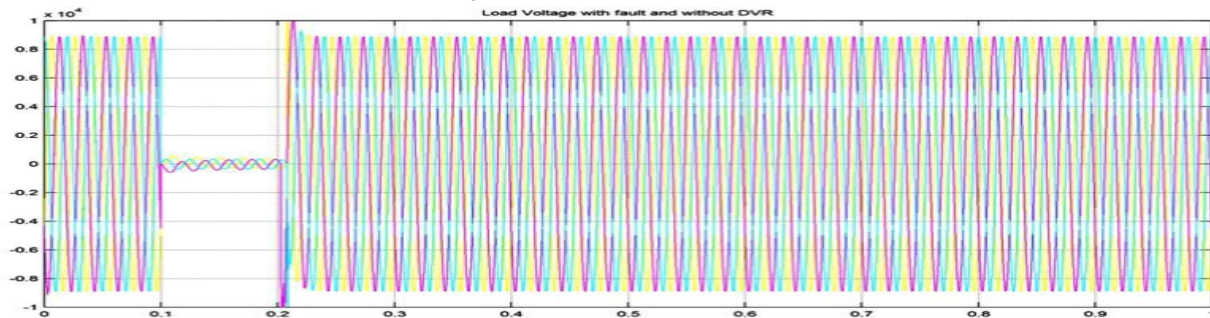
The simulation time for the model is taken as 1 sec. The first simulation was done without creating any fault at the network where supply is 11 KV with frequency 50 Hz. Fig 7 shows the waveforms of both input and load voltage without fault. Y- Axis shows the magnitude of voltage and X-axis shows the simulation time. Hence from the Fig 7 the input voltage is almost same. The second simulation is done by applying three phase to ground fault with fault resistance of 0.66Ω for a time duration of 100 ms i.e. from 0.1s to 0.2s and the ground resistance is 0.001Ω. Supply is 11KV, with frequency 50 Hz. Waveforms for the load voltages (with and without compensation) are given below. Fig 8 shows the waveform of the input voltage with fault and without DVR. Even after the fault is created the input voltage remains almost same as before while load voltage experiences a huge change. Fig .9 shows the waveform of load voltage with fault and without DVR. With the application of the fault to the circuit the magnitude of the load voltage decreases at the fault period from 9000V to 800V. This voltage dip is needed to be compensated to get the desired voltage at the load.



Waveform of input and load voltage without fault



Waveform of input voltage with three phase fault and with DVR



Waveform of input voltage with three phase fault and without DVR

The third simulation is carried out at the same scenario as above but the DVR is now introduced at the load side to compensate the voltage sag occurred due to the three phase fault applied. The waveform obtained from the test model is shown in Fig.10. It is clearly observed that the voltage waveform that is obtained after connection of DVR in series is almost similar to the supply voltage i.e. the DVR we installed is working efficiently

V. CONCLUSION

In this paper, the comparison of a DVR AND of DSTATCOM is done using MATLAB/SIMULINK software. these carried out to improve the power quality in distribution networks with static linear and non linear loads Thus it became easier to construct the large distribution network and analyse the various result for two different types of faults. The controlling of DVR and DSTATCOM is done with the help of PI controller. The simulation results clearly showed the performance of the DVR and DSTATCOM in mitigating the voltage sag due to different fault conditions in distribution systems. DVR is one of the fast and effective custom power devices. DVR has shown the efficiency and effectiveness on voltage sag compensation hence it makes DVR to be an interesting power quality improvement Device. This has been proved through simulation and hardware implementation. From the analysis it is found that in case of a three phase fault almost 91% of compensation is done and in line to line fault voltage compensation took place for almost 44%. Besides PI controllers, other controllers like fuzzy controllers and adaptive PI fuzzy controllers can also be used in the DVR compensation technique. In future years, the multilevel concept of inverters will be a prominent choice for power electronic systems mainly for medium voltage operation. Multilevel concept is the best alternator to employ low-frequency based inverters with low output voltage distortion.

The results shows the satisfactory performance of DVR and DSTATCOM in the distribution networks under different fault conditions and it can be concluded that DSTATCOM effectively improves the power quality in distribution networks than DVR..

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