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A Voltage Controlled D-STATCOM for Power Quality Improvement with DVR

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Abstract:

Improvement of Power quality has become a major area of concern in electrical power system. Increased sensitive and sophisticated loads results nonstandard voltage, current and frequency and reduce quality of power. This nonstandard power results failure of the loads connected to the distribution systems. Thus it has been very important to improve the quality of power which is very severe for the industrial customers as it can cause malfunctioning of several sensitive electronic equipments. Voltage quality is the major problem which is very severe for the sensitive electronic equipments. This paper describes voltage quality improvement by using Dynamic Voltage Restorer (DVR) and Distribution Static Synchronous Compensator (D-STATCOM). DVR or D-STATCOM is a custom power device (CPD), which is connected in series or in shunt with the network to maintain flat voltage profile in electrical distribution system. This paper presents modelling and simulation of DVR and D-STATCOM in MATLAB SIMULINK. Switching or triggering signals for the switching devices are provided by PI controller and discrete PWM generator which are used to control the output of DVR and D-STATCOM. Simulation result shows the performance of DVR and D-STATCOM under various faults such as single line to ground fault (LG), double line to ground fault (LLG), three phase to ground fault etc. The simulation result shows DVR is more efficient than D-STATCOM for power quality improvement.

Keywords: Custom Power Device (CPD), Dynamic Voltage Restorer (DVR), Distribution Static Synchronous Compensator (D-STATCOM), Power quality, Pulse Width Modulator(PWM).

1.INTRODUCTION

Modern society is fully dependent on the Power generated by generating station. Electricity serves modern society example heating, cooling, light, communication, and transportation. Traditional power system comprises of three parts i.e. generation, transmission and distribution of electrical power in the form of AC. The generated power should have good quality so that it can energize all equipments or appliances equally and satisfactorily. Due to heavy loads or any abnormal conditions or faults on the line reduces the quality of the power, becomes less suitable for further applications.

Voltage magnitude is one of the major factors that determine the quality of electrical power [10] and it is necessary to improve the quality of power before further used. As utilization of power is directly related to distribution system, power quality directly affects the end users or customers. The distribution system can be defined as that part of power system which distributes electrical power to the consumer for utilization. [2] Earlier day‟s power system reliability was taken care-off by generation and transmission system but now a day‟s prime focus is on distribution system because distribution network is most affected by the electrical failures.

The power provided by generating station must be improved for delivering pure and clean power to the end users. For delivering a good quality of power Flexible AC Transmission System (FACTS) devices like static synchronous series compensator (SSSC), static synchronous compensator (STATCOM), interline power flow controller (IPFC), unified power flow controller (UPFC) etc. were used. Generally FACTS devices are modified to be used in electrical distribution system known as Custom Power Devices. Some of the widely used custom power devices are Distribution Static Synchronous Compensator

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(DSTATCOM), Dynamic Voltage Restorer (DVR), Active filter (AF), Unified power quality conditioner (UPQC) [4]. These devices are used to reduce power quality problems. DVR is one of the most efficient and effective custom power devices due to its fast response, lower cost and smaller size [12].

Control Unit is the main part of the DVR and D-STATCOM. The function of the control unit is to detect the voltage differences (sag or swell) in the electrical distribution system and generate gate signal to operate the Voltage Source Converter (VSC) for supplying required amount of compensating voltage. Proportional Integral (PI) Controller is used to generate control signal and a PWM Generator is used for generating switching signal, which control the output of DSTATCOM & DVR. PI controller is used as feedback controller operates with a weighted sum of error signal and generates the desired signal for the PWM generator.

The Phase locked loop (PLL) and dq0 transformation are also the basic components of the compensating device [7]. This paper presents the performance of DVR and D-STATCOM for improving voltage sag and swell under different fault conditions i.e. LG, LLG, LLLG. The theory related to operation of DSTATCOM & DVR has been discussed in the next section. This paper composed of additional four sections. In section II, configuration of DVR & DSTATCOM is explained. In section III, operation of DVR & DSTATCOM is explained. In section IV analysis of the results of the test system are illustrated. In the last section, some conclusions are drawn.

II. Configuration Of DVR And D-Statcom

Figure 1 and 2 shows the basic configuration of DVR and D-STATCOM.

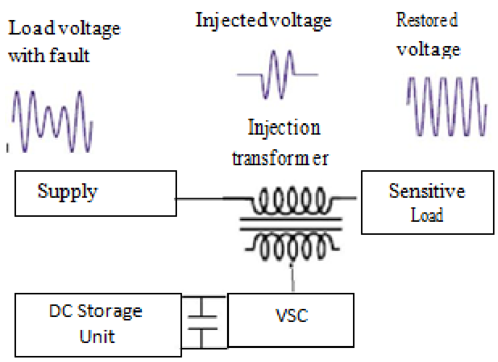

Fig.1 Dynamic Voltage Restorer (DVR)

DVR & D-STATCOM is a solid state power electronic switching device comprises of the following components:

(1) DC Storage unit: The function of this part is to supply the necessary energy to the VSC for converting DC to AC signal. Batteries are most widely used DC storage unit. The amount of voltage which has to be compensated determines the capacity of the battery.

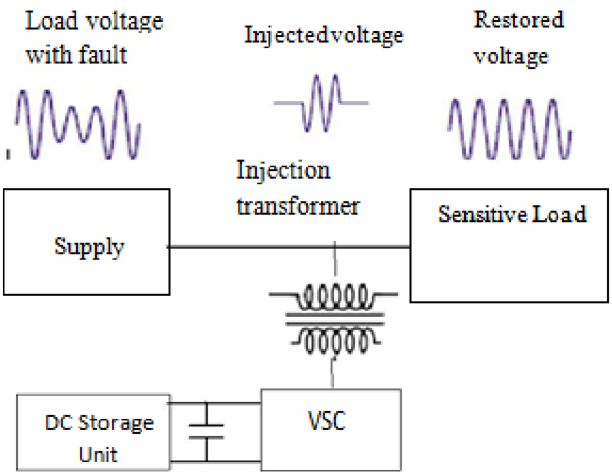

Fig.2 Distribution Static Synchronous Compensator (D-STATCOM)

(2) Voltage Source converter (VSC): Converter used here is a voltage source inverter (VSI). It is a power electronic

device consisting of IGBTs and a DC storage unit. VSI is used to generate three phase AC voltage at any required magnitude, phase and frequency to compensate the load voltage at the required value.

(3) Injection transformer: It is used to couple the VSC to the distribution line. 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 inject the voltage which is required for the compensation from DC side of the inverter to the distribution network through the injection transformer. This paper uses three single phase transformers instead of a three phase transformer. Transformers are connected in series (in case of DVR) and in shunt (in case of DSTATCOM) with each phase of the distribution line. It also isolates the line from the VSC.

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(4) Control unit: PI controller is used to generate switching signal for proper operation of VSC which detect the difference of voltage sag/swell and operate VSC to mitigate the voltage sag/swell. A comparator is used to compare load voltage with fault and the reference voltage and error signal will be generated, which drives the PI controller and the final output signal (Fig.3) controls the gate pulses for the Inverter. By multiplying error signal with constant proportional gain constant proportional response is obtained and the integral response is proportional to both the magnitude of error and duration of error.

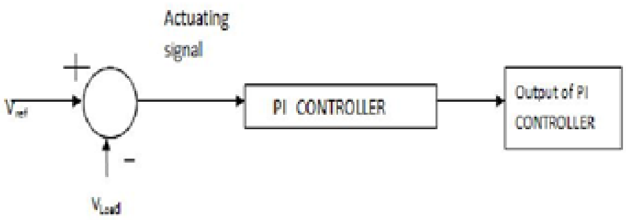

Fig.3 Operation of PI controller [16]

The dq0 transformation or the Park‟s transformation is used in this paper for voltage calculation. dq0 transformation is used to convert the three phase stationary co-ordinate to the dq0 rotating quantity and V0, Vd and Vq are obtained as

$$V_0 = \frac{1}{3}\left(V_a + V_b + V_c\right) = 0$$

$$V_d = \frac{2}{3}\left[V_a \sin \omega t + V_b \sin\left(\omega t - \frac{2\pi}{3}\right) + V_c \sin\left(\omega t + \frac{2\pi}{3}\right)\right]$$

$$V_q = \frac{2}{3}\left[V_a \cos \omega t + V_b \cos\left(\omega t - \frac{2\pi}{3}\right) + V_c \cos\left(\omega t + \frac{2\pi}{3}\right)\right]$$

III. OPERATION OF DVR AND D-STATCOM

Among the power quality problems like sag, swell, harmonic, transients etc, voltage sag is the most severe disturbance in the power distribution system, generally caused by faults. It last for duration ranging from 3 cycles to 30 cycles [10]. Starting of large induction motors can also result in voltage sag as it draws a large amount of current during starting which will affect other equipments connected to the system. In order to mitigate voltage sag or swell in distribution system DVR & DSTATCOM is used. DVR & DSTATCOM is connected in series and in shunt with the line, injects or absorbs reactive power in order to compensate the voltage sag or swell in the distribution line and maintains flat voltage profile at the load end.

The connection of DVR with the line is shown in the Fig 1. The main function of the DVR is to boost up the voltage at load side so that equipments connected at the load end is free from any power disruption. In addition to voltage sag compensation DVR also carry out other functions such as line voltage harmonic compensation, reduction of transient voltage and fault current.

The equivalent circuit diagram of DVR and D-STATCOM is shown in Fig.4 and Fig 5.

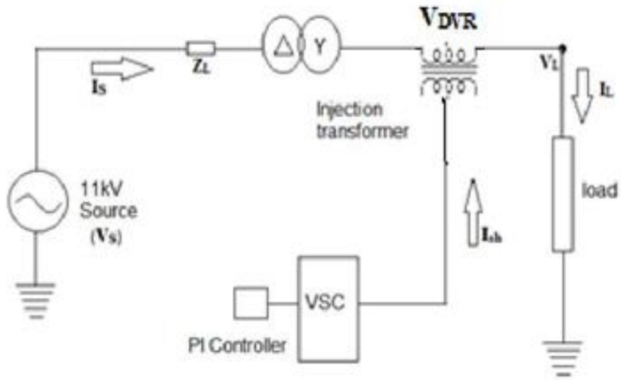

Fig.4 Overall diagram of DVR test model

From the equivalent circuit of DVR given in Fig.4 the equation is found to be

VDVR= Vload1 - Vload2

Where, V_{load1}= Desired load Voltage

V_{load2}= Load voltage during fault

V_s = Supply voltage to the system

The equivalent circuit diagram of a D-STATCOM is shown in Fig.5. In this diagram, the current injected or absorbed by D-STACOM (I_{sh}) corrects the voltage sag or swell. The value of I_{sh} is controlled by the PI controller, which in turn control the output voltage of the VSC. The injected current I_{sh} can be written as

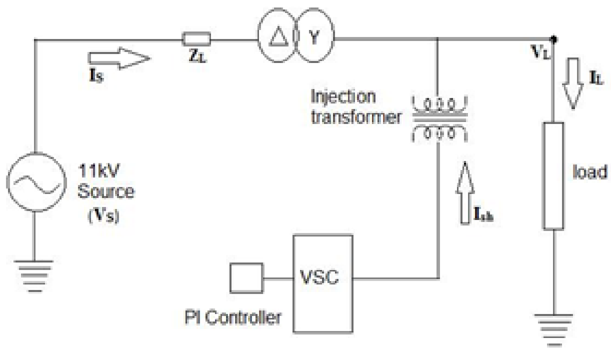

Fig.5 Overall diagram of DVR test model

From the Fig.5 load current can be written as,

$$I_L = I_s \pm I_{sh}$$

$$\pm I_{sh} = I_L - I_s$$

Where, I_L= Load current.

I_s= Source current.

I_{sh}= Shunt current injected by D-STATCOM

Z_L= Line impedance.

During fault the system voltage drops from the desired load voltage and the compensating device will injects a series voltage (V_{DVR}) in case of DVR or shunt current (I_{sh}) in case of D-STATCOM via the injection transformer so that the load voltage can be maintained at desired value.

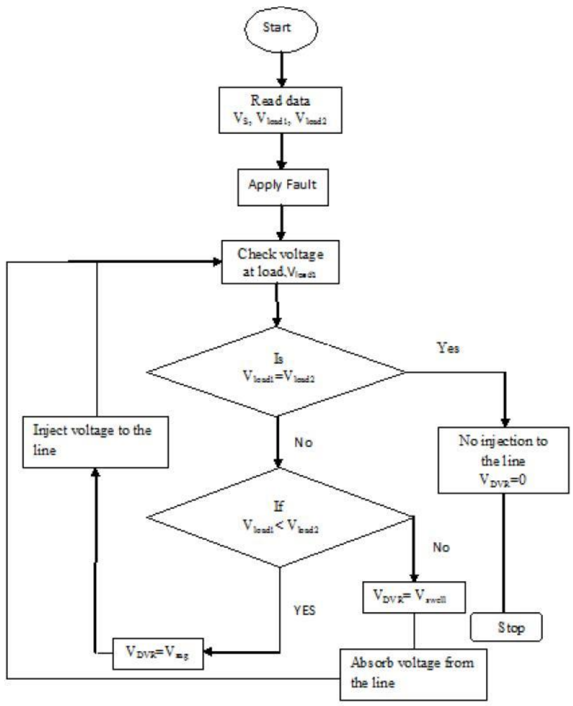

Fig.6 Flowchart of control scheme of DVR. [17]

The above flow chart above depicts the method which has been implemented in this paper. At the beginning magnitude of line voltage (V_{line}) and load voltage(V_{load1}) are measured and they are found to be equal. When a fault is applied on the distribution line the magnitude of load voltage reduce suddenly to a great extent 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} gate signal will be generated and DVR will inject the sag voltage V_{sag} to the main line and if V_{load2} is greater than V_{load1} DVR will absorb extra voltage. After injection the new voltage will be V_{load2}=V_{load1}. 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.

IV. RESULTS AND ANALYSIS OF DVR & DSTATCOM TEST MODEL

Fault analysis:

Application of faults on the test system created voltage fluctuations. In this section effect of various faults on the test system and their compensated load voltage waveform is also shown. The test system comprises of 11kV, 50 Hz distribution network with non-inductive three phase parallel load.

The simulation is carried out for a time duration of 100 ms i.e. from 0.1s to 0.2s with fault resistance of 0.66Ω and the ground resistance is 0.001Ω.

(1) Single line to ground fault:

Fig.7 shows input voltage and input current waveform when LG fault is applied on phase „A". Fig.8 shows the load voltage and load current waveform during fault without compensation. It is seen from the Fig.7 input voltage is not affected by the fault but input current is fully affected by the fault, it is increased from 10A to 400A as the fault current is supplied by the source.

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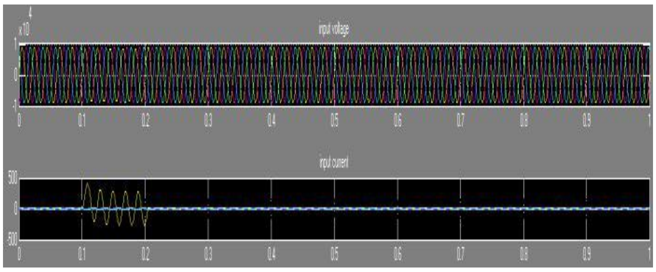


Fig.7 Input voltage and input current waveform without compensation

It is seen from the Fig.8 during LG fault voltage at the faulted line reduced from 10000V to 250 V i.e. voltage deep occurs at phase „A" and voltage at the other two phases increased from 10000V to 13000V i.e. at phases „B" and „C" voltage swell occurs.

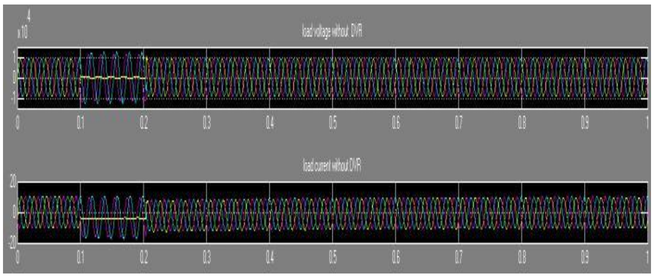
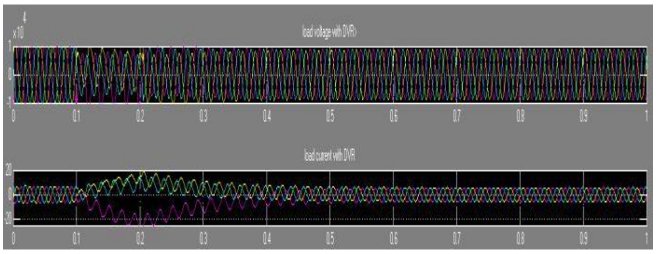


Fig.8. load voltage and load current waveform without compensation

Compensation by using DVR:
It is seen from the Fig.9 that load voltage during fault is almost equal to the desired load voltage. Load current magnitude is almost equal to 8A but still there is some unbalances between the phases for a small duration of time.



Compensation by using DSTATCOM:
When compensation is done with D-STATCOM (Fig.10) voltage magnitude is almost equal to the desired load voltage but current become unbalanced for the entire duration of time.

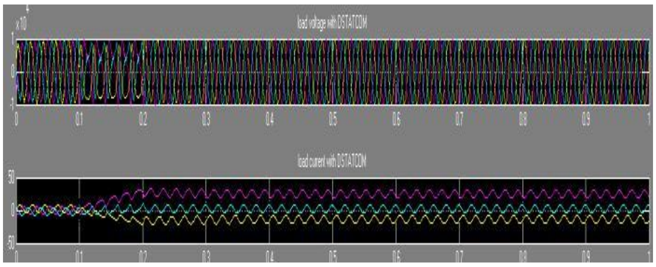


Fig.10 load voltage and load current waveform after compensation (D-STATCOM)

(2) Double line to ground fault:

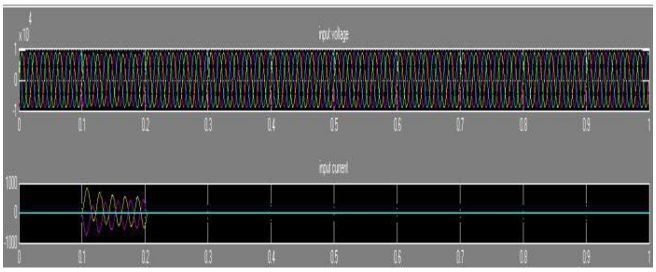


Fig.11 Input voltage and input current waveform without compensation

Fig.11 shows input voltage and input current waveform when LLG fault is applied on phase „A" and „B". Fig.12 shows the load voltage and load current waveform during fault without compensation. It is seen from the Fig.11that the input voltage is not affected by the fault but input current is fully affected by the fault, it is increased from 10A to 800 A as the fault current is supplied by the source.

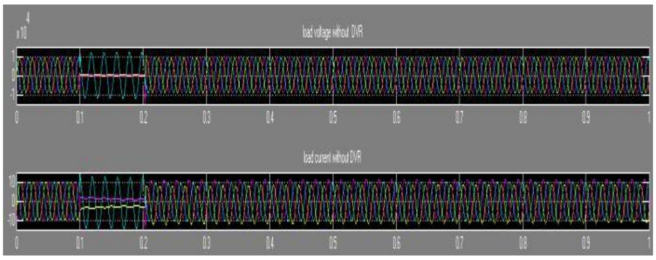


Fig.12 load voltage and load current waveform without compensation

Compensation by using DVR:
It is seen from the Fig.13 that load voltage during fault is almost equal to the desired load voltage. Load

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current magnitude is almost equal to 8 A but still there is some unbalances between the phases for a few seconds of time.

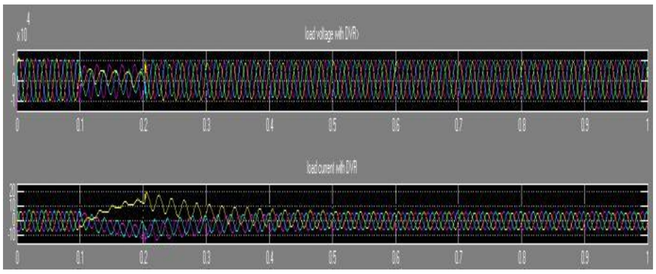

Fig.13. load voltage and load current waveform after compensation (DVR)

Compensation by using DSTATCOM:

When compensation is done with D-STATCOM (fig.14) voltage magnitude is almost equal to the desired load voltage but current become unbalanced for the entire duration.

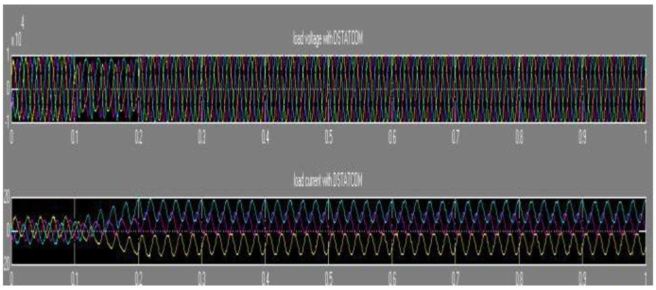

Fig.14 load voltage and load current waveform after compensation (D-STATCOM)

(3) Three phase to ground fault:

Fig.15 shows the input voltage and load voltage waveform by applying three phase fault on the test system. From the waveform it is seen that input voltage is slightly affected but input current is fully affected by the fault. Input current has increased from 10 A to 1000 A.

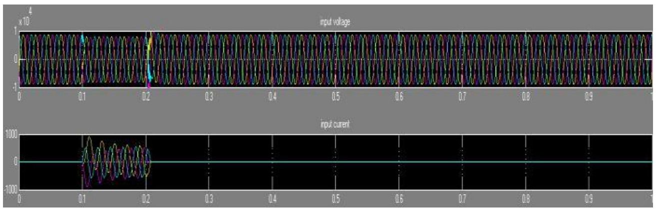

Fig.15 Input voltage and input current waveform during fault.

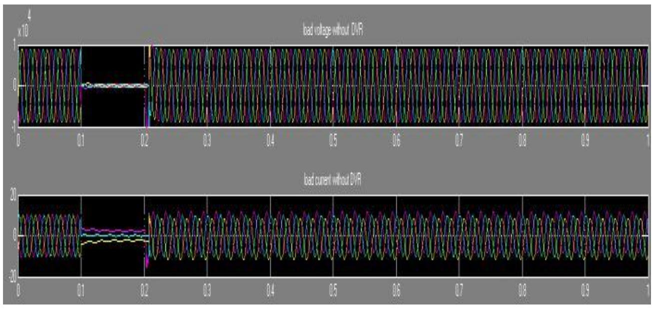

Fig.16. Load voltage and load current during fault

Fig.16 shows the load voltage and load current waveforms with fault and without DVR. During fault the magnitude of the load voltage decreases from 10000V to 800V and load current reduces as from 10 A to approximately 2 A as the fault is short circuit fault whole current passed through fault line. This voltage and current is to be compensated to get the desired load voltage for operating the load connected to the system satisfactorily.

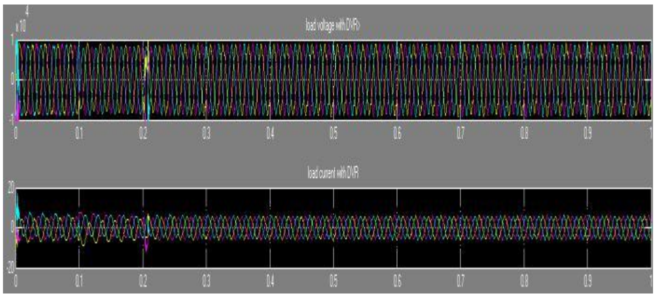

Fig.17 Load voltage and load current with DVR

From Fig.17 it has been observed that when DVR is connected to the line load voltage and load current almost become equal to the load voltage without fault.

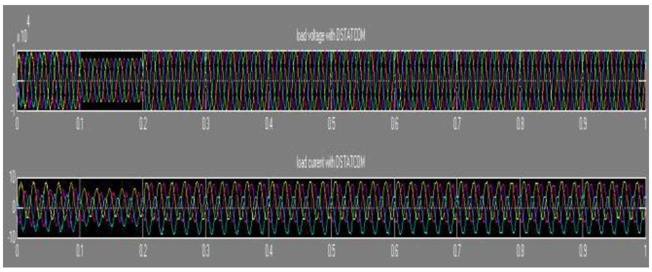

Fig.18 Load voltage and load current after compensation (D-STATCOM)

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It has been observed from the above Figures when DSTATCOM is connected to the test system the load voltage not exactly to the load voltage without fault and load current waveform is not exactly same as the load current before the fault.

V. CONCLUSION

In this paper, comparison of DSTATCOM & DVR is done by comparing the simulation results i.e. by comparing load voltage and load current waveforms. Simulation is done by using MATLAB SIMULINK software. Various results were obtained and analyzed by using three different types of short circuit faults. The controlling of and DSTATCOM & DVR is done with the help of PI controller. From the simulation result it is seen that compensated load voltage and load current waveforms by using DVR is much better than the compensated load voltage and load current waveforms by using D-STATCOM. The simulation results clearly showed the more efficient performance of the DVR than D-STATCOM in mitigating the voltage sag and swell due to different faults on distribution systems. DVR is one of the fast and effective custom power devices. DVR has shown the efficiency and effectiveness on voltage and current quality improvement hence it makes DVR to be an interesting power quality improvement device. This has been proved through simulation. PI controller has been used for generating operating signal of DVR & DSTATCOM, besides this other controllers like adaptive PI fuzzy controllers and fuzzy controllers can also be used in the compensation technique. In future the multilevel 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.

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