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Application of Distribution Static Synchronous Compensator in Electrical Distribution System

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Abstract: The concept of flexible alternating current transmission systems devices (FACTs) and custom power devices (CPD) are widely used for improving the flow of power in a transmission and distribution network. The term Power quality and Reliability are becoming very important issues for the sensitive loads connected to the systems. For low voltage distribution system Custom Power Devices (CPDs) such as Dynamic Voltage Restorer (DVR), Distribution static synchronous compensator (D-STATCOM) and Unified Power Quality Compensator (UPQC) etc. are used for improving the quality of power and reliability of supply without affecting entities such as factories, industries, and home etc. Among the Custom Power Devices D-STATCOM is mainly used to mitigate the fluctuation in voltage due to fault and the application of dynamic load which is connected in shunt with the main line that injects or absorbs the reactive current into/ from the line to maintain the flat load voltage profile. In this paper the simulation of D-STATCOM is done by using SIMULINK tool of MATLAB software. The control signal of the D-STATCOM is provided through the discrete PWM generator and PI Controller to improve the quality of power under different abnormal conditions like single line to ground fault (LG) double line to ground fault (LLG), three phase ground fault and the application of Dynamic Load has been described in this paper and the simulation result shows the efficient performance of D-STATCOM under different voltage swell and sag conditions.

Keywords: Power Quality, CPD, D-STATCOM, Dynamic load, FACTS.

I. INTRODUCTION

In the present scenario of electrical power system voltage is generated in the form of ac. The generated power must possess certain electrical properties that allow electrical system to function in a proper way i.e. it can operate all the electrical equipment equally and satisfactorily. Due to various abnormal conditions like faults on the power system network changes the power quality and thus it becomes less suitable for any further applications. Voltage magnitude is one of the major factors that determine the quality of electrical power [1]. Hence it is necessary to improve the quality of power before it is fed to excite a load. Though, both the transmission system and the distribution system are important aspects of electrical power system, now a day's power quality is directly associated to distribution system as the distribution system is present at the end of the power system and is directly related to the customer. The distribution system is defined as that part of power system, which distributes electrical power/ energy to the consumer for utilization and any disturbance occurring in the distribution system may lead to massive amount of monetary losses which may result in the loss of productivity and competitiveness [2].

Now a day's due to the development of voltage-sensitive load equipment in different industries have been quick, such as computer centers, high-precision processing, automatic production lines, hospital equipments, and so on, their processes have also become much more vulnerable to change in the quality of power supply. voltage harmonics, and voltage swells can cause severe Voltage quality problems in the form of voltage sags, process disruptions, resulting in substantial economic and/or data losses. Faults at either the transmission or distribution line may cause voltage sag and swell in the entire system or a large part of it. Also the application of dynamic load in distribution line can give rise to voltage quality problems. Voltage sags or dips are brief reductions in voltage and it occurs when r.m.s voltage decreases with respect to the nominal voltage [1]. Voltage swells or surges, on the other hand, are brief increases in voltage. Voltage sag and swell may lead to failure of sensitive equipment, production rates fluctuation and dropout of circuit breakers and relays due to the creation of large current unbalance. These effects caused ranges from small variations in power to resulting in high damages in the equipment. Hence these effects can be very expensive.

Many efforts have been under taken in order to maintain a flat voltage profile. There are many different methods to mitigate voltage sags and swells, but the use of Custom Power Devices such as distributed STATCOM is considered to be one of the most efficient methods. A D-STATCOM is a shunt device that generates reactive current, which in turn causes a reactive power injection into the system through an injection transformer. The load voltage during abnormal conditions determines the current and the power injection/ absorption of the D-STATCOM.

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This paper shows the performance of D-STATCOM in improving the quality of power under different voltage sag and swell conditions which is due to the LG, LLG, LLLG and the dynamic load connected to the distribution line. The operation of D-STATCOM can be controlled by the use of different controller. In this paper control mechanism of DSTATCOM is done using PI controller. The theory related to D-STATCOM operation and its different parts have been discussed in the next section. This paper composed of additional four sections which includes configuration and operation of D-STATCOM, control mechanism, simulation details of D-STATCOM, results analysis of the test system and some conclusions.

II. CONFIGURATION AND OPERATION OF D-STATCOM

The power quality problems like voltage sag and swell, harmonics are generally caused by faults on the power systems. Also the application of dynamic load, voltage of a system tends to fluctuate, which in turn affect the end users. In order to mitigate this problem D-STATCOM is used which is an efficient and effective CPD.

D-STATCOM is a solid state switching device. It is connected in shunt to the main distribution line for compensation of voltage sag and swell. It comprises of the following components:

a. Voltage source converter (VSC)
b. Injection transformer
c. Control unit.
d. Energy storage device.

Principle of operation of D-STATCOM: It is a voltage source converter (VSC) that is connected in shunt with the distribution system through a coupling transformer by means of a tie reactance connected to compensate the load current and maintain a fixed voltage profile. The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are coupled with the ac system through the reactance of the injection transformer and they are in phase with the line voltage. The 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. This type of configuration allows the device to absorb or generate controllable active and reactive power. If the load voltage/ line voltage is higher than the desired load voltage, the D-STATCOM absorbs reactive current or power; on the other hand, when the amplitude of the load voltage lower than the desired load voltage, it supplies reactive current or power to improve the load voltage. Fig.1. shows the basic block diagram of D-STATCOM.

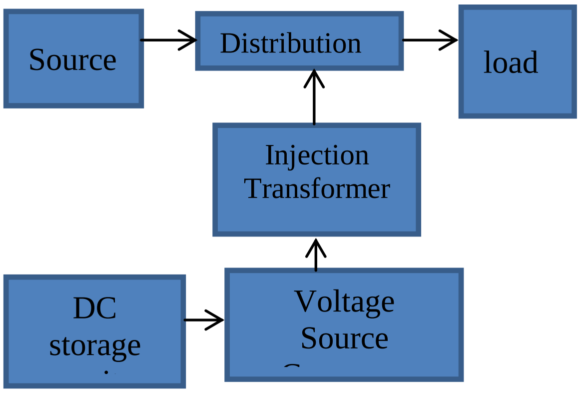

Figure-1. Basic block diagram of DSTATCOM

a. Voltage Source Converter (VSC): The VSC connected in shunt with the AC system converts the dc voltage of the storage device. It serves three purposes:
   - Voltage generation and reactive power injection.
   - Correction of power factor.
   - Elimination of current harmonics.

b. Injection transformer: It is a two winding transformer one is high voltage side and other is low voltage side. One side i,e the high voltage side is connected in shunt with the distribution network while the low voltage side is connected to the D-STATCOM circuit. The D-STATCOM transfers the current into the system through the injection transformer. In this paper three single phase transformer is used to couple D-STATCOM and the three phase distribution line. The injection transformer also isolates the distribution line from the D-STATCOM.

c. Control unit: A controller is used for proper operation of D-STATCOM system. In this paper PI controller is used to study the operation of D-STATCOM under the influence of faults and dynamic load.

d. DC storage: The function of the energy storage device or dc storage is to supply necessary energy to the VSC which will convert the direct quantity into alternating quantity and fed to the main distribution line through the injection transformer. Batteries are most commonly used energy storage devices and the battery determines the amplitude of the voltage sag or swells which can be compensated by the D-STATCOM.

PI based DSTATCOM:

The control unit is basically a controller which defines the proper operation the D-STATCOM. Different types of controller such as PI, PID, Fuzzy, etc. can be used. In this paper uses PI controller and observe the behaviour of D-STATCOM under different faults and the application of dynamic load.

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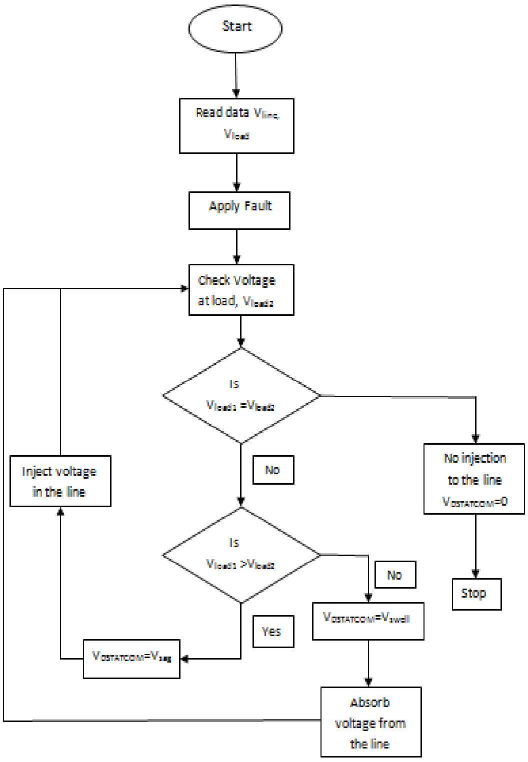

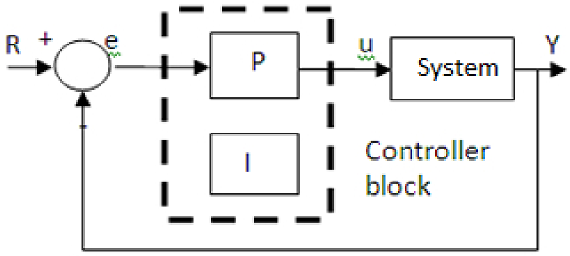

Figure-2.Basic PI controller

PI controller is the combination of proportional and integral terms. It helps in increasing the speed response and also to eliminate the steady state error. The block diagram of PI controller is shown in Fig.2. The proportional and integral term is given as:

$$u(t) = K_p e(t) + K_i \int e(t)dt$$

K_p and K_i are proportional and integral constant respectively that is used to adjust the output. D-STATCOM detects the presence of voltage sag, swell and operates to mitigate the voltage sag and swell. Pulse Width Modulation (PWM) control technique is used for inverter switching so as to generate a three phase 50 Hz sinusoidal voltages at the load terminals. The load voltage magnitude is compared with reference voltage i.e. the supply voltage and if there is any difference then error signal will be generated. Switching or triggering signal is provided by the error signal which is required to drive the PI controller, in turn control the operation of the D-STATCOM.

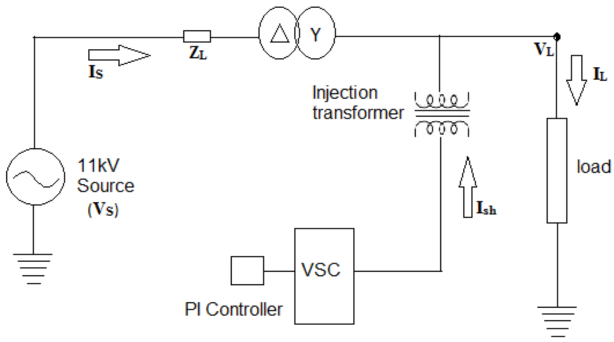

Figure-3. Schematic diagram of a D-STATCOM

III. THEORITICAL CONCEPT OF D-STATCOM

The schematic diagram of a D-STATCOM is shown in Fig.3. 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 controls the output voltage of the VSC. The injected current **I_{sh}** can be written as

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

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

$$= I_L - \frac{V_S - V_L}{Z_L}$$

Where, I_L= Load current.

I_{sh}= Reactive current generated by D-STATCOM.

I_s= Source current.

Z_L= Line impedance.

The flow chart of Fig.4 depicts the method implemented in this paper. At the very beginning the magnitude of the line voltage (V_{line}) and load voltage (V_{load1}) which is in quadrature with the current are measured which are approximately equal due to small line drop. Then on the application of the fault/ dynamic load the magnitude of the load voltages changes to a great extent. The load voltage is measured again and it becomes equal to V_{load2}. Then with dynamic load voltage and without it is compared if V_{load2} = V_{load1} then D-STATCOM will not inject/ absorb any current, if $V_{load2} < V_{load1}$ then D-STATCOM will inject the current and if $V_{load2} > V_{load1}$ then it will absorb the current to improve the voltage sag and swell. The D-STATCOM will inject or absorb the current till it detects the difference in load voltages i.e. V_{load1} and V_{load2}. The D-STATCOM will maintain the load voltage at the desired level.

Figure-4. Flow chart of control scheme of D-STATCOM

IV. SYSTEM PARAMETERS

Table 1 shows the parameters of proposed D-STATCOM model. The test model consisting of a distribution line supplied by a 3- phase source of 11Kv, 50 Hz and a two winding transformer.

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TABLE 1 SYSTEM PARAMETERS

Sl. No.	System Quantities	Standards
1	Source	3 phase, 11Kv, 50 Hz
2	VSC	IGBT based, 6 pulse Carrier frequency=1080 Hz, Sample time=50 μs
3	PI Controller	Kp1=20, Kj1=154, Sample time=50 μs Kp2=25, Kj2=260, Sample time=50 μs
4	Dynamic Load	Active power- 50MW, Reactive power- 25MW Nominal L-L Voltage- 10KV, Frequency- 50Hz np= 1.3 nq=2, Tp1=Tp2=Tp3=Tp4=0
5	Two Winding Transformer	Y_g/?,11/11Kv

V. SIMULATION RESULTS AND ANALYSIS OF PROPOSED DSTATCOM MODEL

In this section the various results obtained after simulation are analysed and discussed. The proposed
simulink model of D-STATCOM is shown in the Fig.5. The test system comprises of 11kV distribution network and the system has been examined under the presence of LG, LLG, LLLG and three phase dynamic load.

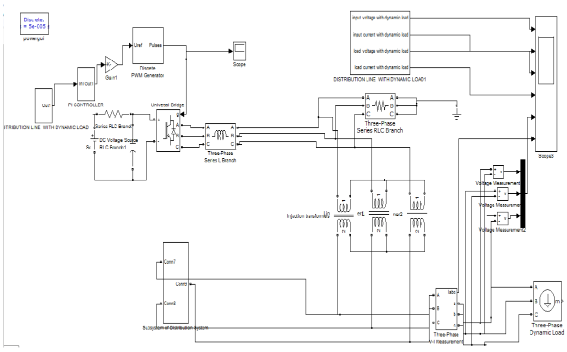

Figure-5. DSTATCOM with dynamic load

The simulation time for model is taken as 1 sec. The first simulation was done in normal condition without any voltage fluctuation at the network where supply is 11kV with 50 Hz frequency. Fig. 6(a) and 6(b) shows the waveform of both input and load voltage during normal condition.

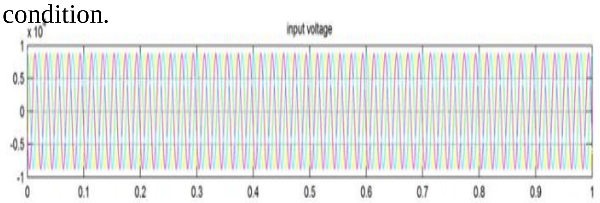

Fig. 6(a): Input voltage waveform.

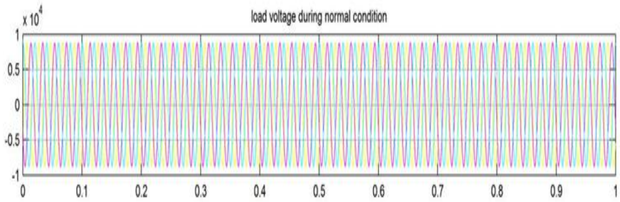

Fig. 6 (b): Load voltage waveform.

(a) Single Line to Ground Fault:

The second simulation is done by applying single line to ground fault with fault resistance of 0.66Ω for a time duration of 100 milliseconds (from 0.1s to 0.2s) and ground resistance is 0.001Ω. Fig. 7 (a) shows the input current with fault, as fault current is supplied by the source only so the current increased during fault from the nominal value and input voltage remains unaffected. 7 (b) shows the waveform of the load voltage with fault and without D-STATCOM. The fault is applied at the phase 'A' of the distribution line, the magnitude of the load voltage decreases closed to zero at the fault period causing voltage sag at that phase and the voltage at other two phases increases from 9 kV to 15 kV causing voltage swell. This voltage fluctuation is compensated to get the desired voltage at the load.

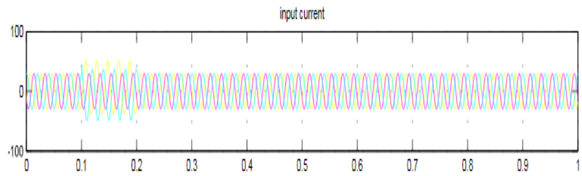

Figure-7(a). Input current waveform with fault

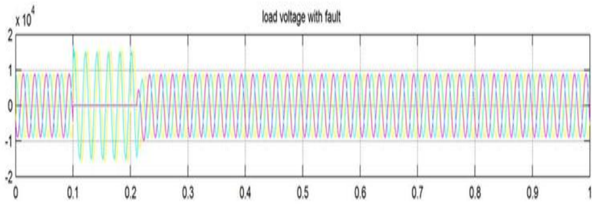

Figure-7(b). Load voltage waveform with fault

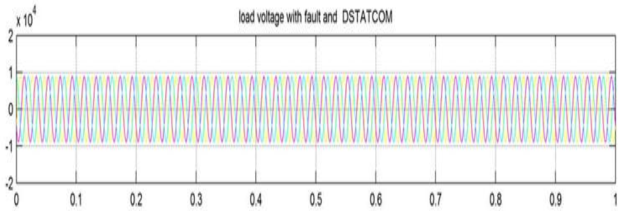

Figure-7(c). Load voltage waveform with fault and DSTATCOM

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Fig. 7 (c) shows the waveform of load voltage when the D-STATCOM is introduced at the load side to compensate the voltage sag and swell occurred due to the single line to ground fault applied. It is clearly observed from the above load voltage waveform that is obtained after connection of D-STATCOM in shunt is equal to the desired load voltage i.e. the installed D-STATCOM is working efficiently.

(b) Double line to ground fault (LLG): Fig. 8(a) shows the input current and 8(b) shows the load voltage waveform when a LLG fault occurs on phase 'A' and phase 'B' and it is observed during fault the input current increases from its nominal value for the two phases. For the load voltage, voltage sag occurs at phase 'A' and phase 'B' and load voltage at the faulted line reduced from 10000V to 500 V and voltage swell occurs at the phase 'C' as it increased from 10000V to 14000V. After compensation voltage magnitude is almost equal to the desired load voltage as shown in fig. 8(c).

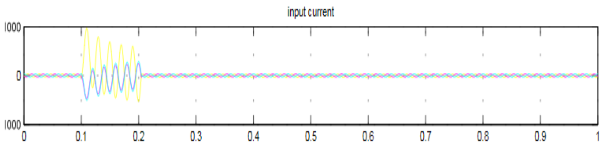

Figure- 8(a). Input current waveform with fault

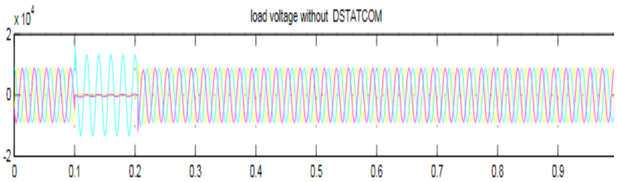

Figure- 8(b). Load voltage waveform with fault

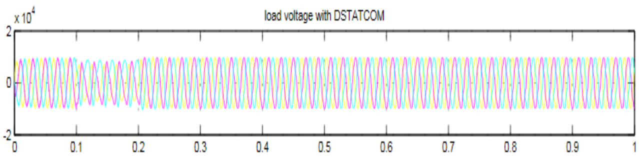

Figure-8(c). Load voltage waveform with fault and DSTATCOM

(c) Three phase to ground fault: Fig.9 (a) shows the input current with fault, as fault current is supplied by the source only so the current increased during fault from the nominal value and input voltage remains unaffected. Fig.9 (b) shows the waveform of the load voltage with fault and without D-STATCOM. When the fault is applied on the distribution line, the magnitude of the load voltage decreases closed to zero at the fault period causing voltage sag. This voltage fluctuation is compensated to get the desired voltage at the load. When the DSTATCOM is connected to the system the load voltage becomes almost equal to the desired load voltage shown in fig. 9(c).

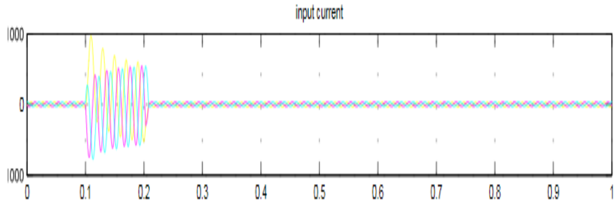

Figure- 9(a). Input current waveform with fault

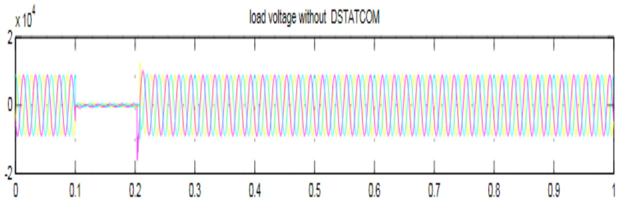

Figure-9(b). Load voltage waveform with fault

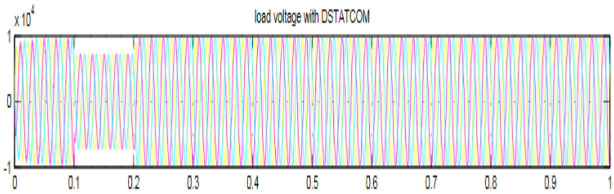

Figure- 9(c). Load voltage waveform with fault and DSTATCOM

(d) Dynamic load:

This simulation is done by applying a dynamic load in the system. Due to the application of the dynamic load voltage magnitude increases from 10kV to 20kV. Fig.10 (a) shows the waveform of load voltage without compensation.

Fig. 10(b) shows the waveform of load voltage with compensation. The DSTATCOM is introduced at the load side to compensate the voltage swell occurred due to application of dynamic load. The swell in voltage is compensated and the voltage that was increased to 20kV due to dynamic load, reduced to 10kV by the application of D-STATCOM connected to the distribution line. It is clearly observed that the voltage waveform that is obtained after connection of D-SATCOM in shunt is almost similar to the desired load voltage.

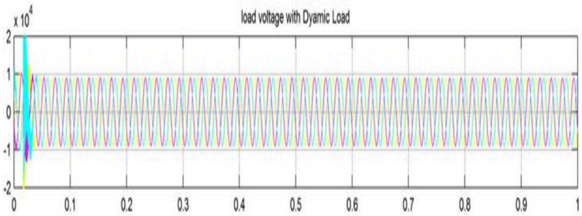

Figure- 10(a). Load voltage waveform without Compensation

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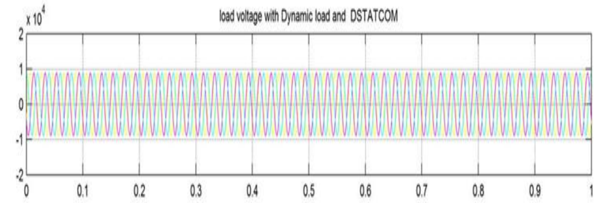

Figure-10(b). Load voltage waveform with Compensation

VI. CONCLUSION

In this paper, the simulation of D-STATCOM is done using MATLAB software and it became easier to construct the large distribution network and analyze the performance of D-STATCOM under two different conditions (such as Voltage Sag and Swell). The controlling of D-STATCOM is done with the help of PI controller. The simulation results clearly showed the performance of the D-STATCOM in mitigating the voltage sag and swell due to LG, LLG, LLLG and application of dynamic load. The control signal of the D-STATCOM can be provided by PI controller. D-STATCOM is one of the fast and effective custom power devices and has shown the efficiency and effectiveness on voltage sag and swell compensation hence it makes D-STATCOM to be an efficient power quality improvement device that has been shown through the simulation results. From the results it is found that in case of LG and LLG faults and application of dynamic load the load voltage becomes almost similar to the load voltage before fault or desired load voltage and LLG fault load voltage not exactly equal to the desired load voltage. In future, the multilevel inverter can also be used for designing D-STATCOM which has been used for voltage sag and swell compensation in this paper.

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BIOGRAPHY

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