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Performance of DVR under various Fault conditions in Electrical Distribution System

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Abstract: *Power quality improvement has become a major area of concern in present era. Due to the increase in modern sensitive and sophisticated loads connected to the Distribution System it has been very important to improve the quality of power because nonstandard voltage, current or frequency results a failure of the loads connected to the systems. Power electronics and advanced control technologies have made it possible to improve the quality of power and operate the sensitive loads satisfactorily. One of the major problems dealt in this paper is the voltage quality which is very severe for the industrial customers as it can cause malfunctioning of several sensitive electronic equipments. Dynamic Voltage Restorer (DVR) is a solution to improve voltage quality, which is connected in series with the network. This paper presents modelling, analysis and simulation of DVR in MATLAB SIMULINK, which includes PI controller and discrete PWM generator for control purpose of DVR. Simulation results of performance of DVR under different fault conditions such as single line to ground fault (SLG), double line to ground fault (DLG), line to line fault (L-L), three phase to ground fault etc. are presented in this paper. The results showed clearly the performance of the DVR in voltage quality improvement.*

Keywords: *Dynamic Voltage Restorer (DVR), voltage quality, PI controller, Pulse Width Modulation (PWM), power quality.*

I. Introduction

Modern society is critically dependent on the supply of electricity. The electrical power system consists of three functional blocks i.e. power generation, transmission and distribution, which is in the form of alternating current. The generated power should have certain electrical properties that allow electrical system to function in their intended manner. It should energize all electrical equipment equally and satisfactorily. Power travels long distances through transmission lines and due to various 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 serve any load. In present scenario power quality is directly related to distribution system because distribution system locates at the end of the power system and is directly connected to the customer. The distribution system can be defined as that part of power system which distributes electrical power to the consumer for utilization [2]. Earlier the prime focus for power system reliability was on generation and transmission system but now a day's distribution system receives more attention 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.

Some consumers require a good quality of power higher than the level provided by modern networks of electricity, hence many efforts have been under taken to fulfil consumer requirement. For delivering clean and pure power 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. Generally FACTS devices are designed for the transmission system and 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) [4]. With the help of these devices power quality problems are reduced to a great extent. 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 heart of the DVR and its main function is to detect the presence of voltage disturbances (sag/swell) in the electrical system and operate the VSC to supply the required amount of compensating voltage. The controlling signal is generated by a Proportional Integral (PI) Controller and a PWM Generator, which control the output of DVR. PI controller is a type of feedback controller which operates the system to be controlled with a weighted sum of error. It generates the desired signal for the PWM generator to trigger the PWM inverter. The Phase lock loop (PLL) and dq0 transformation are also the basic components of DVR [7].

This paper shows the performance of DVR in improving the quality of power under different fault conditions i.e. single line to ground fault, double line to ground fault, line to line fault, three phase to ground fault,. The theory related to DVR operation and its different parts have been discussed in the next section. This paper composed of additional five sections. In section 2 configuration and operation of DVR is explained. In section 3 control mechanism and simulation details of DVR are provided. In section 4 Analysis of the results of the test system are illustrated. In the last section, some conclusions are drawn.

II. Configuration And Operation Of DVR

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 is one of the efficient and effective custom power devices. DVR is connected in series with the line and injects or absorbs voltage in order to compensate the voltage sag or swell in the load side and maintains flat voltage profile at the load end.

DVR is a solid state power electronic switching device comprises of the following components:

i. Storage unit
ii. Voltage source Inverter
iii. Injection transformer
iv. Control unit.

2.1. Principle of operation of DVR

DVR is connected in series with the line between main supply and load as 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.

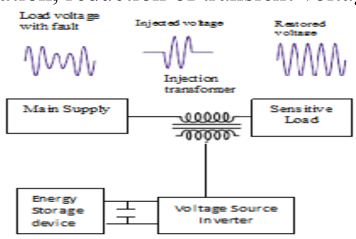


Fig.1. Operating principle of DVR

i) Storage unit: The function of the storage unit 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 storage unit and the capacity of the battery is determine the amount of the voltage which should be compensated by the DVR.

ii) Voltage Source Inverter (VSI): A voltage source inverter is a power electronic device consisting of switching devices and a storage unit such as battery. VSI is used to generate three phase voltage at any required magnitude, phase and frequency to compensate the load voltage at the required value. IGBT is the newer compact switching device that is used to design VSI for DVR operation.

iii) Injection transformer: It is used to couple the VSI 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. In this paper three single phase transformers are connected instead of a single three phase injection transformer and each transformer is connected in series with each phase of the distribution line to couple the VSI (at low voltage level) to the higher distribution level. The transformer also helps in isolating the line from the DVR system.

iv) Control unit: A controller is used for proper operation of DVR, which detect the presence of voltage disturbance and operate VSI to mitigate the voltage sag/swell. Pulse Width Modulation (PWM) control technique is applied for inverter switching so as to generate a three phase sinusoidal voltage. The magnitude of load voltage is compared with reference voltage and if any difference is there error signal will be generated, which is an actuating signal. This error signal drives the PI controller and the final output signal which is obtained (Fig.2) controls the pulses for the Inverter. PI controller is a feedback controller which controls the system depending on the error signal. In PI controller technique the proportional response can be obtained by multiplying the error with constant K_p (proportional gain) and the integral response is proportional to both the magnitude of error and duration of error.

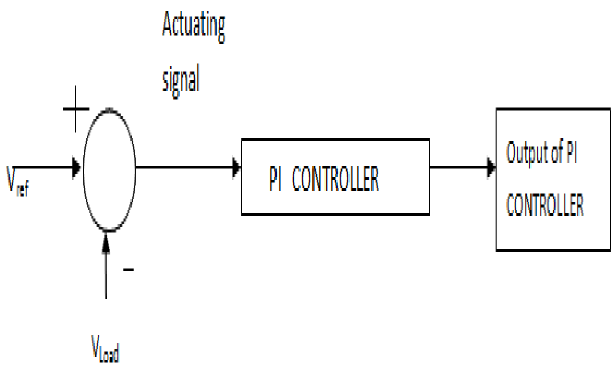


Fig.2. Operation of PI controller

In this paper, 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 dq0 rotating quantity. The dq0 transformation technique is used to give the information of the depth (d) and phase shift (q) of voltage sag/ swell with starting and ending time. The V_0, V_d and Vq are obtained as

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

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

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

Conversion of the three phase voltage $V_{a,}$ V_b and V_c into two constant voltages V_d and V_q is done for easy control of the system. The controller input is the output voltage measured by three-phase V-I measurement at load and this load voltage is then transformed into the dq form. If there is any voltage sag/ swell then the error signal is generated from the difference between the dq voltage and the reference voltage. The d- reference is set to the rated voltage while the q- reference is always set to zero. The gains such as K_p and K_i control the stability of the system. The output obtained from the PI controller is then again transformed back to V_{abc} by dq0 to abc converter before it is forwarded to the PWM generator, which generates 6 pulses to trigger the PWM inverter.

2.2 Mathematical Model of DVR:

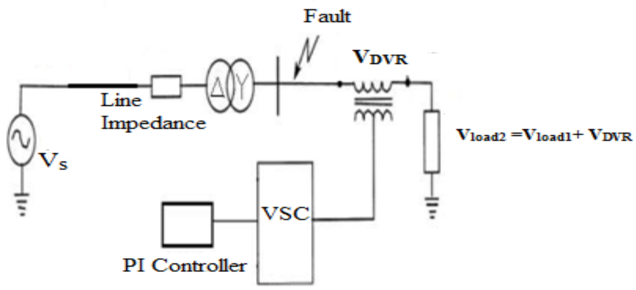


Fig.3. Overall diagram of DVR

From Fig.3 the equation of voltage is found to be

$V_{DVR} = V_{load2} - V_{load1}$ (4)

Where,
V_{load2} = Desired load Voltage
V_{load1} = Load voltage during fault
V_s = Supply voltage.

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_{load1} can be maintained at required level.

III. Control Mechanism And Simulation Details Of DVR

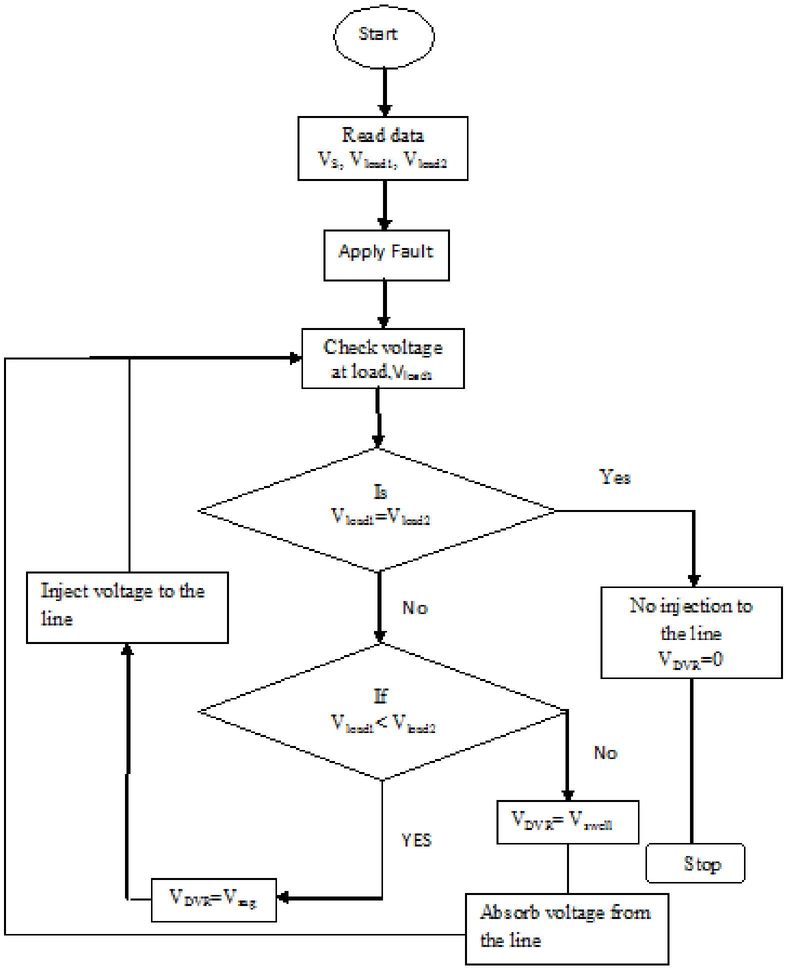


Fig.4. Flow chart of control scheme of DVR

The Fig.4 shows flow chart of the method implemented in this paper. At the very beginning the magnitude of source voltage V_S and load voltage V_{load2} are measured. When a fault is applied at the distribution line and magnitude of the load voltage is measured again and it becomes V_{load1}. Then V_{load1} is compared with V_{load2} if V_{load1} is equal to V_{load2} then DVR will not operate i.e. no injection of voltage to the line. But if V_{load1} is less than V_{load2} then DVR will inject the sag voltage V_{sag} and if V_{load1} is greater than V_{load2} DVR will absorb extra voltage. After injection or absorption the new voltage will be $V_{load1}=V_{load2.}$ The DVR will operate until it detects the difference between the load voltage before fault and during fault, i.e. the DVR will maintain the load voltage at nominal value until the fault is removed.

Table 1: System Parameters

Sr. No	Parameters	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 μs
3	Proportional Integral Controller [2]	K_{p1} = 20, K_{i1} = 154, Sample time = 50 μs, K_{p2} = 25, K_{i2} = 260, Sample time = 50 μs
4	RL load	Active power = 1kW, Inductive Reactive power = 500 VAR
5	Two winding transformer	Y_g/Δ, 11/11KV

The components required for constructing the DVR test model is shown in the Fig.3 and Table1 shows the parameters of DVR test system consisting of 11KV, 50 Hz source feeding one distribution line through a two winding transformer.

IV. Results And Analysis Of The Proposed DVR Model

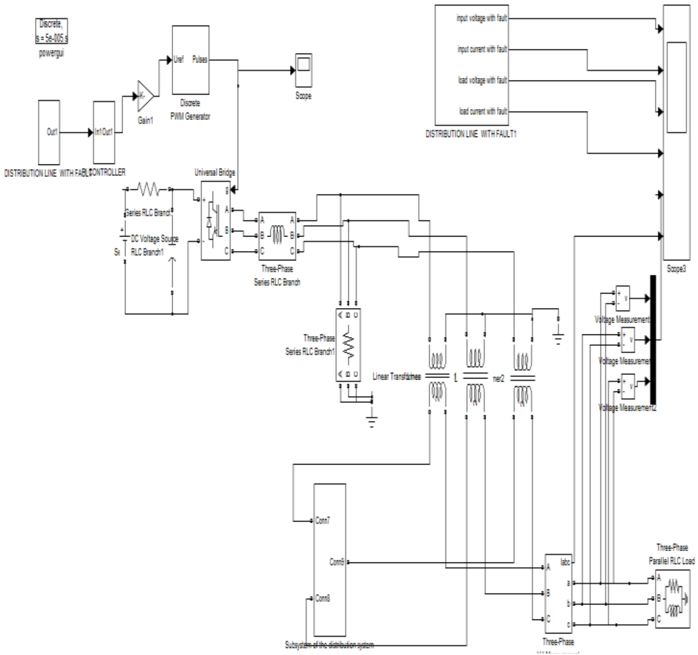


Fig.4. DVR Test model

4.1 Fault analysis:

Voltage disturbance is created by applying fault on the test system at the load side. The various results obtained by applying different types of faults i.e. SLG, DLG, L-L fault, three phase fault to ground. Simulation results are analysed and discussed. The test system is shown in Fig. 4, which is implemented by using MATLAB software. The test system comprises of 11KV distribution network with three phase parallel RL load.

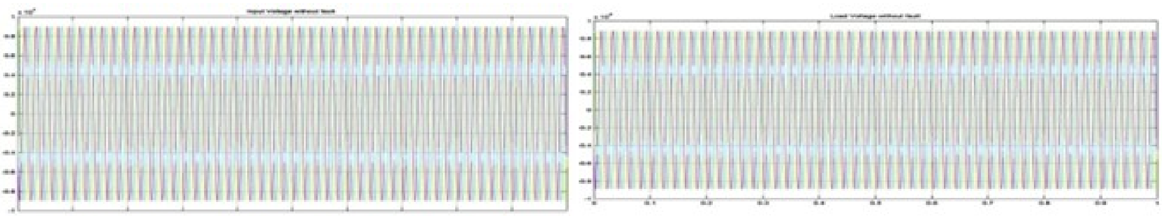
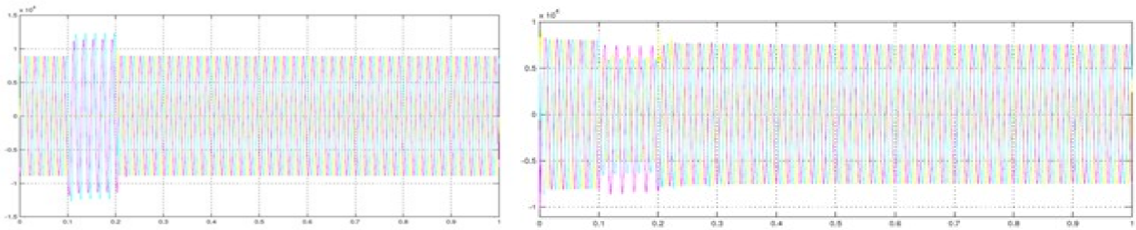


Fig.5.Input and load voltage without fault

Fig.5 shows the waveforms of input voltage and load voltage without creating any fault on the distribution network. Input voltage and load voltage is found to be almost equal to 9000KV. Load voltage is slightly less than input voltage due to voltage drop in the line. The system is operated twice for each types of fault. The simulation time for the model is taken as 1 sec. The first simulation is without DVR and second simulation is with DVR 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.

4.1.1 Single line to ground fault:

Fig.6 (a) shows the load voltage when single line to ground fault applied on phase 'A'. Fig.6 (b) shows the load voltage after compensation.

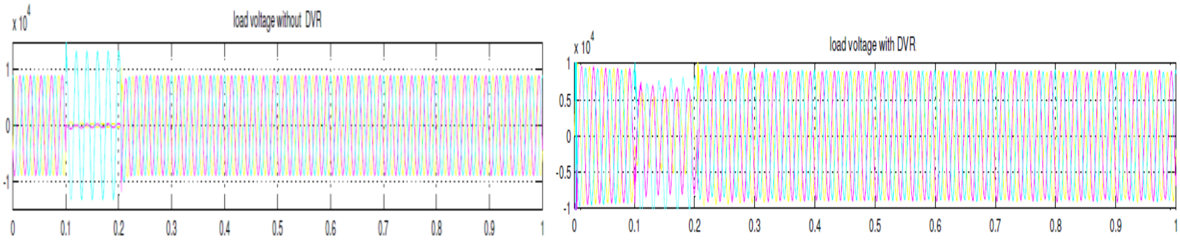


(a) (b)

Fig.6 (a) load voltage without DVR; (b) load voltage with DVR.

It is seen from the Fig.6 during SLG fault voltage at the faulted line reduced to 250 V from 9000V i.e. voltage sag occurs at phase 'A' and voltage at the other two phases increased to 13000V from 9000V i.e. at phases 'B' and 'C' voltage swell occurs. When DVR is connected to the line the load voltage becomes almost equal to the desired load voltage.

4.1.2 Double line to ground fault:

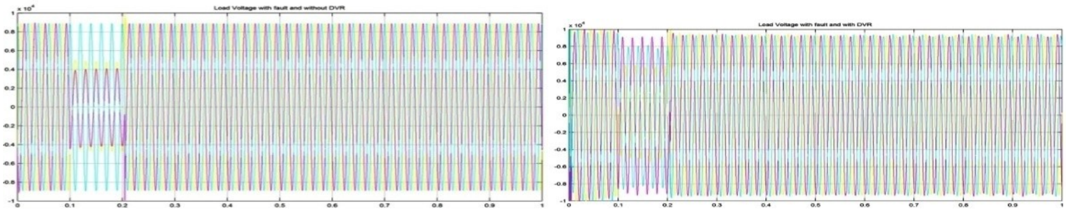


(a) (b)

Fig.6 (a) load voltage without DVR; (b) load voltage with DVR.

Fig.6 (a) shows the load voltage when double line to ground fault is applied on phase 'A' and phase 'B'. Fig.7 (b) shows the load voltage after compensation. The fault is applied on phase 'A' and 'B' thus voltage dip is observed in Red and Yellow phase of the system and its magnitude reduced to 500 V while phase 'C' i.e. voltage of Blue phase has been increased to 1.4 KV. When DVR is connected to the system it is seen that voltage dip occurring in the two phases are compensated to a great extent.

4.2.3 Line to line fault:



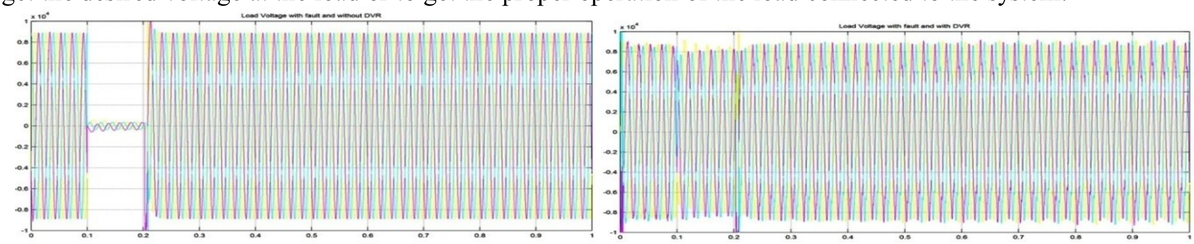
(a) (b)

Fig.7. (a) load voltage without DVR; (b) load voltage with DVR.

Fig.7 (a) shows waveforms for the load voltage without DVR compensation for L-L fault. When fault is applied in phase 'A' and 'B' voltage dip is observed in Red and Yellow phase of the system and its magnitude reduces from 9000 to 5000 V while phase 'C' i.e. voltage of Blue phase remains unaffected. Simulation result of Fig. 7 (b) shows the load voltage waveform when DVR is connected to the system and it is seen that voltage dip occurred in the two phases are compensated to a great extent.

4.1.4 Three phase to ground fault:

Fig.8 (a) shows the waveform of load voltage with fault and without DVR. During fault period the magnitude of the load voltage decreases from 9000V to 800V. This voltage dip is needed to be compensated to get the desired voltage at the load or to get the proper operation of the load connected to the system.



(a) (b)

Fig.8. (a) load voltage without DVR; (b) load voltage with DVR.

The simulation result of Fig.8 (b) shows the load voltage waveform when DVR is introduced at the load side to compensate the voltage sag occurred due to the three phase fault applied. From this figure it is clearly observed that the voltage waveform that is obtained after connection of DVR in series is almost similar to the load voltage without fault.

It is observed from the above figures that due to fault the load voltage reduce to a very low value. If we compare the waveforms of load voltage with and without DVR, we observed that when the DVR is in operation the voltage dip is compensated almost completely and the r.m.s voltage at the sensitive load is maintained at desired value i.e. near about 9000 V. The DVR is designed to supply or absorb difference in voltage under different fault conditions i.e. until the fault is removed from the network.

V. Conclusion

In this paper, the simulation of a DVR is done using MATLAB SIMULINK software. Thus it became easier to construct the large distribution network and analyse the performance DVR under different fault conditions. The controlling of DVR is done with the help of PI controller. The simulation results clearly showed the performance of the DVR in improving the quality of voltage due to faults in distribution system. DVR is one of the fast and effective custom power device has shown the efficiency and effectiveness on voltage sag and swell compensation hence it makes DVR to be an effective power quality improvement Device. This has been proved through simulation implementation. The proposed work showed that in case of SLG fault and three phase fault almost 95% of compensation is done and in case of DLG and L-L fault voltage compensation took place for almost 75% and 44%.

Besides PI controllers, other controllers like fuzzy controllers and adaptive PI fuzzy controllers can also be used as a DVR controller. In future, the multilevel concept of inverters will be a prominent choice for power electronic systems mainly for medium voltage operation. Multilevel inverter concept is the best alternator to employ low-frequency inverters with low output voltage distortion.

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