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Investigation and Performance Analysis of Distribution System Using Dynamic Voltage Restorer

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Abstract—

This One of the major problems observed in distribution system in recent days in power system as Capacitor switching, lightning surge, Interruptions, Sags/Swells, Harmonics, Flicker. The major problem sag and swell not only occur by the disturbed power quality but also due to high system tapping at the point of common coupling in the system. The non linear load is also creating the same problem at the load end. The Dynamic Voltage Restorer is recognized as the best solution for distributed system.

This modeling, simulation and analysis of advanced DVR system for solving sags and swell problem. The PI control scheme is used for generating the gate pulse for IGBT bridge converter. The different types of fault are creating in the system and for analyzing the result. The role of DVR is to compensate the load current and voltage is investigated during the fault condition. Over all the DVR is improving the voltage quality as well as the reactive power demand during the uncharacteristic condition. Result is compare with and without DVR system and validated in different input/output conditions.

Keywords— DVR, PWM, SLG, MATLAB & SCADA.

I. INTRODUCTION

It had been observed that in modern industrial devices most of devices are based on electronic devices such as programmable logic controllers and electronic drives. The power electronic devices are very sensitive to disturbances and become less tolerant to power quality problems such as voltage sags, swells and harmonics in the entire problems associated with voltage dips is considered as one of the most severe disturbances to the industrial equipment.

To saturate the growing need of power in developing countries like India dispersed generation will provide power to rural areas by the application and development of wind, photovoltaic generators, micro turbines, mini hydro plants and biomass, etc. Dispersed generators are connected to power grid through power electronics based converters. Therefore their protection attains great significance and their emergence with the main power grid affects the power quality to a large extent. Therefore, the future electrical delivery system must be shaped up in such a way that it becomes capable of meeting various requirements of electrical power customers. For this, the power supply must utilize several new equipment and technologies that are under developing stage at present.

The problem of poor power quality like voltage sag for sensitive loads can be better dealt or solved by power electronics based Dynamic Voltage Restorer[1]. With the application of DVR, the power system can be operated without voltage sag and the power supply by flexibly changing the distribution configuration after the occurrence of a fault.

A safe, reliable and clean power supply to industries is a pre-requisite for their profitable operation and industrial activities. The concept of custom power supply has been proposed using advanced power electronics equipment to ensure a high quality of power supply and which could better mitigate the problems associated with power quality.

Custom power technology is a general term for the equipments which are capable to mitigate numerous power quality problems including voltage sags.

The basic three customer power applications are as follows:

- Switching the load to another supply
- Injected missing voltage from an energy storage
- Injected missing voltage by increasing the line current (booster)

Basic functions of customer power applications are fast switching and current or voltage injection for correcting anomalies in supply voltage or load current. Injecting or absorbing both active and reactive power is possible in these applications. Current injection is typically used for protecting the power system from a polluting load.

The DVR is a series conditioner based on a pulse width modulated (PWM) voltage source inverter (VSI), which could generate or absorb real or reactive power independently[2]. The condition of Voltage sags caused by unsymmetrical line to line, single line to ground (SLG), double line to ground fault and symmetrical three phase faults is, influenced in case of sensitive loads. The DVR injects the individual voltages to restore and maintained sensitive loads to its nominal value[3].

SSSC and DVR are the two different devices used for mitigating voltage sags like protecting a sensitive load for network disturbance. Both devices are having same structure, but operating principles of these devices differs significantly. Means the operating differences are more significant than the structural differences. SSSC injects a balanced voltage in series but the DVR may have to inject unbalanced voltages to maintain the voltage at the load terminals in case of an unbalanced sag in the supply side. The advantages offered by the DVR in comparison of SSSC are its faster response, ability to compensate for voltage sag and a voltage phase shift using an inverter system[4].

The problem of supplying clean power to sensitive loads could better be handled and simplified by the application or integration of DVR systems. Voltage at a load side could be achieved by reactive power injection at the load point of common coupling. The common coupling methods are used to install mechanically switched shunt capacitors in the primary terminal of the distribution transformer. The mechanical switching may be on a scheme, through the signals from a supervisory control and data acquisition (SCADA) system, using some timing schedule, or no switching at all and the only demerit is that, high speed transients cannot be compensated. Some voltage sags are not corrected within the limited time frame of mechanical switching devices. To mitigate or eliminate the demerits transformer taps may be employed, but tap changing under load is costly.

A new control strategy has been developed for achieving maximum benefits by eliminating or mitigating voltage sag / swell and power quality problem when abnormal condition occur in the distribution system, for this purpose the dynamic voltage restorer is proposed to improve the power quality and to reduce the sag and swell problem in the system[5]. The DC link capacitor clamped converter is connected with series through transformer. We have proposed that if DC source is integrated with grid, with developing adequate control of grid-interfacing inverter, all objectives can be accomplished either individually or simultaneously..

The DVR could be utilized as:

- Power converter to inject power at the time of fault in the system from DC source to the Grid.
- Compensating voltage unbalance, sags, and load reactive power demand.
- A supplier of the voltage at the time of heavily loaded conditions (with permissible limit).
- When system is lightly loaded, DVR can store the power or capacitor can be charges through it, which is utilize at the time of abnormal condition.
- As a very less cost effective device for improving the quality of power in distribution system comparatively other methods.

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II. OBJECTIVES OF THE PAPER

The various objectives formulated and positioned for observation in the thesis are:

1. To study and analyze the complete distribution system and their problem.
2. To develop a mathematical model of various components DVR System, Voltage Sag, Three-Phase Inverter with Output LC Filter.
3. To examine and analysis proposed model with and without Dynamic Voltage Restorer (DVR) system using MATLAB / SIMULINK.
4. To study the input/output condition of developed DVR system for different case like voltage sag, swell and faulty observation with different fault conditions.

III. DIFFERENT POWER QUALITY ISSUE IN THE DISTRIBUTED SYSTEM

Quality of power is a parameter which ensures the robustness, consistency, permanence, constancy and harmonization of voltage; Power quality means the fitness of electrical power and its stabilized disposition to power consumer device. Synchronization of the voltage frequency and phase allows electrical systems to function in their intended manner without significant loss of its performance or expected life[6].

Power quality issues are obtaining increasing attention by both industrial and commercial electrical consumers because on its escalating utilities. Power quality is defined in the term of transmission and distribution voltages turn up relatively few complaints about the quality of their incoming power.

Power quality is not a single unit measurement it is a collection of several typeset which includes:

- Capacitor switching (Transient)
- Lightning surge (Transient)
- Interruptions (Disturbance)
- Sags/Swells (Disturbance)
- Harmonics (Steady-state)
- Flicker (Steady-state)
- Voltage regulation (Steady-state)
- Reliability (Steady-state)
- Power factor (Steady-state)

IV. DESIGINIG AND OPERATION OF DYNAMIC VOLTAGE RESTORER

DVR is a recently proposed series connected solid state device that injects voltage into the system in order to regulate the load side voltage. It is usually configured or organized in an allocation system in between the supply and the critical load feeder at the point of common coupling (PCC)[7].

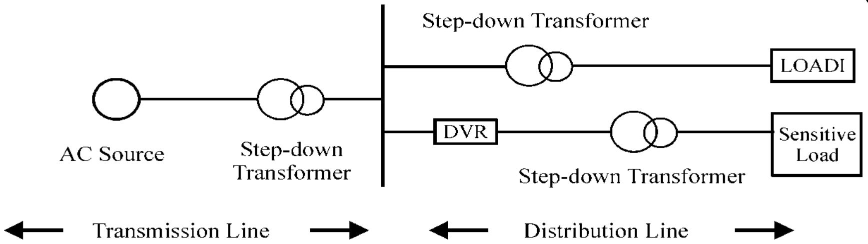

Fig. 1 location of DVR

A. ***Basic Principle of DVR Operation***

A DVR is a solid state power electronics switching device consisting of whichever GTO or IGBT, a capacitor depository as a power storage device and inoculation transformer[8]. It is linked in series between a distribution and a load that shown in fig. 2

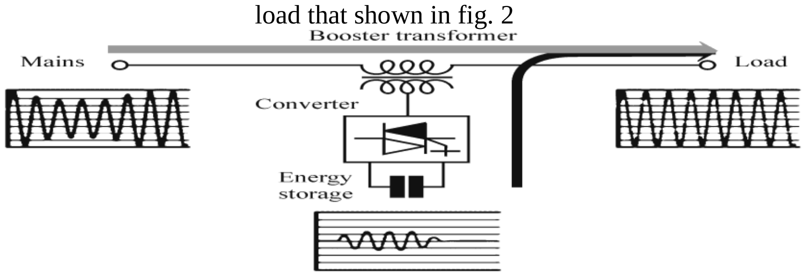

Fig. 2 Principle of DVR with a response time of less than one millisecond

B. ***Basic Configuration of DVR***

The general arrangement of the DVR is composition of:

1) An Injection/ Booster transformer
2) A Harmonic filter
3) Storage Devices
4) Voltage Source Converter (VSC)/VSI
5) DC charging circuit
6) Control and Protection system

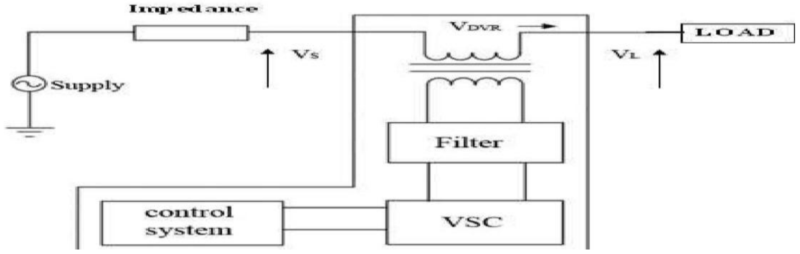

Fig. 3 schematic diagram of DVR

C. ***Operating Modes of DVR***

The fundamental functions of the DVR are to inject vigorously proscribed voltage V_{DVR} which is generated by a forced commutated converter in sequence or series to the bus voltage by resources of a booster transformer. To eliminate any detrimental effects of a bus fault to the load voltage V_L, the momentary amplitudes of the three injected phase voltages are controlled which meant that any differential voltages generated by transient disturbances in the AC feeder will be compensated by an comparable electrical energy generated by the converter and injected on the medium voltage level through the booster transformer[9].

D. ***Protection Mode***

If the excess current on the load side passes over a acceptable boundary or limit due to short circuit on the load or large inrush current, the DVR will be isolated from the systems by using the bypass switches (S2 and S3 will open) and supplying another path for current (S1 will be closed)[10].

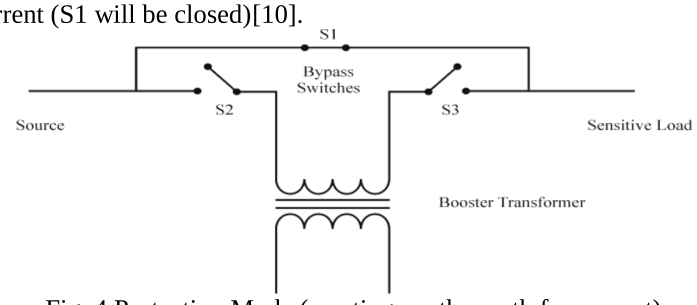

Fig. 4 Protection Mode (creating another path for current)

IV. MATHEMATICAL MODELING OF DVR SYSTEM, PI CONTROLLER ANDVOLTAGE SAG/SWELL IN DISTRIBUTED SYSTEM

A. *Voltage sag calculation*

Consider fig. 5 a normal condition (no fault), current through load A and load B is equal (balance load).When there's fault on feeder 1, a high current (short circuit current) will flow to feeder 1. So, based on Kirchhoff's Law, currents flow to feeder 2 will be reduced. Consequently, voltage will also drop in feeder 2.This voltage drop will be defined as voltage sag.

Assume
Load A = $Z_{LOAD\_A,}$
Load B = Z_{LOAD_B}
Source reactance = X_S , Feeder 1 Reactance = X_1, Feeder 2 Reactance = X_2
Current from supply source = I, Current in feeder 1 = I_1, Current in feeder 2 = I_2,
From fig 1, by using KCL,

$$I = I_1 + I_2 \tag{4.1}$$

In normal condition (without fault in system)

$$I = \frac{V_2}{X_1 + Z_{LOAD\_A}} + \frac{V_2}{X_2 + Z_{LOAD\_B}} \tag{4.2}$$

When a fault occurs (see fig. 5) in feeder 1, because of short circuit, a high current will flow through feeder 1 as well as source current I. During this time, voltage in feeder 2 is decreased due to increasing of voltage drop across source reactance X_S, which results into voltage sag.

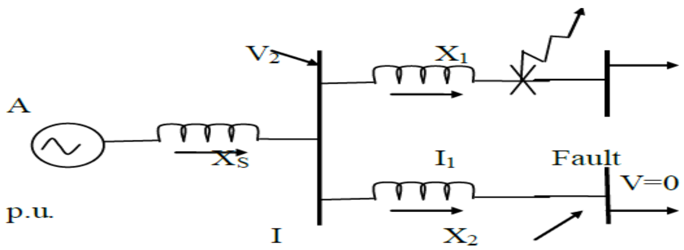

Fig. 5 Calculation for Voltage Sag

$$I = \frac{V_2}{X_1} + \frac{V_2}{X_2 + Z_{LOAD\_B}} \tag{4.3}$$

Here

$$V_2 = V_S - IXS \tag{4.4}$$

Where V_S = Source voltage (i.e., V = 1p.u)

During the fault condition, voltage drop (IXS) increases and hence from equation (4.4), V_2 decreases from its nominal value (i.e., V_2 become as voltage sag).

B. *Mathematical Modeling of PI Controller*

The definition of proportional feedback control is still

$$u = K_p e \tag{4.5}$$

Where
e = is the error, K_P = Proportional gain
The characterization of the essential feedback is

$$u = K_i \int_0^t e(t)\,dt \tag{4.6}$$

K_i = Integration gain factor
In the PI controller we have a combination of P in addition to I control, that is:

$$u = K_p e + k_i \int_0^t e(t)\,dt \tag{4..7}$$

$$u = K_p e + \frac{1}{T_i} \int_0^t e(t)\,dt \tag{4.8}$$

$$u = K_p \left(e + \frac{1}{T_n} \int_0^t e(t)\,dt \right) \tag{4.9}$$

Where

T_i = Integration time, T_n = Reset time

In Proportional plus Integral Control action the actuating signal consists of proportional error signal with integral of the error signal[11]. The block diagram is as shown in fig. 6.

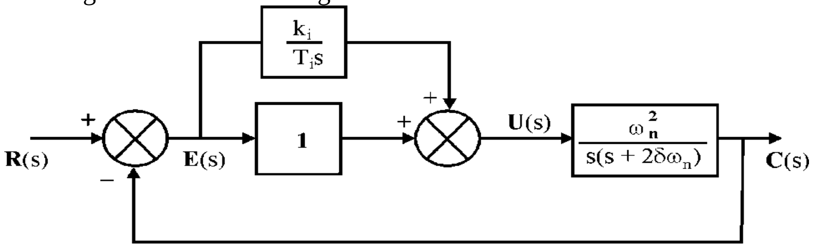

Fig.6 Block diagram of Proportional plus Integral Controller (here K_p = 1)

The input output relationship of PI control action when K_p = 1/t is

$$u(t) = e(t) \frac{+K_i}{T_i} \int_0^t e(t)\, dt \qquad (4.10)$$

The transfer function of the system is

$$\frac{U(s)}{E(s)} = \left[I + \frac{K_i}{T_i s} \right] \qquad (4.11)$$

Where gain, K_p = 1 (already assumed) and T_i =integral time

K_p and T_i are constant and can be adjusted to any required values. Any change in K_p will affect the both the actions i.e. propositional and integral control of the controller while change in T_i would affect only the integral control action.

V. DYNAMIC VOLTAGE RESTORER SYSTEM WITH PI CONTROLLER

Voltage sag is created at load terminals via a fault. Load voltage is sensed and passed through a sequence analyser[12]. The degree is evaluated with position voltage (V_{ref}).

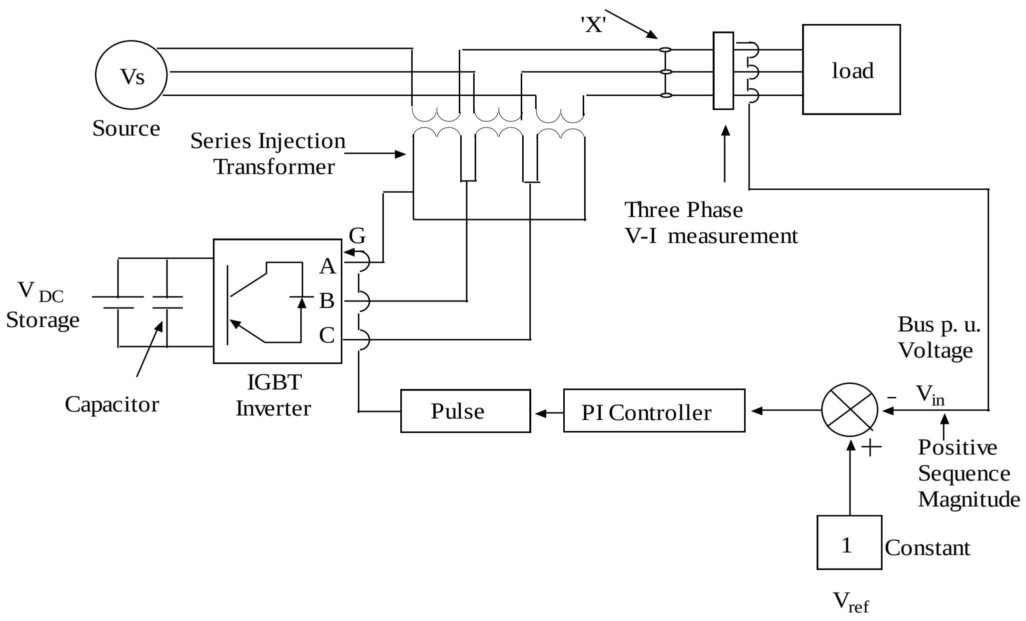

Fig. 7 Circuit Model of DVR System

A. *Dynamic Voltage Restorer with PI Controller*

A dynamic voltage restorer (DVR) is a custom power device used to correct the voltage sag by injecting voltage as well power in to the system. The mitigation capacity of DVR is generally influenced by the maximum load; power factor and maximum voltage dip to be compensated[13]. The DVR is to transfer the voltage which is required for the compensation from DC side of the inverter to the injected transformer after filter. Therefore, there is a maximum voltage required below which the inverter of the DVR cannot generate the required voltage thus size and rating of capacitor is very important for DVR power circuit. The DC capacitor charge in support of a three phase scheme can be consequential. The advantage of these capacitors is the potential to supply high current pulses repetitively for hundreds of thousands of cycles. Assortment of capacitor ranking is conferred on the fundamental of RMS charge of a capacitor current, rated electrical energy of a capacitor in addition to VA evaluation of the capacitor[14].

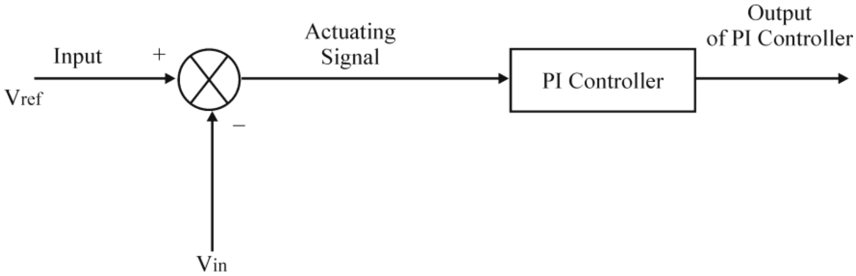

Fig. 8 Schematic of a typical PI controller

VI. SIMULATIONRESULT ANALYSAIS & DISCUSSION

A. *SIMULINK Performance of DVR in Voltage Swell and Sags Conditions*

A systematic presentation of the simulation results for the developed Dynamic Voltage Restorer system connected to the distribution system is presented for both the with and without DVR system conditions. Several different conditions' i.e. voltage rise, voltage dip, single line to ground, double line to ground, triple line to ground and triple line fault etc. simulation result are presented to validate the developed models and control for the proposed DVR system[15].

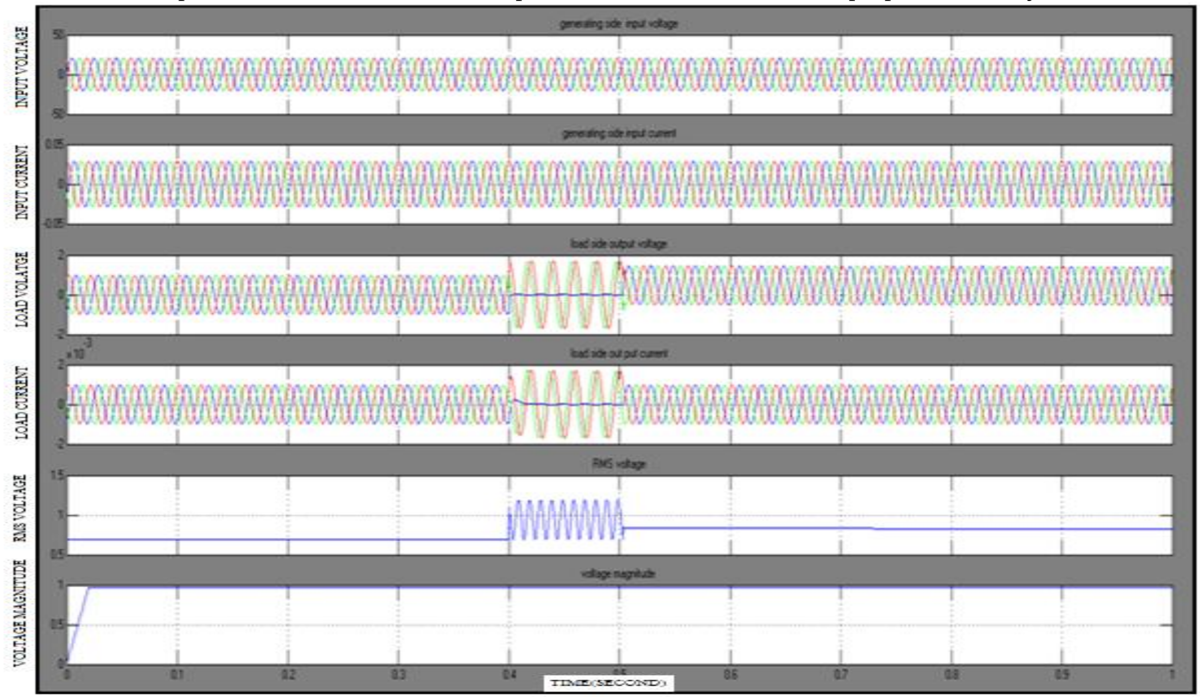

Fig. 9. Output Results for Single Line to Ground

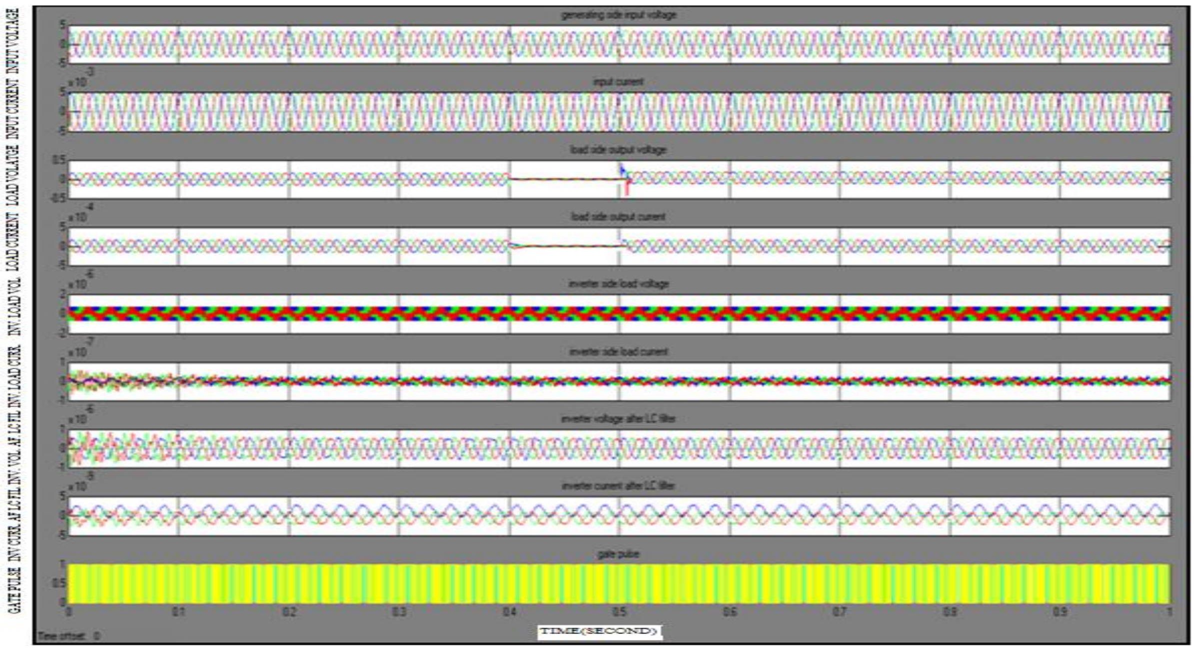

Fig. 10 Output Result for Triple Line to Ground Fault without DVR

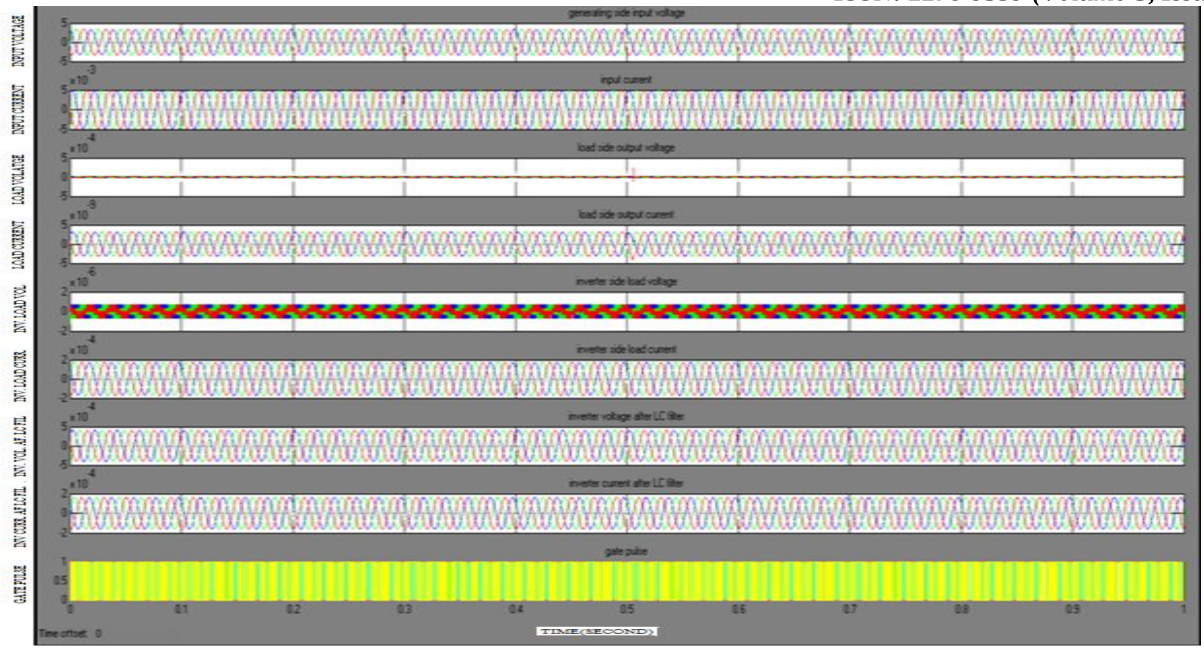

Fig. 11 Output Result for Triple Line to Ground Fault with DVR

VII. CONCLUSION AND FUTURE SCOPE

This report had presented the power quality problems such as voltage sag with the compensation techniques of custom power electronics device DVR. This research work presents comprehensive results for the design and application of DVR for voltage sag. A controller utilizes the error signal which is actually the difference between the reference signal and the actual signal. Voltage source convertor (VSC) was implemented with the help of pulse width modulation. Modeling and Simulation of DVR is done through MATLAB/SIMULINK computer software. The simulation carried out here shows that DVR provide better voltage regulation capabilities. Based on analysis of test system, it is suggested that percentage sag and operating voltage are major factors in estimating the requirement of DC storage capacity. The effectiveness of a DVR system mainly depends upon the amount and stiffness of DC energy storage device. Investigations were carried out for various cases of voltage sags at different transmission voltage levels. Result show that any increase in transmission voltage and voltage sag demands sufficient increase in DC storage capacity. An expression is developed to estimate the required DC storage voltage for specified transmission voltage and percentage sag. In the test system, it is observed that after a particular amount of increases in the load on feeders, the voltage levels at the load terminal decreases.

The following issues are under recommendation for future work in DVR:

- Change the controller of DVR like fuzzy based controller, ANN based controller and PSO based controller scheme.
- The multi-level DVR can be investigated for future work.
- Use of DVR for interconnecting the renewable source to grid.

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