Modeling & Simulation of a Dynamic Voltage Restorer (DVR)

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***ABSTRACT*- Power quality is one of major concerns in the present era. It has become important, especially, with the introduction of sophisticated devices, whose performance is very sensitive to the quality of power supply that results in a failure of end use equipment. One of the major problems dealt here is the voltage sag. To solve this problem, custom power devices are used. One of those devices is the Dynamic Voltage Restorer (DVR), which is the most efficient and effective modern custom power device used in power distribution networks. Its appeal includes lower cost, smaller size, and its fast dynamic response to the disturbance. It can provide the most commercial solution to mitigation voltage sag by injecting voltage as well as power into the system. This paper presents modeling, analysis and simulation of a Dynamic Voltage Restorer (DVR) using MATLAB. The efficiency of the DVR depends on the performance of the efficiency control technique involved in switching the inverters. In this model a PI controller and Discrete PWM pulse generator was used.**

***Keywords* – DVR, MATLAB, PWM.**

1. INTRODUCTION

Modern electric power systems are complex networks with hundreds of generating stations and thousands of load centers are interconnected through long power transmission and distribution networks. Power quality is major concern in industries today because of enormous losses in energy and money. With the advent of myriad sophisticated electrical and electronic equipment, such as computers, programmable logic controllers and variable speed drives which are very sensitive to disturbances and non-linear loads at distribution systems produces many power quality problems like voltage sags, swells and harmonics and the purity of sine waveform is lost. Voltage sags are considered to be one of the most severe disturbances to the industrial equipments.

Power quality problems are associated with an extensive number of electromagnetic phenomena in power systems with broad ranges of time frames such as long duration variations, short duration variations and other disturbances. Short duration variations are mainly caused by either fault conditions or energization of large loads that require high starting currents. Depending on the electrical distance related to impedance type of grounding and connection o f transformers between the faulted/load location and the node, there can be a temporary loss of voltage or temporary voltage reduction (sag) or voltage rise (swell) at different nodes of the system.

Power distribution systems, ideally, should provide their customer with an uninterrupted power flow at smooth sinusoidal voltage at the contracted magnitude level and frequency .A momentary disturbance for sensitive electronic devices causes voltage reduction at load end leading to frequency deviations which results in interrupted power flow, scrambled data, unexpected plant shutdowns and equipment failure. Voltage lift up at a load can be achieved by reactive power injection at the load point of common coupling (PCC). The common method for this is to install mechanically switched shunt capacitors in the primary terminal of the distribution transformer. The mechanical switching may be on a schedule, via signals from a supervisory control and data acquisition (SCADA) system, with some timing schedule, or with no switching at all. The disadvantage is that, high speed transients cannot be compensated. Some sag is not corrected within the limited time frame of mechanical switching devices. Transformer taps may be used, but tap changing under load is costly.

Another power electronic solution to the voltage regulation is the use of a dynamic voltage restorer (DVR). DVR's are a class of custom power devices for providing reliable distribution power quality. They employ a series of voltage boost technology using solid state switches for compensating voltage sags/swells. The DVR applications are mainly for sensitive loads that may be drastically affected by fluctuations in system voltage.

3. METHODOLOGY

DYNAMIC VOLTAGE RESTORER

INTRODUCTION:

Among the power quality problems (sags, swells, harmonics…) voltage sags are the most severe disturbances. In order to overcome these problems the concept of custom power devices is introduced recently. One of those devices is the Dynamic

Voltage Restorer (DVR), which is the most efficient and effective modern custom power device used in power distribution networks. DVR is a recently proposed series connected solid state device and is normally installed in a distribution system between the supply and the critical load feeder at the point of common coupling (PCC). It employs a series of voltage boost technology using solid (static) state switches of 3-PHASE VSC that injects voltage into the system; to restore the load side voltage for compensating voltage sags/swells. Other than voltage sags and swells compensation, DVR can also added other features like: line voltage harmonics compensation, reduction of transients in voltage and fault current limitations.

FEATURES OF DVR:
i. Lower cost, smaller size, and its fast dynamic response to the disturbance.
ii. Ability to control active power flow.
iii. Higher energy capacity and lower costs compared to the SMES device.
iv. Less maintenance required. UPS is costly, it also requires a high level of maintenance because batteries leak and have to be replaced as often as every five years.

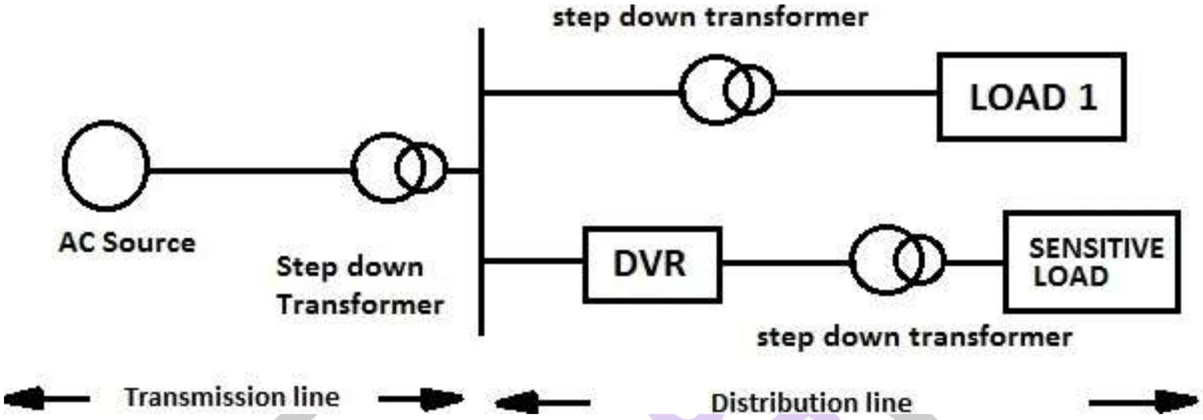

Figure 1: Location of DVR

When a fault occurs on the line feeding Load 1, its voltage collapses to zero. Load 2 experiences sag equals to the voltage at the PCC and the voltage of sensitive load protected by the DVR is restored to its pre-fault value.

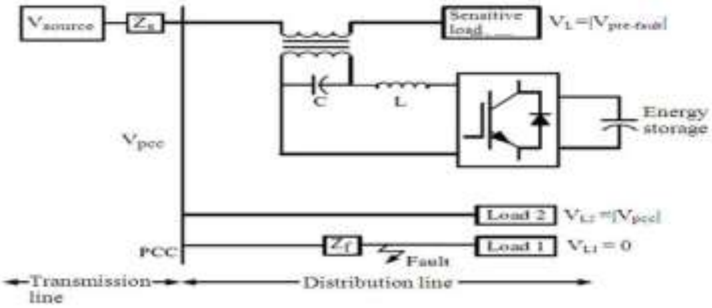

Figure 2: Basic structure of DVR

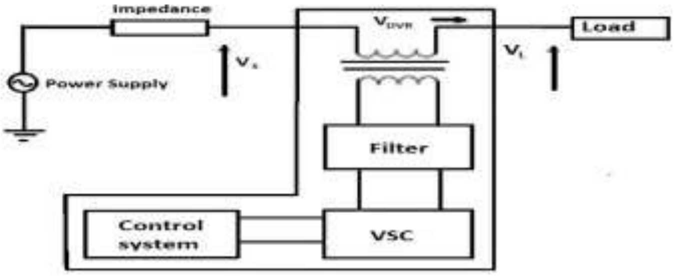

Figure 3: Schematic diagram of DVR

VOLTAGE SOURCE CONVERTER:

A VSC is a power electronic system consists of a storage device and switching devices, which can generate a sinusoidal voltage at any required frequency, magnitude, and phase angle. In the DVR application, the VSC is used to temporarily replace the supply voltage or to generate the part of the supply voltage which is missing.

There are four main types of switching devices: Metal Oxide Semiconductor Field Effect Transistors (MOSFET), Gate Turn-Off thyristors (GTO), Insulated Gate Bipolar Transistors (IGBT), and Integrated Gate Commutated Thyristors (IGCT). Each type has its own benefits and drawbacks. The IGCT is a recent compact device with enhanced performance and reliability that allows building VSC with very large power ratings. Because of the highly sophisticated converter design with IGCTs, the DVR can compensate dips which are beyond the capability of the past DVRs using conventional devices.

The purpose of storage devices is to supply the necessary energy to the VSC via a dc link for the generation of injected voltages. The different kinds of energy storage devices are Superconductive magnetic energy storage (SMES), batteries and capacitance.

EQUATIONS RELATED TO DVR:

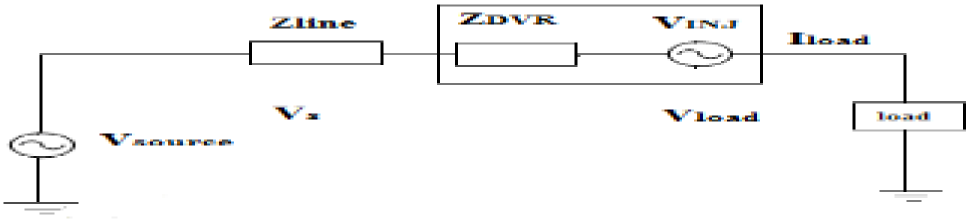

Figure 4: Equivalent circuit diagram of DVR

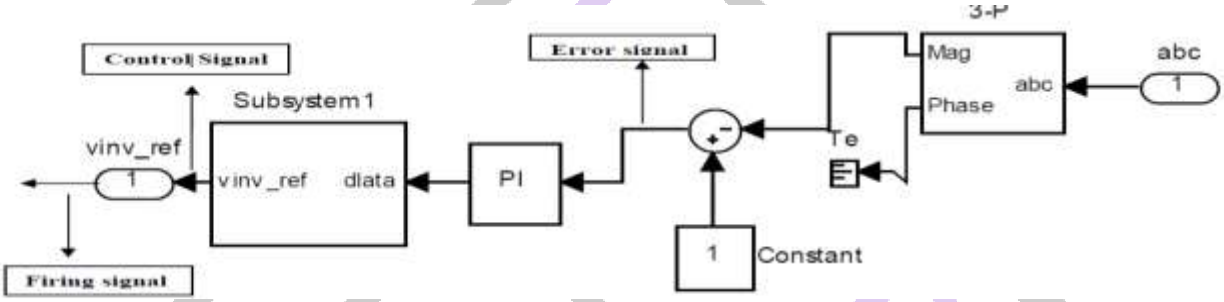

Figure 5: Simulink model of DVR controller

4. RESULTS

The following shows the simulation results for the system

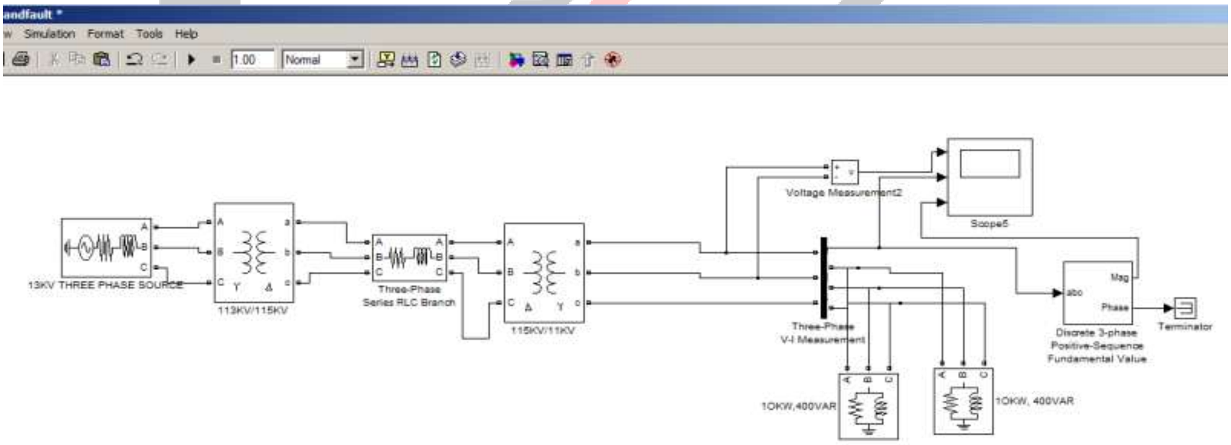

Figure 6: System without DVR and fault

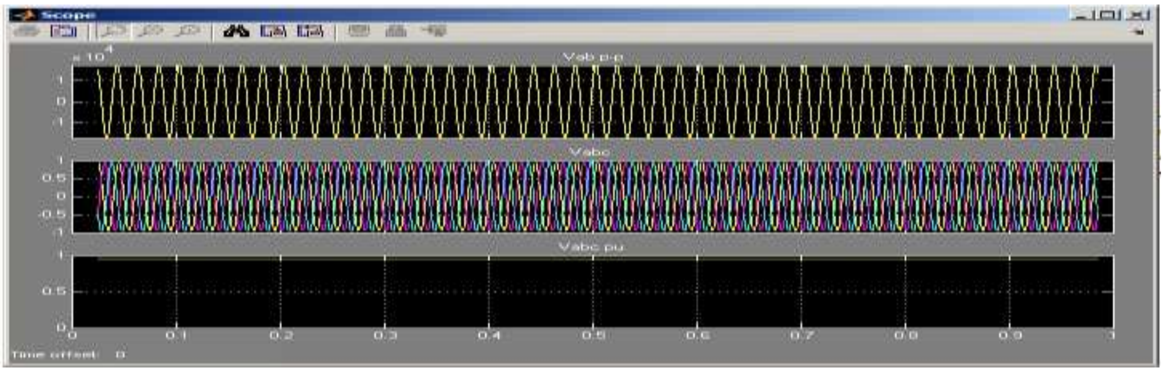

Figure 7: Phase –phase, three-phase and p.u. voltages at load point

After the MATLAB Simulation of faults in transmission line, it was observed that the voltage and current waveforms are transient. During the initial part of the short circuit, the short-circuit current was limited by sub- transient reactance of synchronous machine & impedance of the transmission line between the machine and the point of fault. After that it was limited by transient reactance of synchronous machine and impedance of line.

Finally, the short-circuit current settled down to steady state limited by synchronous reactance of the machine and line impedance. The negative and zeo sequence components were present initially only and disappeared after the circuit breaker cleared the fault.

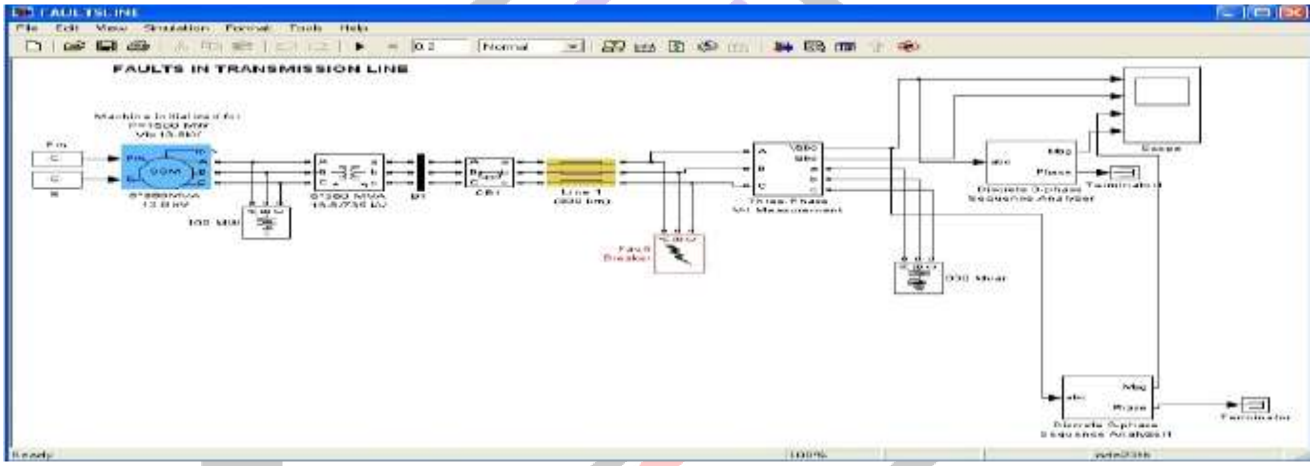

Figure 8: Faults in transmission line.

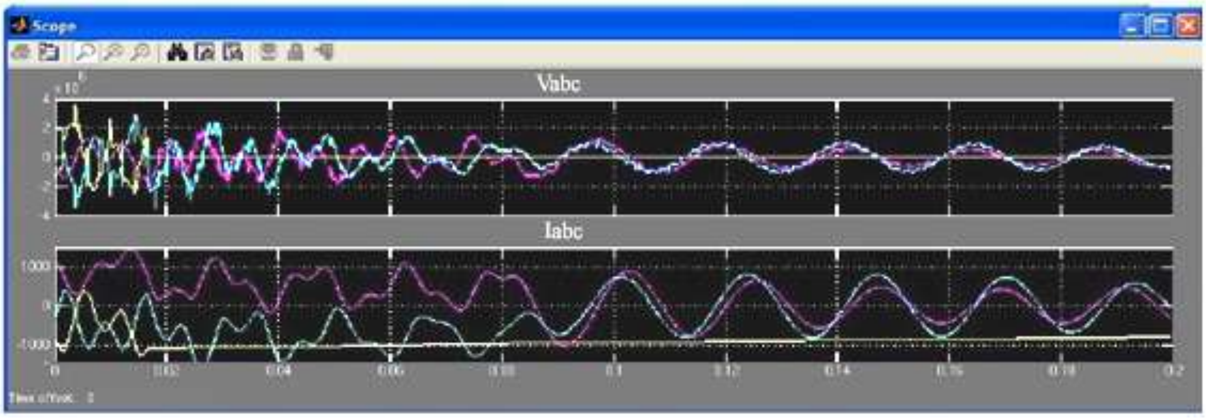

Figure 9: V_{abc}, I_{abc} for single L-G fault

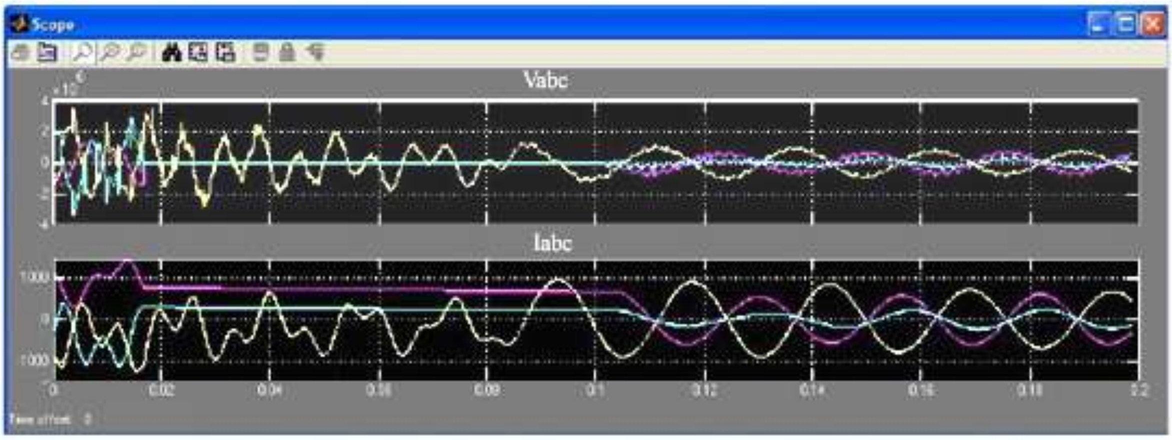

Figure 10: V_{abc}, I_{abc} for double L-G fault

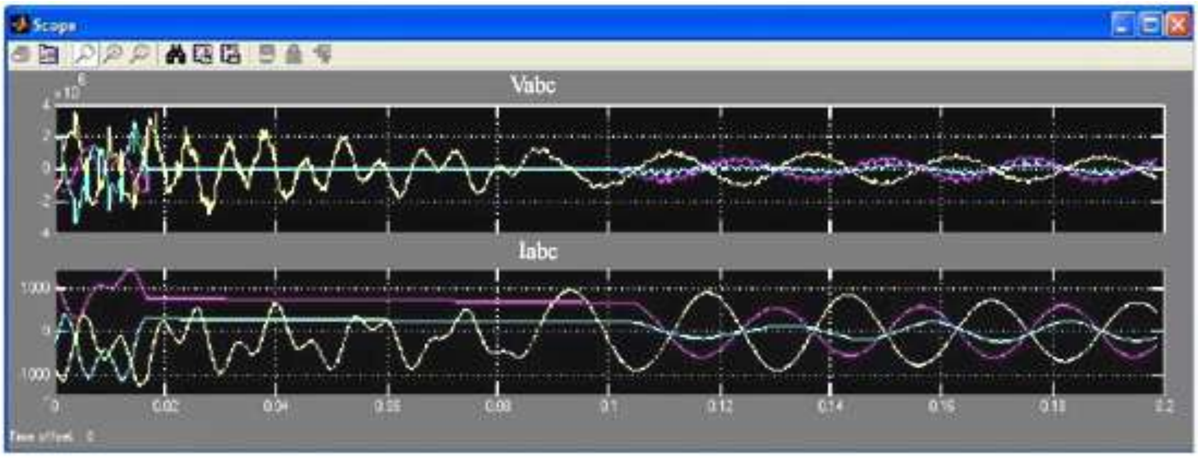

Figure 11: V_{abc}, I_{abc} for three phase-G fault

Next simulation was done with no fault and a three phase fault, double line fault and single L-G fault is applied to the system at point with fault resistance of 0.66 U for time duration of 200 ms with voltage sag magnitude of 0.1, 0.5 and 0.9 p.u. respectively.

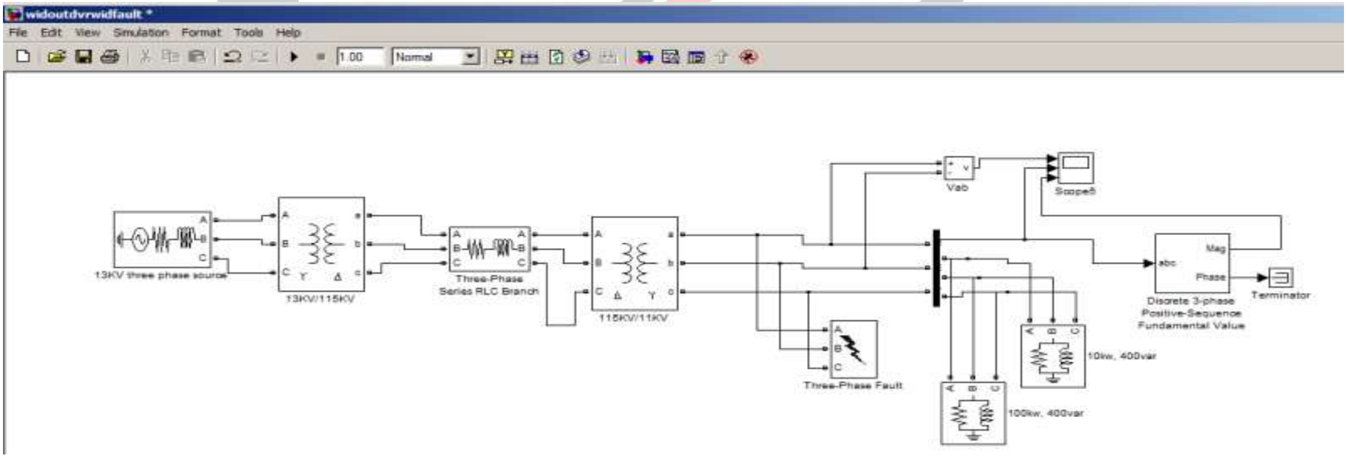

Figure 12: System without DVR and with fault

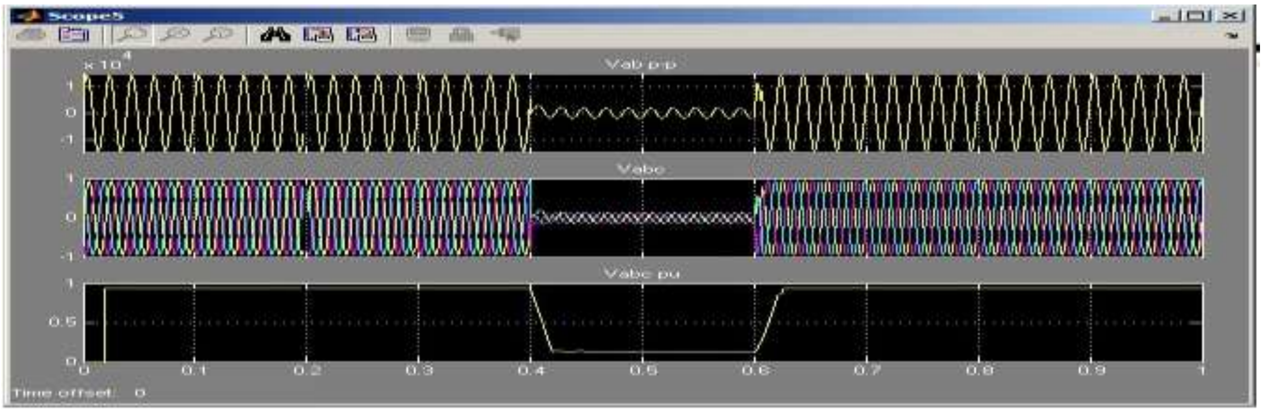

Figure 13: Phase –phase, three-phase and p.u. voltages at load point for a-b-c fault

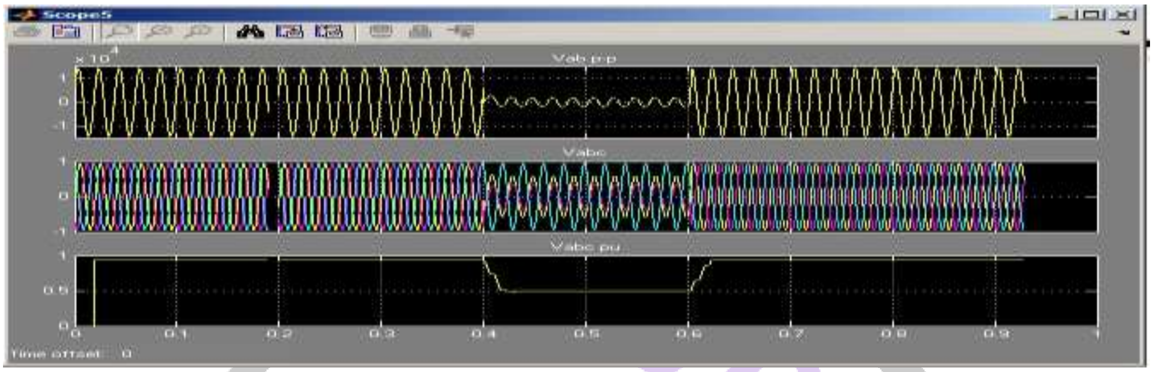

Figure 14: Phase –phase, three-phase and p.u. voltages at load point for a-b fault

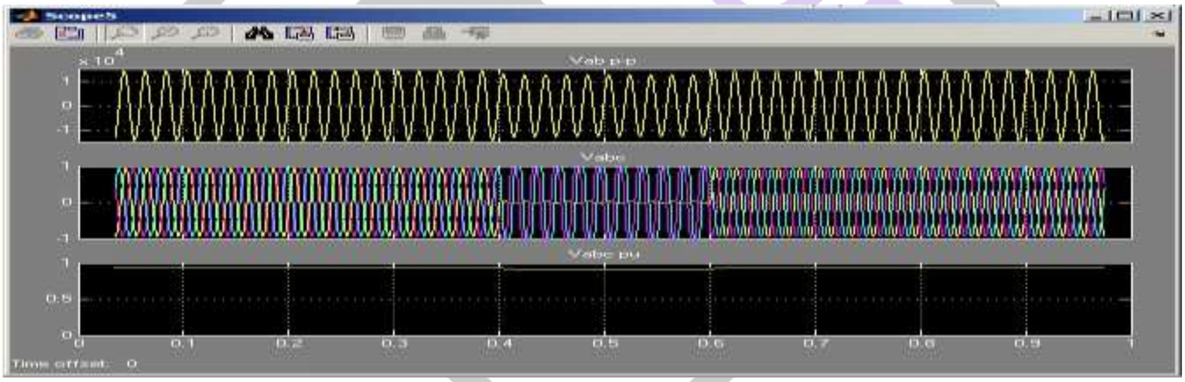

Figure 15: Phase –phase, three-phase and p.u. voltages at load point for a-g fault

Each mosfet conducts for 180 degree. Three mosfets remain on at any instant of time. There are six modes of operation in a cycle and the duration of each mode is 60 degree. The gating signals are shifted from each other by 60 degree to obtain three-phase balanced (fundamental) voltages.Fig 5.4.1 is simulated in MATLAB and sinusoidal phase-ground voltages are obtained.

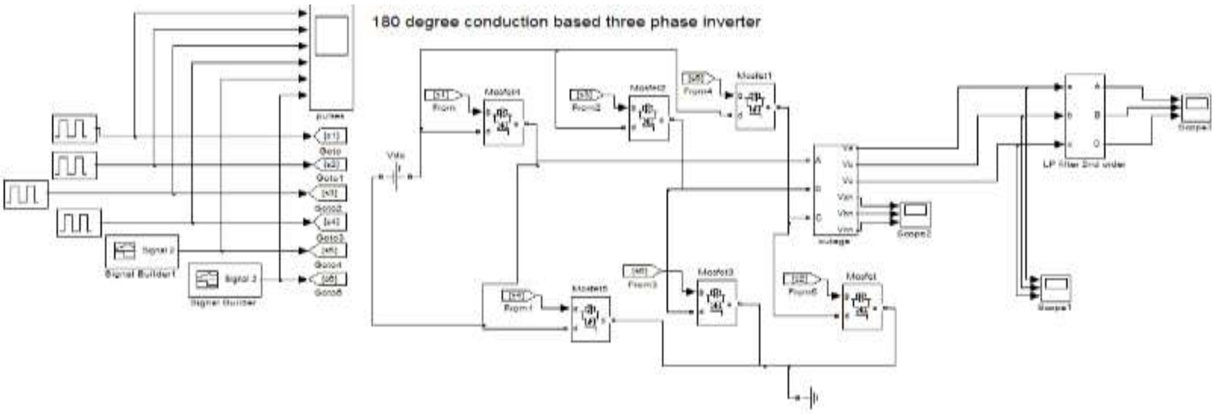

Figure 16: 180 degree conduction based three phase inverter

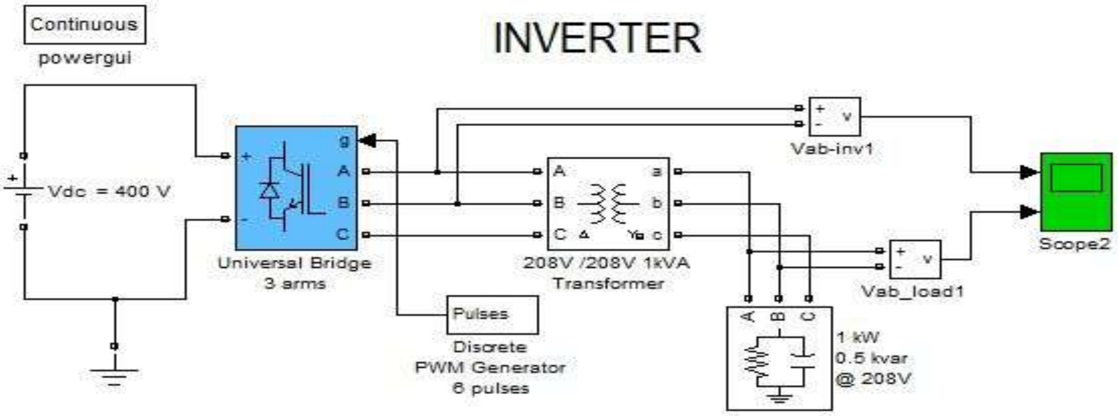

Figure 17: Sine wave inverter

Next simulation is carried out at the same scenario as above but a DVR is now introduced at the load side to compensate the voltage sag occurred due to the three phase fault applied.

When the DVR is in operation the voltage interruption is compensated almost completely and the rms voltage at the sensitive load point is maintained at normal condition.

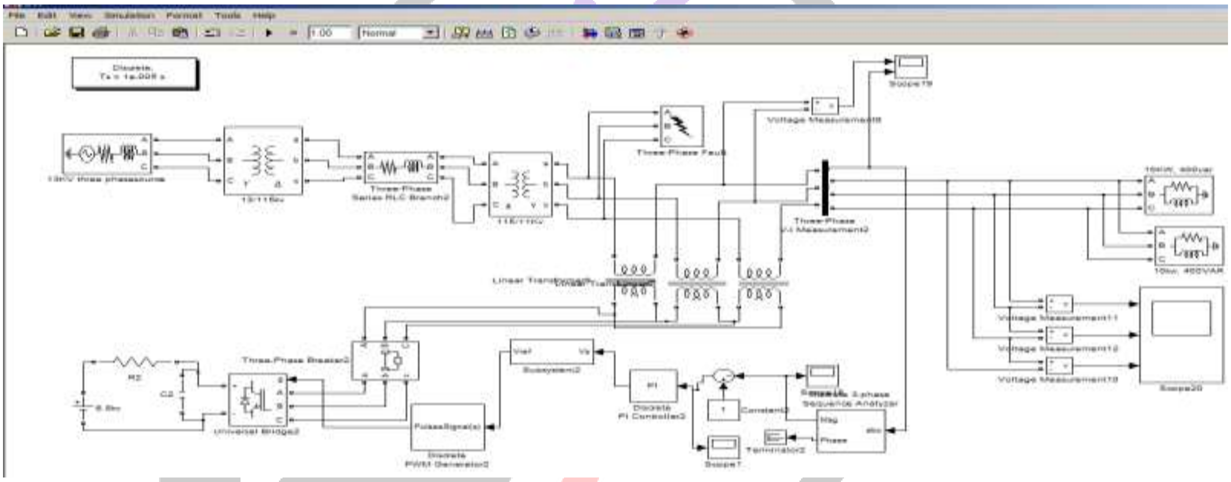

Figure 18: System with DVR and fault

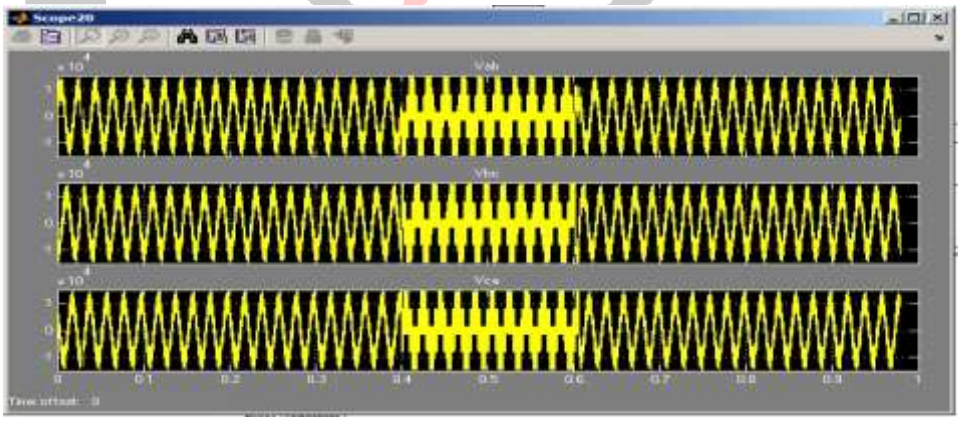

Figure 19: Phase –phase voltages at load point for a-b-c fault

5.CONCLUSION

In order to show the performance of DVR in mitigation of voltage sags, s simple distribution network is simulated using MATLAB. A DVR is connected to a system through a series transformer with a capability to insert a maximum voltage of 50% of phase to ground system voltage. In-phase compensation method is used. DVR handles both balanced and unbalanced situations without any difficulties and injects the appropriate voltage component to correct rapidly any deviation in the supply voltage to keep the load voltage constant at the nominal value. The main advantages of the proposed DVR are simple control, fast response and low cost. The proposed PWM control scheme using PI controller is efficient in providing the voltage sag compensation. As opposed to fundamental frequency switching schemes already available in the MATLAB/SIMULINK, this PWM control scheme only requires voltage measurements. This characteristic makes it ideally suitable for low-voltage custom power applications. DVR works independently of the type of fault as tested for the system as based on the analysis of test system DVR mitigates voltage sags due to three phase, single L-G and double line faults. The main shortcoming of the DVR, being a series device, is its inability to mitigate complete interruptions.

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