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Development and Simulation of Dynamic Voltage Restorer for Voltage SAG Mitigation using PWM Firing Control Strategy

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Abstract - The quality of electricity is currently one of the main problems. This has become especially important with the introduction of sophisticated devices whose performance is very sensitive to power quality. A power quality problem is a phenomenon manifested as a non-standard voltage, current or frequency that results in a malfunction of the end device. One of the main issues addressed here is performance degradation. Custom power supplies are used to solve this problem. One such device is the Dynamic Voltage Restorer (DVR), which is the most effective and efficient modern self-powered device used in distribution networks. Its appeal includes lower cost, smaller size, and fast dynamic response to interference. This paper presents the modeling, simulation and analysis of a dynamic voltage restorer (DVR) using MATLAB. In order to improve the DVR's ability to recover from voltage drops, this paper deals with the modeling of the control structure using a discrete PWM pulse generator. The obtained results show that the developed DVR exhibits a good ability to starch the voltage level during voltage sag conditions.

1 Introduction

Nowadays, modern industrial equipment is mostly based on electronic devices such as programmable logic controllers and electronic drives. Electronic devices are very sensitive to interference and become less tolerant of power quality issues such as voltage sags, surges and harmonics. Voltage drops are considered one of the most serious disturbances in industrial equipment.

Load voltage support can be achieved by injecting reactive power at the load point of the common link. The usual method is to install mechanically switched shunt capacitors on the primary terminal of the distribution transformer. Mechanical switching can be scheduled, via signals from a supervisory control and data acquisition (SCADA) system, timed, or without switching. The disadvantage is that high-speed transients cannot be compensated for. Some dips are not corrected in the limited time frame of mechanical switching devices. Transformer taps can be used, but it is expensive to replace the on-load taps.

Another power electronics solution to voltage regulation is the use of a dynamic voltage restorer (DVR). DVRs are a class of proprietary power devices for providing reliable distribution quality electrical power. They use a range of voltage boosting technologies using solid state switches to compensate for voltage dips/surges. DVR applications are primarily intended for sensitive loads that can be drastically affected by system voltage fluctuations.

2 Dynamic Voltage Restorer

This section presents a brief description about the basic principles of a dynamic voltage restorer used in transmission system. Figure 1shows the basic elements of a DVR in a single-phase representation.

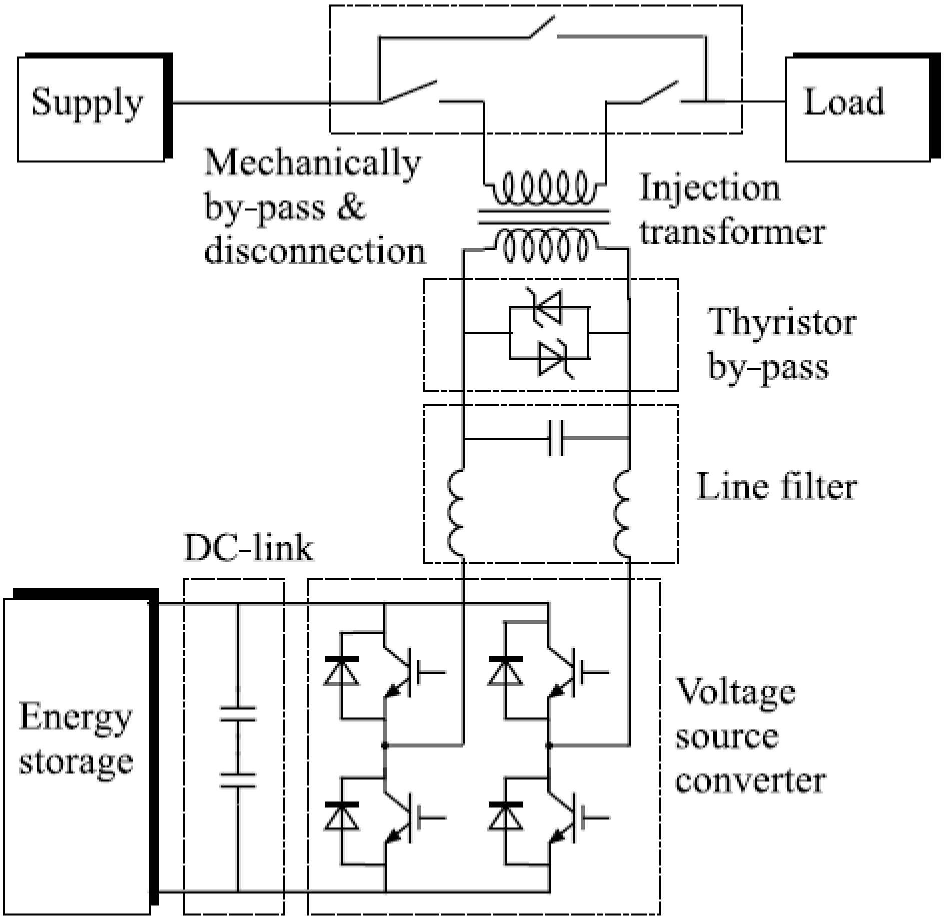


Figure 1The basic elements of a DVR in a single-phase representation

The basic elements of a DVR, are:

- Converter; The converter is most likely a Voltage Source Converter (VSC), which Pulse Width modulates (PWM) the DC from the DC-link/storage to AC-voltages injected into the system.
- Line-filter; The line-filter is inserted to reduce the switching harmonics generated by the PWM VSC.
- Injection transformer; In most DVR applications the DVR is equipped with injection transformers to ensure galvanic isolation and to simplify the converter topology and protection equipment.
- DC-link and energy storage; A DC-link voltage is used by the VSC to synthesize an AC voltage into the grid and during a majority of voltage dips active power injection is necessary to restore the supply voltages.
- By-pass equipment; During faults, overload and service a bypass path for the load current has to be ensured. Illustrated in Figure 1 as a mechanical bypass and a thyristor bypass
- Dis-connection equipment; To completely disconnect the DVR during service etc.

3 Control Structure of Developed DVR

3.1 Discrete PWM-Based Control Scheme

In order to alleviate the simulated voltage drops in the test system of each compensation technique and also to compensate the voltage drops in practical application, a discrete PWM-based control scheme is implemented with a reference to the DVR. The aim of the regulation scheme is to maintain a constant magnitude of the voltage at the sensitive point of the load when the system is disturbed. For example, the control system only measures the rms voltage at the load point, there is no need to measure the reactive power.

Figure 2 shows the diagram of the DVR controller implemented in MATLAB/SIMULINK. The DVR control system controls the voltage angle as follows: the error signal is obtained by comparing the reference voltage with the effective voltage measured at the load point. The PI controller processes the error signal and generates the desired angle δ to compensate for the error, for example; the rms voltage of the load will revert back to the reference voltage.

It should be noted that, an assumption of balanced network and operating conditions are made. The modulating angle δ or delta is applied to the PWM generators in phase A, whereas the angles for phase B and C are shifted by 240° or -120° and 120° respectively.

$$V_A = \text{Sin}\,(\omega t + \delta) \quad \ldots(3.1)$$

$$V_B = \text{Sin}\,(\omega t + \delta - 2\pi/3) \quad \ldots(3.2)$$

$$V_C = \text{Sin}\,(\omega t + \delta + 2\pi/3) \quad \ldots(3.3)$$

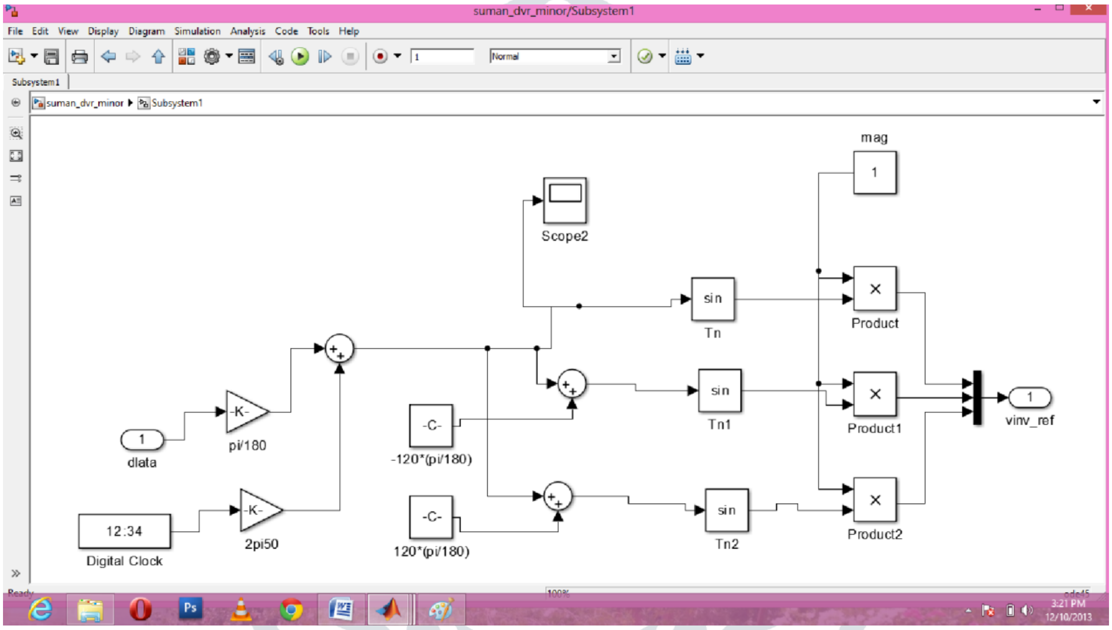


Figure 2 firing angle controller scheme

3.2 Test system for DVR

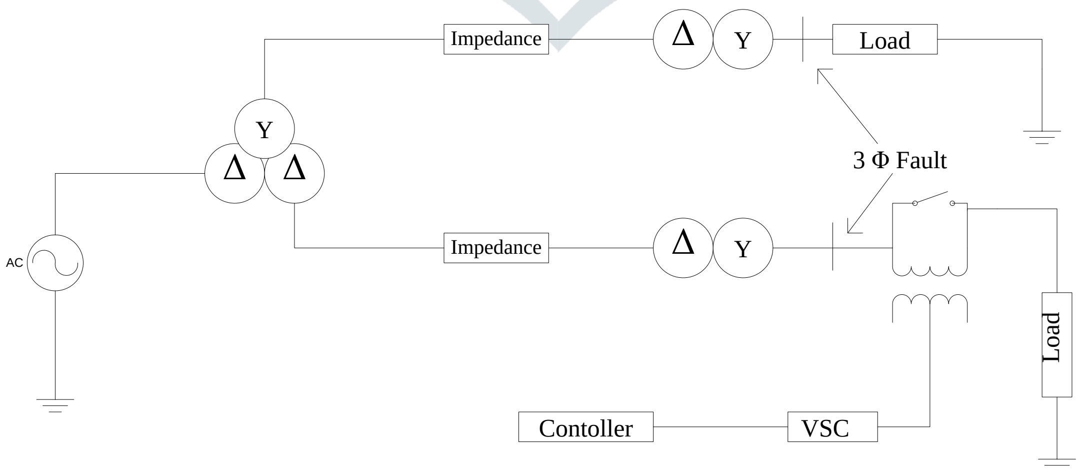
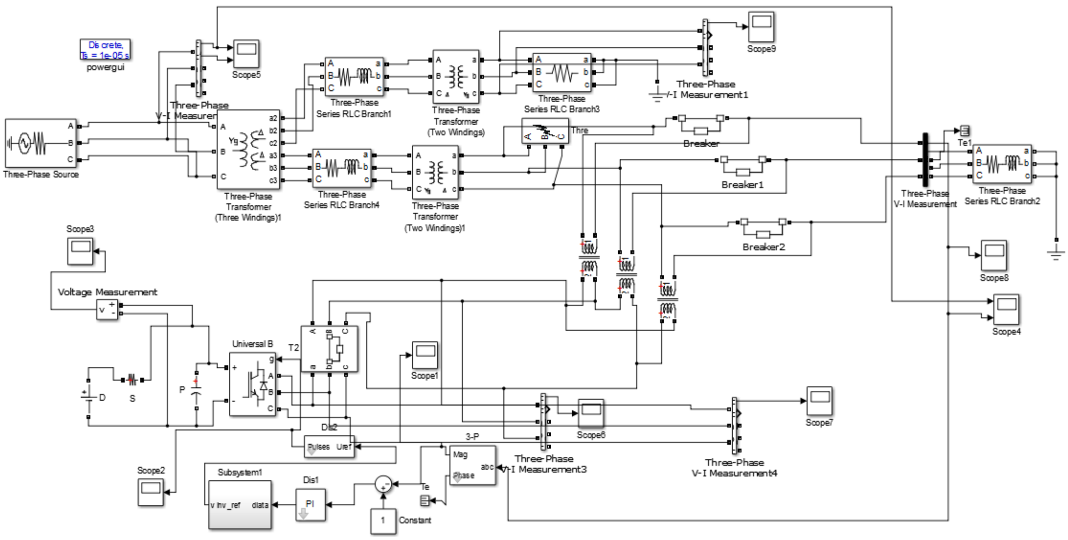


Figure 1 Single line diagram of test system

Single line diagram of the test system for DVR is composed by a 13 kV, 50 Hz generation system, feeding two transmission lines through a 3- winding transformer connected in Y//, 13/115/115 kV. Such transmission lines feed two distribution networks through two transformers connected in /Y, 115/11 kV. To verify the working of DVR for voltage compensation a fault is applied at point X at resistance 0.66 U for time duration of 200 ms. The DVR is simulated to be in operation only for the duration of the fault. Figure (3) shows the actual simulation model developed for the proposed work.



4 Simulation and Results

The first simulation was done with no DVR and a three phase fault is applied to the system at point with fault resistance of 0.66 U for a time duration of 200 ms. The second 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.

Figure 4 shows the rms voltage at load point when the system operates with no DVR and a three phase fault is applied to the system. 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.

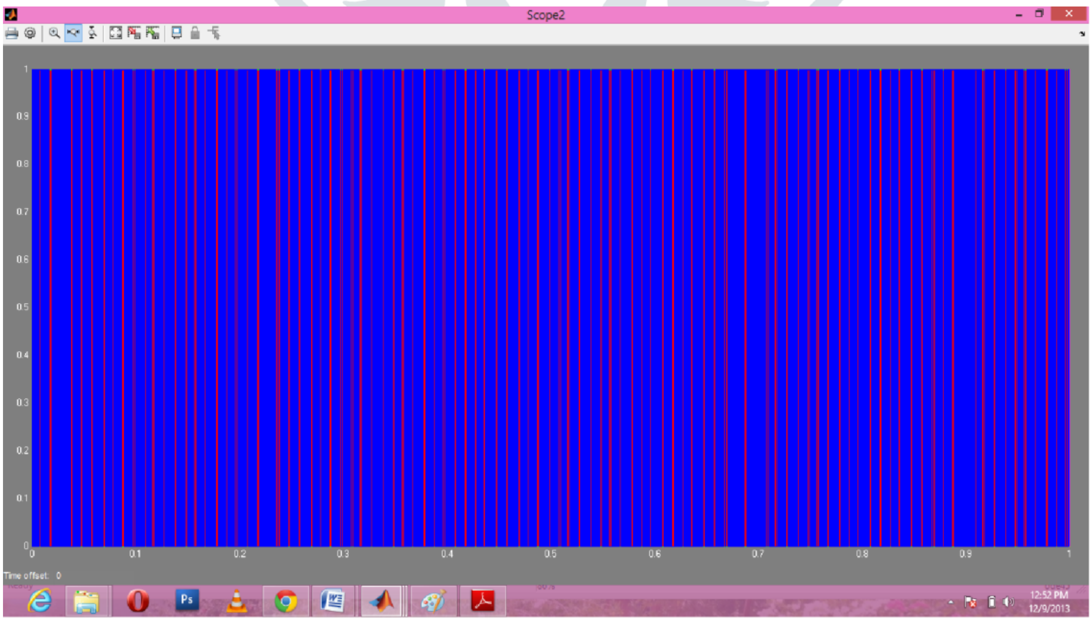


Figure 4 Firing pulse generated by discrete PWM generator

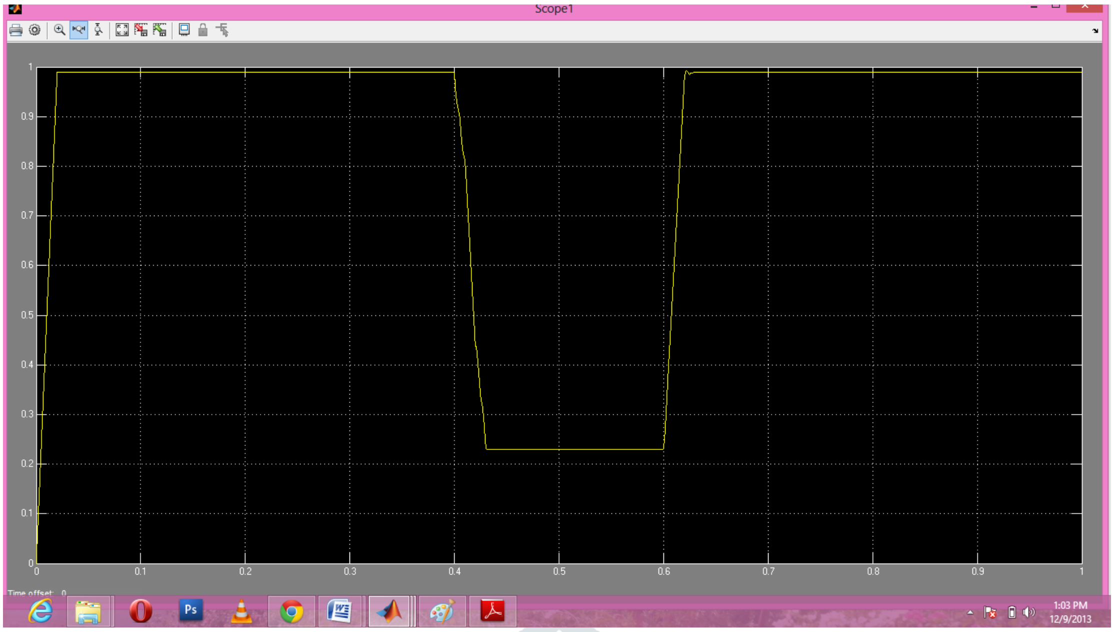


Figure 5 P.U Voltage at load point, with 3-Ø fault, without DVR

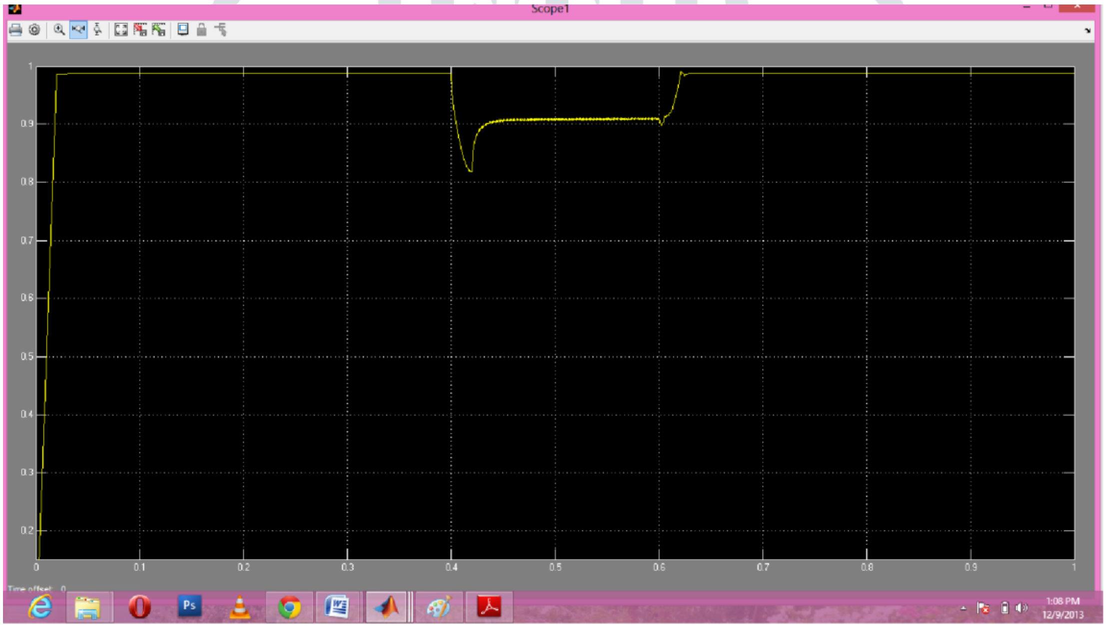


Figure ***Error! No text of specified style in document.*** *P.U Voltage at load point, with 3-Ø fault, with DVR*

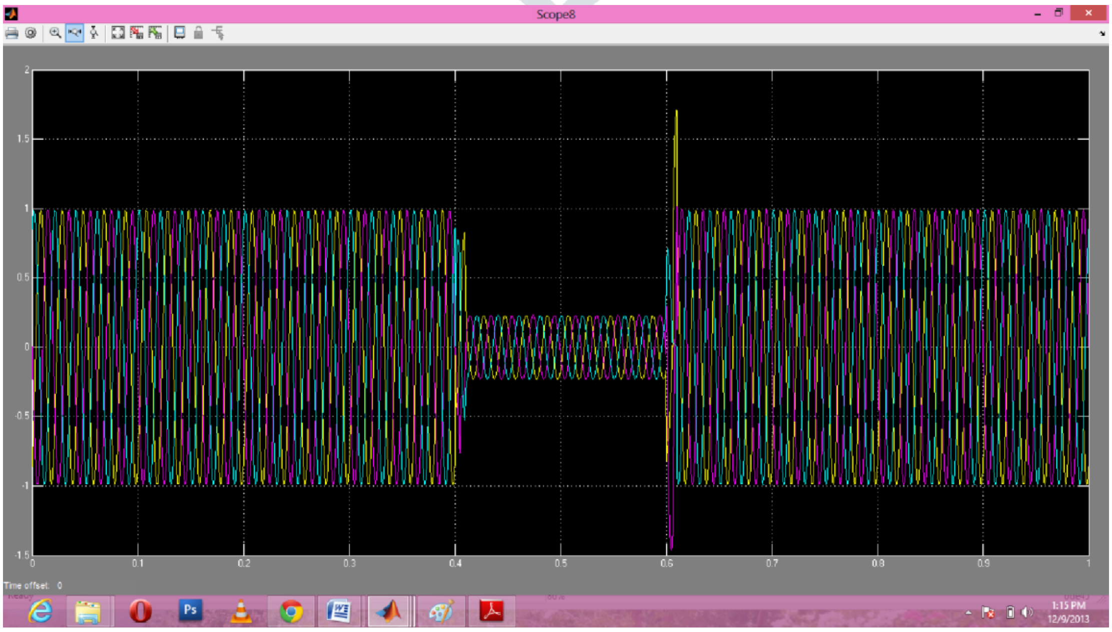


Figure 7 3-Ø Voltage at load point, with 3-Ø fault, without DVR

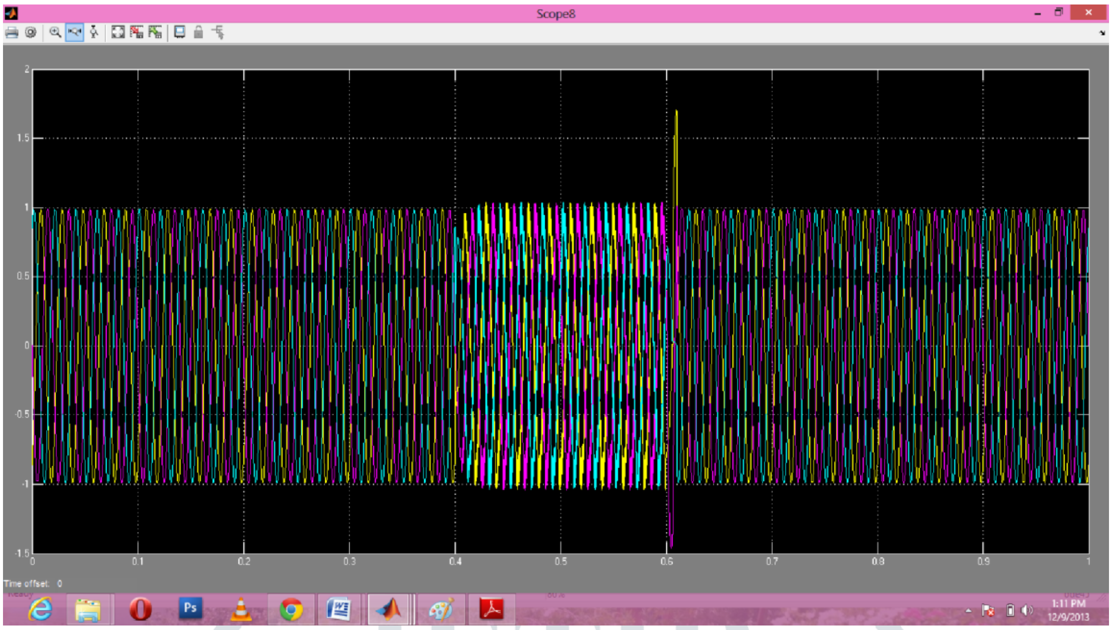


Figure 8 3-Ø Voltage at load point, with 3-Ø fault, with DVR

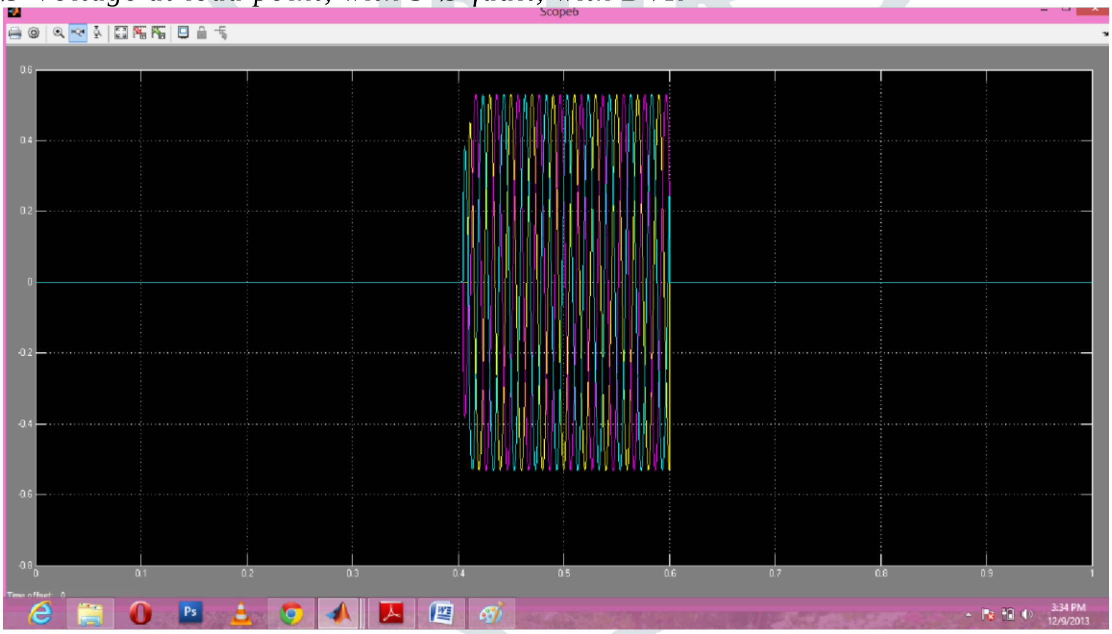


Figure 9 Input voltage at injection transformer, without DVR

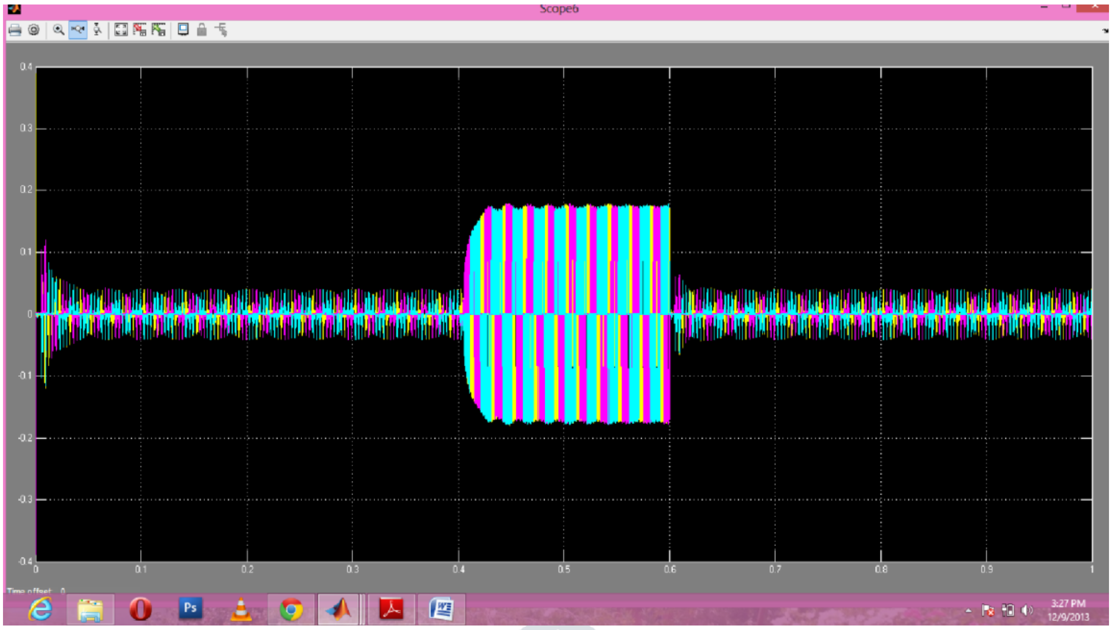


Figure 10 Input voltage at injection transformer, with DVR

5 Conclusion

This paper addresses the most critical issue of voltage sag recovery that often degrades power quality in a transmission line system. The compensation techniques of a custom DVR power electronic device were successfully modeled and simulated in MATLAB Simulink. A PWM based control scheme has been implemented. Unlike the base frequency switching schemes already available in MATLAB/SIMULINK, this PWM control scheme only requires voltage measurements. This feature makes it ideally suited for low-voltage self-powered applications.

In the results section, it is shown that the PWM control technique is able to inject a sufficient amount of voltage when voltage dips occur. The result is satisfactory, but the injected voltage suffers from harmonics. In the future, this problem can be overcome by using modified PWM techniques such as DSPWM, GSPWM techniques.

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