Performance Analysis of Dynamic Voltage Restorer (DVR) using Sinusoidal and Space vector PWM Techniques

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Abstract

This paper presents the researches on the Dynamic Voltage Restorer (DVR) application for power quality Improvement in electrical distribution network. Due to increasing complexity in the power system, voltage sags are now becoming one of the most significant power quality problem. voltage sags is a short reduction voltage from nominal voltage, occurs in a short time . temporary Voltage sag is bound to have a greater impact on the industrial customers. If the voltage sags exceed two to three cycles, then manufacturing systems making use of sensitive electronics equipments are likely to be effected leading to major problems .It ultimately leads to wastage of resources as well as financial losses. The increasing competition in the market and the declining profits has made it pertinent for the industries to realize the significance of high power quality. This is possible only by ensuring that uninterrupted flow of power is maintained at proper voltage levels .This can solve by using custom power devices such as DVR, Distribution static compensator (D-STATCOM) and un interruptible power supply (UPS). The Dynamic voltage Restorer appears to be an especially good solution in the current scenario. Two pulse width modulation –based control techniques, viz. sinusoidal PWM and space vector PWM ,are presented for controlling the electronic valves in two level voltage source converter(VSC) used in the DVR system .The Simulation study of space vector PWM technique for DVR is compared with sinusoidal PWM. The performance of DVR as well as the adopted control algorithm is illustrated by simulation. The results obtained in PSCAD/EMTDC.

Keywords-**Custom power, DVR, Power quality,Voltage sag, SPWM, SVPWM, PSCAD/EMTDC.**

1.Introduction

Power quality problems to sensitive loads is one of the major concerns in electricity industry today .this is due to the advent of a large numbers of sophisticated electrical and electronics equipment, such as computers, programmable logic controllers, variable speed drives, and so forth. The use of these equipments very often requires power supplies with very high quality. voltage sag, which is a momentary decrease in rms voltage magnitude in the range of 0.1 to 0.9 per unit (p.u) [1], is considered as the most serious problem of power quality. It is often caused by faults in power systems or by starting of large induction motors. It occurs more frequently than any other power quality phenomenon does. Therefore , the loss resulted due to voltage sag problem for a customer at the load-end is huge .DVR and D-STATCOM are recently being used as the active solution for voltage sag mitigation. In this paper, DVR is proposed device to mitigate the voltage sag. Dynamic voltage restorer is a series compensator which is able to protect a sensitive load from the distortion in the supply side during fault or over loaded in power system. The basic principle of a series compensator is simple, by inserting a voltage of required magnitude and frequency ;the series compensator can restore the load side voltage to the desired amplitude and waveform even when the source voltage is unbalanced or distorted [2] .sinusoidal PWM and space vector PWM control techniques are used for controlling the DVR. space vector PWM can utilize the better dc voltage and generates the fewer harmonic in inverter output voltage . simulation results are compared for both the SPWM and SVPWM.

2. Mathematical model for voltage sag calculation

Consider Figure 1 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 ,

$$I = I_1 + I_2 \quad (1)$$

In normal condition (without fault in system)

$$I = \frac{V_2}{X_1 + Z_{LOAD\_A}} + \frac{V_2}{X_2 + Z_{LOAD\_B}} \quad (2)$$

When a fault occurs (see Fig 1) in feeder 1, because of short circuit, a high current will flow through feeder1 as well as source current I [3]. During this time, voltage in feeder 2 is decreased due to increasing of voltage drop across source reactance X_S, this causes voltage sag.
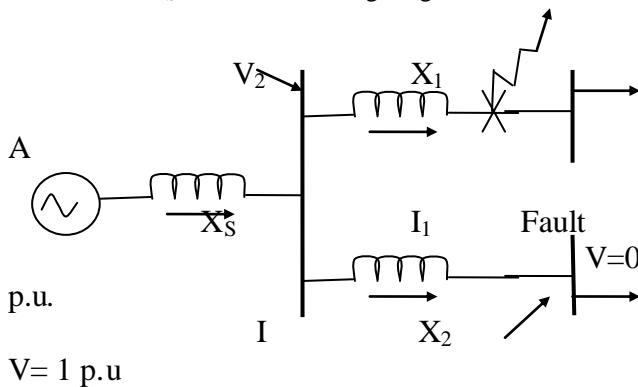
Fig .1: calculation for voltage sag

$$I = \frac{V_2}{X_1} + \frac{V_2}{X_2 + Z_{LOAD\_B}} \quad (3)$$

Here

$$V_2 = V_S - IX_S \quad (4)$$
V_S = Source voltage (i.e., V= 1 p.u)

During the fault condition, voltage drop (IX_S) increases and hence from equation (4), V_2 decreases from its nominal value (i.e., V_2 become as voltage sag).

3. Mathematical Model for voltage sag correction by Dynamic voltage restorer

The schematic diagram of a typical DVR is shown in Fig (2). The circuit left hand side of the DVR represents the Thevenin equivalent circuit of the system. The system impedance ($Z_{th} = R_{th} + jX_{th}$) depends on the fault level of the load bus. When

the system voltage (V_{th}) drops, the DVR injects a series voltage V_{DVR} through the injection transformer so that the desired load voltage magnitude V_L can be maintained.
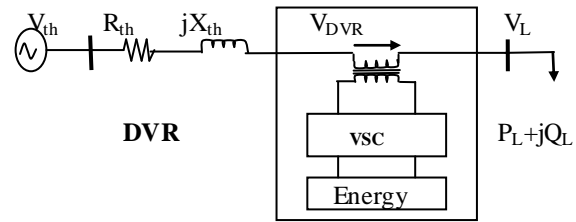

Fig 2: schematic diagram of a DVR

Consider the schematic diagram shown in the above fig 2. By using KVL

$$V_{th} - Z_{th} I_L + V_{DVR} = V_L \quad (5)$$
$$\Rightarrow V_{DVR} + V_{th} = V_L + Z_{th} I_L \quad (6)$$

Therefore, the series injected voltage of the DVR can be written as

$$V_{DVR} = V_L + Z_{th} I_L - V_{th} \quad (7)$$

Here,
V_{th} = system supply voltage (Thevenin voltage)
V_L = load bus voltage
Z_{th} = system impedance (Thevenin impedance)
I_L = load current

$$I_L = \left[\frac{P_L + JQ_L}{V_L} \right]^* \quad (8)$$

When V_L is considered as a reference, equation (6) can be rewritten as

$$V_{DVR} \angle \alpha = V_L \angle 0^0 + Z_{th} I_L \angle \beta - \phi - V_{th} \angle \delta \quad (9)$$

Here α , β and δ are the angle of V_{DVR}, Z_{th} and V_{th} respectively and ϕ is the load power factor angle with

$$\phi = Tan^{-1}(Q_L/P_L). \quad (10)$$

The complex power injection by the DVR can be written as

$$S_{DVR} = V_{DVR} I_L^* \quad (11)$$

4. Test System Implemented In PSCAD/EMTDC

Single line diagram of the test system for DVR is shown in Figure-(4.1) and the test system employed to carry out the various DVR simulations presented in this section is shown in Figure-(4.2), which the same system is presented in [28]. Such system is composed by a 13 kV, 60 Hz generation system, feeding two transmission lines through a 3-winding transformer connected in Y/ Δ / Δ , 13/115/115 kV. Such transmission lines feed two distribution networks through two transformers connected in Δ /Y, 115/11 kV

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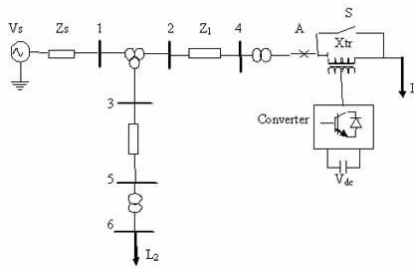
Fig 3: Single line diagram of the test system for DVR

        The DVR coupling transformer is connected in delta in the DVR side, with a leakage reactance of 10%. A unity transformer turns ratio was used, i.e., no booster capabilities exist. Using the facilities available in PSCAD/EMTDC, the DVR is simulated to be in operation only for the duration of the fault, as it is expected to be the case in a practical situation.

5. DVR Control Strategy

The main aim of the control system is to maintain the constant voltage magnitude at the point where a sensitive load is connected, under system disturbances [4].
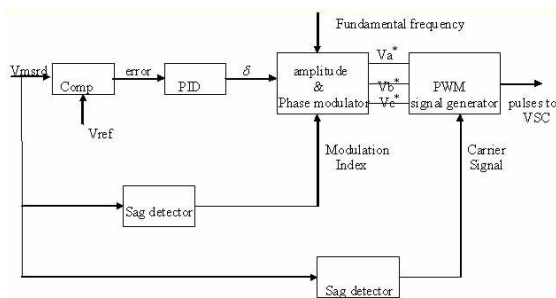
Fig 4: sinusoidal PWM – based control system for DVR
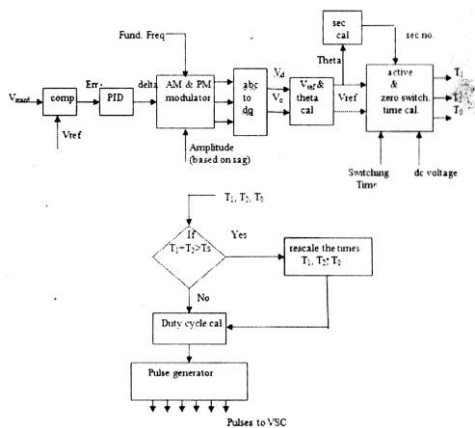
Fig 5: space vector PWM-based control system for DVR

Switching time duration at any sector:
The active and zero switching time for a particular sector are calculated by using the following formulae

$$T_1 = \frac{\sqrt{3}.T_s.\left|\overline{V}_{ref}\right|}{V_{dc}}.\left(\sin\frac{n}{3}\pi - \theta\right) \qquad (12)$$

$$T_2 = \frac{\sqrt{3}.T_s.\left|\overline{V}_{ref}\right|}{V_{dc}}.\left(\sin\left(\theta - \frac{n-1}{3}\pi\right)\right) \qquad (13)$$

$$T_0 = T_s - (T_1 + T_2) \qquad (14)$$

Where, n=1 through 6, i.e sector 1 to 6 and

$$0 \le \theta \le 60^0.$$

When $T_1+T_2>T_s$, the time T_1 and T_2 are simply rescaling as follows [9]

$$\begin{bmatrix} T_a \\ T_b \end{bmatrix} = \frac{T_s}{T_1 + T_2}\begin{bmatrix} T_1 \\ T_2 \end{bmatrix} \qquad (15)$$

So that $T_a+T_b=T_s$ and $T_0 = 0$. According to this rescaling process, the converter can operate up to the modulation index 0.952.from the equations (12)-(15) duty cycles can be calculated by

$$\frac{T_1.or.T_a}{T_s} = d_1 = \frac{\sqrt{3}.\left|\overline{V}_{ref}\right|}{V_{dc}}.\left(\sin\frac{n}{3}\pi - \theta\right) \quad (16)$$

$$\frac{T_2.or.T_b}{T_s} = d_2 = \frac{\sqrt{3}.\left|\overline{V}_{ref}\right|}{V_{dc}}.\left(\sin\left(\theta - \frac{n-1}{3}\pi\right)\right)$$
$$(17)$$

$$d_0 = 1 - (d_1 + d_2) \qquad (18)$$

        These duty cycles are symmetrically distributed corresponding to each sector .By this symmetrical distribution, only one phase is changing to on or off during the changing of adjacent state vector and hence swithing losses will be reduced

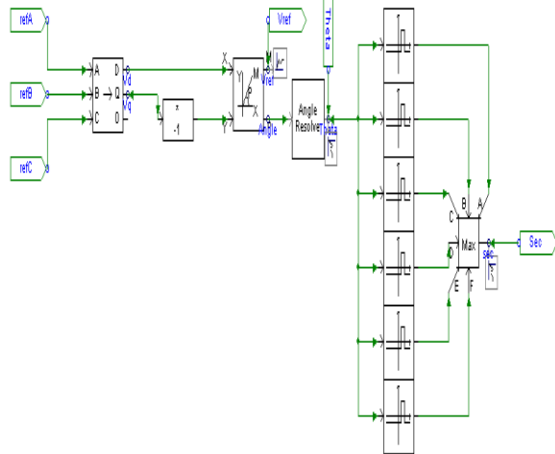## 6.Modeling of space vector PWM in PSCAD/EMTDC

        This section describes the modeling of space vector PWM in PSCAD/EMTDC. To develop the model of SVPWM in PSCAD/EMTDC, four user defined sub-systems ((a)-(d)) are created as shown in figure-(6.a) to figure-(6.d).
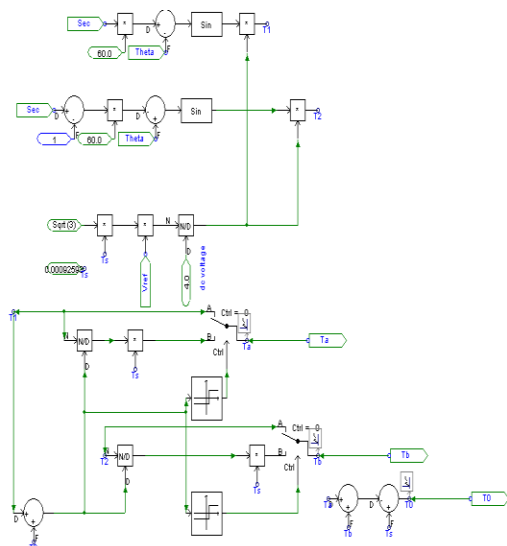
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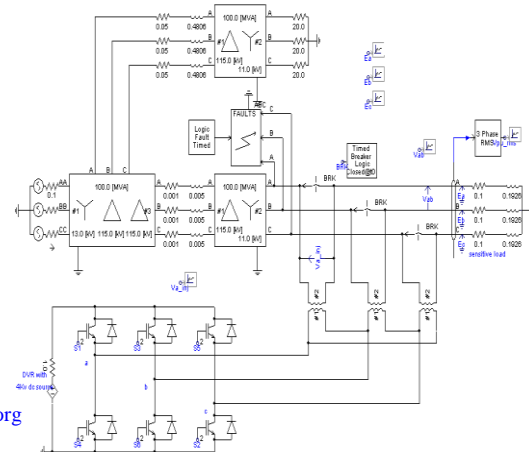
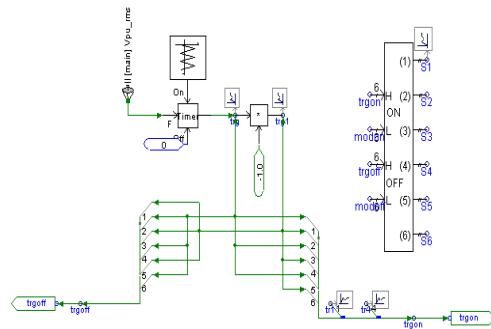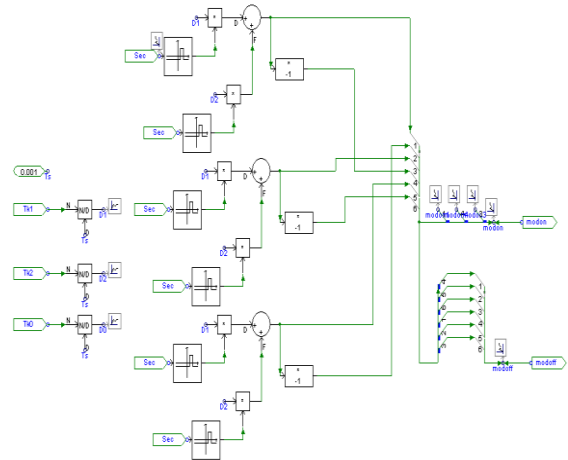**Fig 6: Test system implemented in PSCAD/EMTDC.**
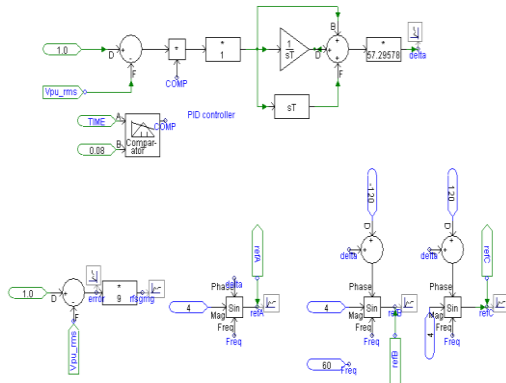
Fig 6a: Calculation of sag magnitude and generation of reference signals.

Fig 6b: calculation of reference vector magnitude and sector.

Fig 6c: calculation of turn-on time of two adjacent vectors and zero vectors.

Fig 6d: calculation of duty cycles and generation of pulses to VSC.

Sub-system (a): In this sub-system, at first angle delta, which is required to track the error to zero, and sag magnitude are determined for obtaining the reference signals.

Sub-system (b): In this sub-system, the reference voltage (vector) magnitude (Vref) and phase angle (Theta) are determined from the reference three-phase voltage. To find out the sector, the range of calculated value of angle (Theta) must be between 0 and 2π.

Sub-system (c): This sub-system is designed to calculate the turn-on time of two adjacent active vectors and the zero state vectors. Equation (15) is also implemented in the simulation as shown in fig (6c).

Sub-system (d): This sub-system is designed to calculate duty cycles and generate modulating signals. In this system carrier signals also generated and compared with modulating signals and generated pulses to DVR.

7.Simulation results of DVR

Fig.6 shows the test system, which is implemented in PSCAD/EMTDC, used to carry out the various

DVR simulations presented in this section, which the same system is presented in[4]. Such system is composed by a 13 kV, 60 Hz generation system, represented by a thevenin equivalent ,feeding two transmission lines through a 3-winding transformer connected in Y/ Δ / Δ , 13/115/115 kV. Such transmission lines feed two distribution networks through two transformers connected in Δ /Y, 115/11 kV.The DVR coupling transformer is connected in delta in the DVR side, with a leakage reactance of 10%. A unity transformer turns ratio was used, i.e., no booster capabilities exist. Here DVR is simulated to be in operation only for the duration of the fault, as it is expected to be the case in a practical situation. In this section, the simulation results of sinusoidal PWM and space vector PWM for a DVR are presented. Per unit voltage, per unit error, phase voltage and line - line voltage outputs of sinusoidal PWM and space vector PWM for different types of faults are shown in below figures. The simulation results are compared with Sinusoidal PWM. Simulation results are presented to demonstrate the validity of space vector modulation technique.
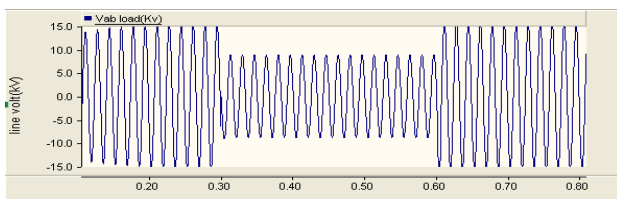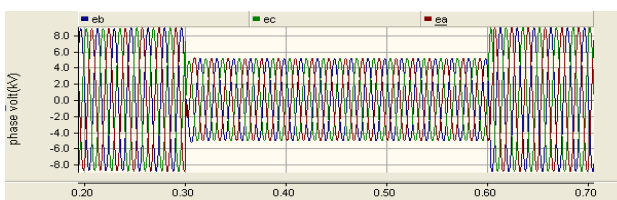

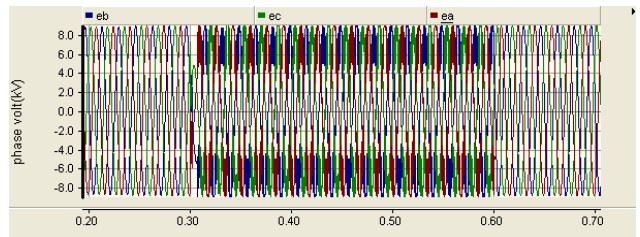**Fig 7:Line to line voltage at sensitive load for three-phase short circuit without DVR**
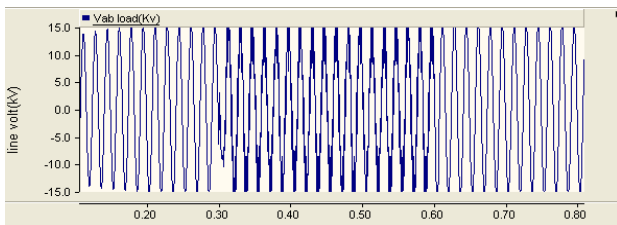
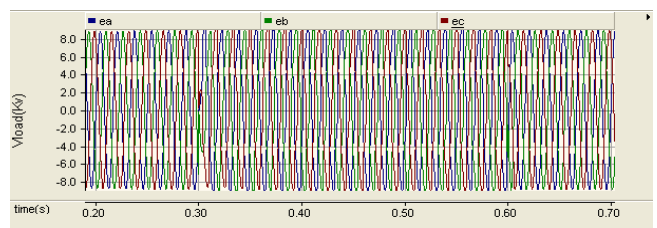**Fig 8: Line to line voltage at sensitive load for three-phase short circuit with DVR for SPWM**
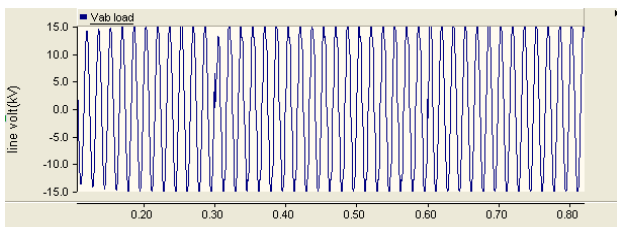
Fig 9:Line to line voltage at sensitive load for three-phase short circuit with DVR for SVPWM
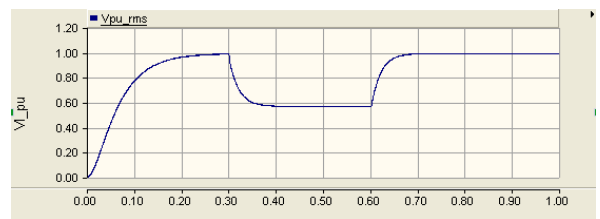

Fig 10: phase voltages at sensitive load for three-phase short circuit without DVR
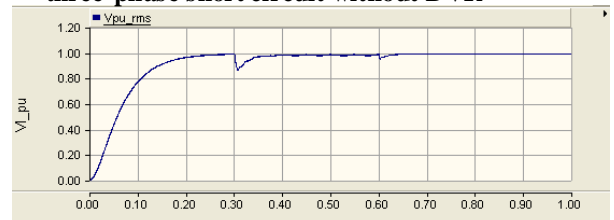

Fig 11: phase voltages at sensitive load for three-phase short circuit with DVR for SPWM
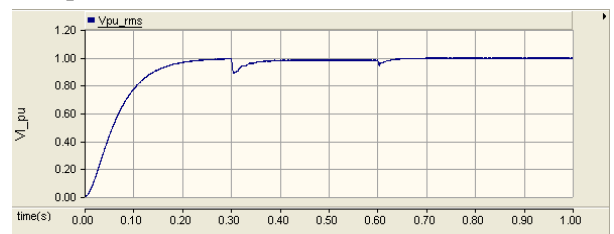

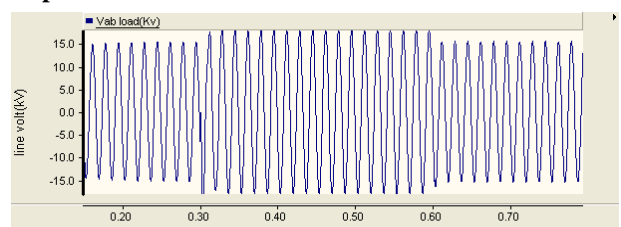**Fig 12: phase voltages at sensitive load for three-phase short circuit with DVR for SVPWM**

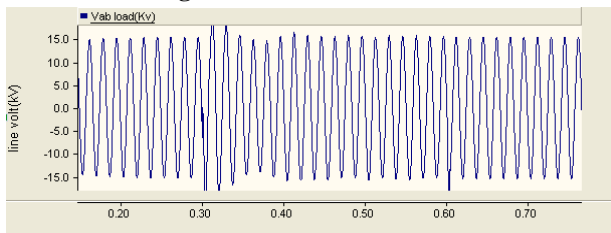**Fig 13: rms per unit value at sensitive load for three-phase short circuit without DVR**

Fig 14: rms per unit value at sensitive load for three-phase short circuit with DVR for SPWM
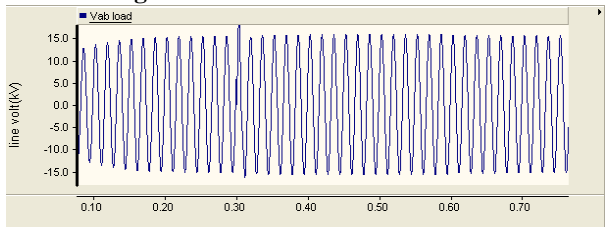

Fig 15: rms per unit value at sensitive load for three-phase short circuit with DVR for SVPWM
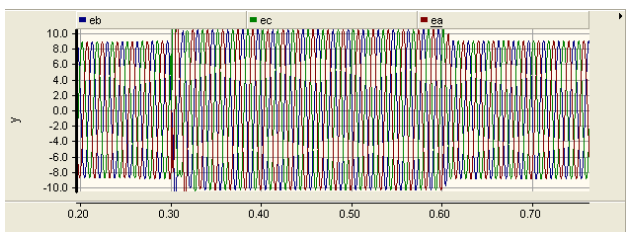
Fig 16:Line to line voltage at sensitive load for voltage swell without DVR
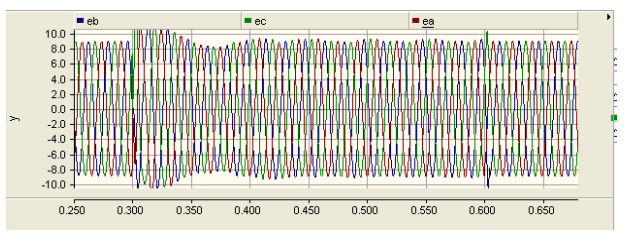

Fig 17: Line to line voltage at sensitive load for voltage swell with DVR for SPWM
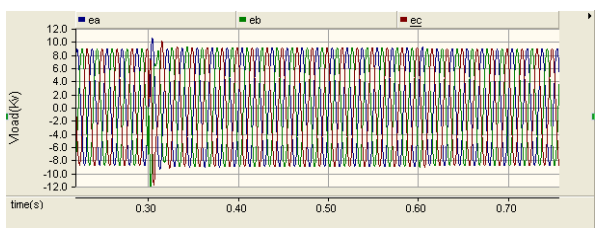

Fig 18: Line to line voltage at sensitive load for voltage swell with DVR for SVPWM
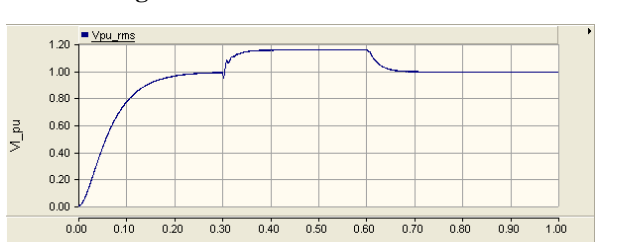

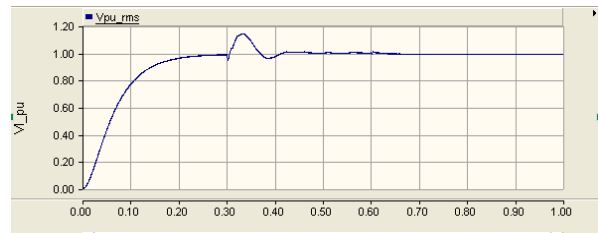**Fig 19: phase voltages at sensitive load for voltage swell without DVR**

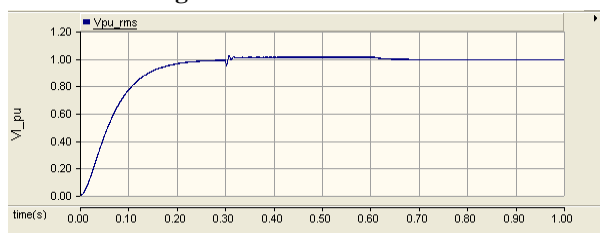**Fig 20: phase voltages at sensitive load for voltage swell with DVR for SPWM**

Fig 21: phase voltages at sensitive load for voltage swell with DVR for SVPWM

Fig 22: rms per unit values at sensitive load for voltage swell with out DVR

Fig 23: rms per unit values at sensitive load for voltage swell with DVR for SPWM

Fig 24: rms per unit values at sensitive load for voltage swell with DVR for SVPWM

8. Conclusion

The power quality problems such as voltage sags and swells are presented in this paper. An electromagnetic transient model of custom power equipment, namely DVR was presented and applied to the study of power quality. The highly developed graphic facilities available in PSCAD/EMTDC were used to conduct all aspects of model implementation and to carry out extensive simulation studies.Two pulse width modulation-based control techniques, viz sinusoidal PWM and space vector PWM, have been implemented for controlling the electronic valves in two level Voltage Source Converter (VSC) used in the DVR system. The control techniques were tested and the reliability and effectiveness of control schemes are shown in results. It is observed that space vector PWM utilized the better dc voltage and reduced the harmonic distortion in line voltage as well as phase voltage when compared with sinusoidal PWM and it effectively mitigated the voltage sags and swells. Compared with sinusoidal PWM, This space vector PWM technique can be applied to any Voltage Source Converter (VSC) based application as an aptitude for wide linear modulation range for output line-to-line voltages and phase voltages are the notable features of space vector modulation. The PWM control scheme controls the magnitude and the phase of the injected voltages, restoring the rms voltage, phase voltages and line voltage very effectively.

9.References

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