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Mitigation of Voltage Sags and Swells using Dynamic Voltage Restorer (DVR) with SPWM and SVPWM Techniques

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ABSTRACT *: This paper presents design and simulation of Dynamic Voltage Restorer (DVR) using sinusoidal pulse width modulation(SPWM) and space vector pulse width modulation(SVPWM) Technique . It describes the problems of voltage sags and swells and its severe impact on nonlinear loads. DVR is a series connected device used for compensating the voltage sags and swells in distribution system. The detection of sags/swells is carried out with the help of dq0 theory, whereas the control of voltage source inverter is done with help of SPWM & SVPWM .The simulation was carried out with the help of simulink and matlab and the results were found to be in accordance with the theoretical values.*

Keywords: *Dynamic voltage restorer (DVR), sinusoidal pulse width modulation (SPWM) space vector pulse width modulation (SVPWM dqo theory, voltage sag/swell .*

I. INTRODUCTION

The term power quality is something that describes the quality of power, it is the quality of voltage rather than the power & current. Power quality problems encompass a wide range of disturbances such as voltage sags/swells, flickers, harmonic distortions, impulse transients and interruptions. Because of voltage deviation electrical utility is not able to supply pure sinusoidal voltage of required magnitude and frequency. Voltage sag can appear at any instant of time with amplitude ranging from 10-90% and a duration lasting for half a cycle to one minute. Voltage sag, on other hand, is defined as increase in rms current or voltage at power frequency for a duration 0.5 cycles to one minute, typical magnitudes are between 1.1 and 1.8 pu. These voltage problems can be solved using a series connected custom power device (DVR). The emphasis has been given for a switching control strategy that is pulse width modulation techniques and their results are presented.

II.DVR

The main function of a DVR [1] is the protection of sensitive loads from voltage sags/swells coming from the network. 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 which is most efficient and effective used in power distribution networks.DVR is recently proposed series connected solid state device that injects voltage into the system in order to regulate the load side voltage. 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.

The DVR is fast, flexible and efficient solution to Power Quality problem. The DVR is a power electronic based device that provides three-phase controllable voltage source, whose voltage vector (magnitude and angle) adds to the source voltage during Sag event, to restore the load voltage to pre-Sag conditions and similarly it reacts quickly to inject the appropriate voltage component (negative voltage magnitude) in order to compensate Voltage Swell. The principal component of the DVR is a voltage source inverter that generates three phase voltages and provides the voltage support to a sensitive load during voltage Sags and Swells.

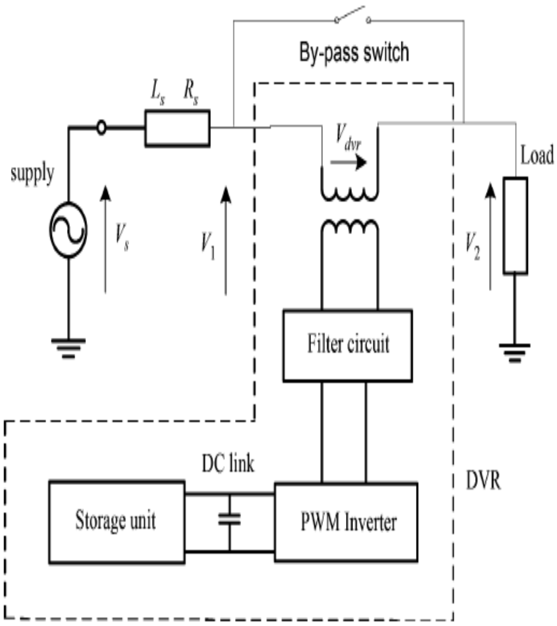

Fig 2.1 Block diagram of DVR

PRINCIPLE OF DVR OPERATION:

A DVR is a solid state power electronics switching device consisting of either GTO or IGBT, a capacitor bank as an energy storage device and injection transformers. It is connected in series between a distribution system and a load that shown in Figure2.2. The basic idea of the DVR is to inject a controlled voltage generated by a forced commuted converter in a series to the bus voltage by means of an injecting transformer. A DC capacitor bank which acts as an energy storage device, provides a regulated dc voltage source. A dc to ac inverter regulates this voltage by Sinusoidal PWM technique. The principle of DVR is simple i.e. whenever the source voltage is unbalanced or distorted the DVR restores the load-side voltage to the desired amplitude by injecting a voltage of required magnitude. In other words we can say that the main function of the DVR is to regulate the load voltage waveform constantly and if any Sag or Swell occurs, the required voltage will be injected to the load point. In short, the principle of DVR can be explained with the help of the following equation which has to be satisfied for all the time.

Source voltage + DVR voltage =Load voltage

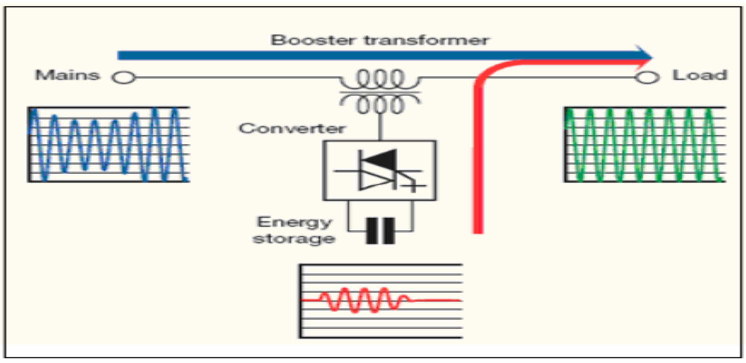

Fig. 2.2: Principle of DVR with a response time of less than one millisecond

During normal operating condition, the DVR injects only a small voltage to compensate for the voltage drop of the injection transformer and device losses. However, when voltage sag occurs in the distribution system, the DVR control system calculates and synthesizes the voltage required to maintain output voltage to the load by injecting a controlled voltage with a certain magnitude and phase angle into the distribution system to the critical load.

Note that the DVR capable of generating or absorbing reactive power but the active power injection of the device must be provided by an external energy source or energy storage system. The response time of DVR is very short and is limited by the power electronics devices and the voltage sag detection time. The expected response time is about 25 milliseconds, and which is much less than some of the traditional methods of voltage correction such as tap-changing transformers.

III.PWM TECHNIQUES

The main aim of any Modulation technique is to obtain variable output having maximum fundamental component with minimum harmonics. The objective of Pulse Width Modulation technique is enhancement of fundamental output voltage and reduction of harmonic content in Three phase voltage source inverters. In this different PWM techniques are compared in terms of Total Harmonic Distortion (THD). SPWM firing control scheme widely used for giving gate pulses to DVR.SPWM voltage source inverter employs carrier based PWM method due to fixed switching frequency, low ripple current and well defined harmonic spectrum. The main disadvantage of SPWM technique is poor dc link utilization. Therefore we go for an alternative method of determination of switching pulse width and their position which is known as Space Vector Pulse Width Modulation . By using Space Vector PWM technique dc link utilization was increased by 15 %.Space Vector PWM generates less harmonic distortion in the output voltage or currents in comparison with sine PWM. In this project work describes the DVR based on Sinusoidal PWM and Space Vector PWM which provides voltage support to sensitive loads and is simulated by using MATLAB/SIMULINK and results are compared in both cases.There are two types of pulse width modulation techniques used in this dynamic voltage restorer.

3.1 Sinusoidal pulse width modulation (SPWM):

Sinusoidal Pulse Width Modulation (SPWM) technique is used to control the fundamental component of the line-to-line converter voltage. Three-phase converter voltages are obtained by comparing the same triangular voltage with three sinusoidal control voltages as shown in Fig. 3.1.The frequency of the triangular voltage determines the converter switching frequency and the frequency of the control voltages determine the fundamental frequency of the converter voltage. Hence, modulating frequency is equal to supply frequency in DVR.

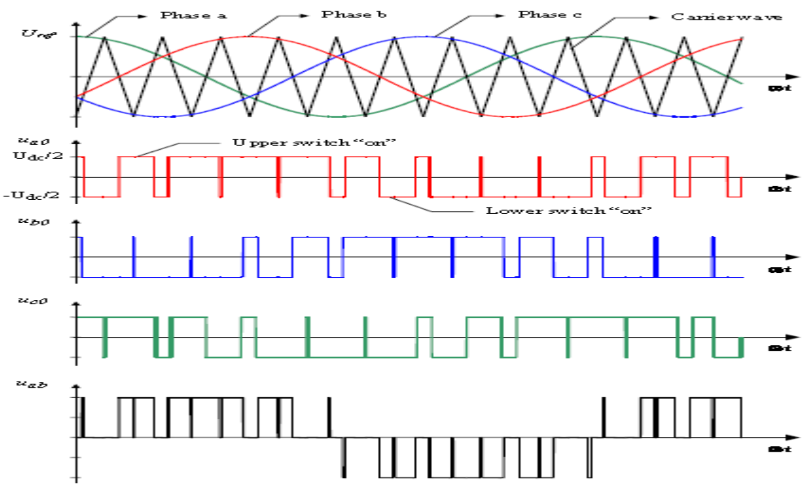

Fig 3.1: Sinusoidal Pulse Width Modulation Technique

For realizing SPWM a high frequency triangular carrier wave is compared with a Sinusoidal reference wave of the desired frequency. The interaction of Carrier and Modulating waves determines the switching instants.

3.2 Space vector pulse width modulation(SVPWM):

Space vector PWM[3] refers to switching scheme of the six power switches of a 3-phase VSI. It generates minimum harmonic distortion and also provides more efficient use of DC supply voltage in comparison with the sinusoidal width modulation method. SVPWM treats the inverter as a single unit. Specifically the inverter can be driven to eight unique states. Modulation is accomplished by switching the state of inverter. Space vector pulse width modulation treats the sinusoidal voltage as a constant amplitude vector rotating at constant frequency.

In a two level three phase inverter total eight vectors are possible among those six are non-zero vectors and two are zero vectors. Six non-zero vectors(V_1-V_6) shape the axes of a hexagonal as depicted in Fig 3.2, supplies power to the load. The angle between any adjacent two non-zero vectors is 60 degrees. Meanwhile, two zero vectors(V_0 and V_7) and are at the origin and apply zero voltage to load. The eight vectors are called the basic **space vectors** are denoted by (V_0, V_1, V_2, V_3, V_4, V_5, V_6, V_7). The same transformation can be applied to the desired output voltage to get the desired reference voltage vector. V_{ref} in the d-q plane. The objective of SVPWM technique is to appropriate the reference voltage vector V_{ref} using the eight switching patterns. One simple method of approximation is to generate the average output voltage of the inverter in small period T_z to be the same as that of V_{ref} in same period.

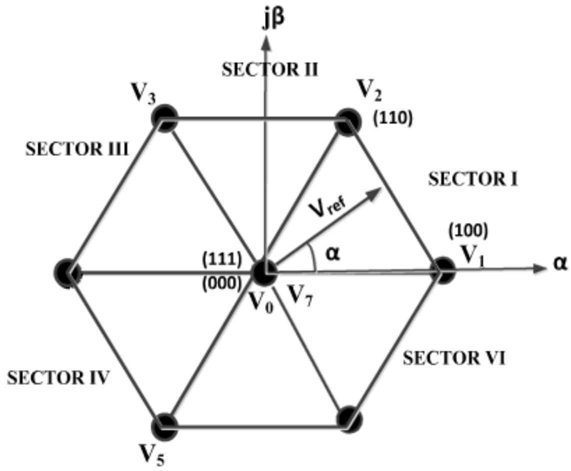

Fig.3.2: Two level space vector diagram

IV.SIMULATION DIAGRAM AND RESULTS

The designed DVR is used to compensate sags/swells of magnitude in range (0.1 p.u–0.9 p.u)
But in reality a DVR can compensate a maximum of 0.5pu. For the purpose of demonstration sag of magnitude 0.2 p.u and a swell of magnitude 0.2 p.u are considered. The VSI is implemented using SPWM as well as SVPWM and the results were compared.

Table 1: Parameter values of simulation

Parameter	Value
RMS line to line voltage	400 v
Resistance and inductance of line	0.1Ω, 0.5mH
Transformer turns ratio	1:1
Transformer no load losses	0.002pu
Filter parameters	R=5Ω C=1μF L=10mH
Active and Reactive power of load	1000W, 200W
Line frequency	50 HZ

4.1 Simulink Model: The designed simulation diagram is shown in fig 4.1

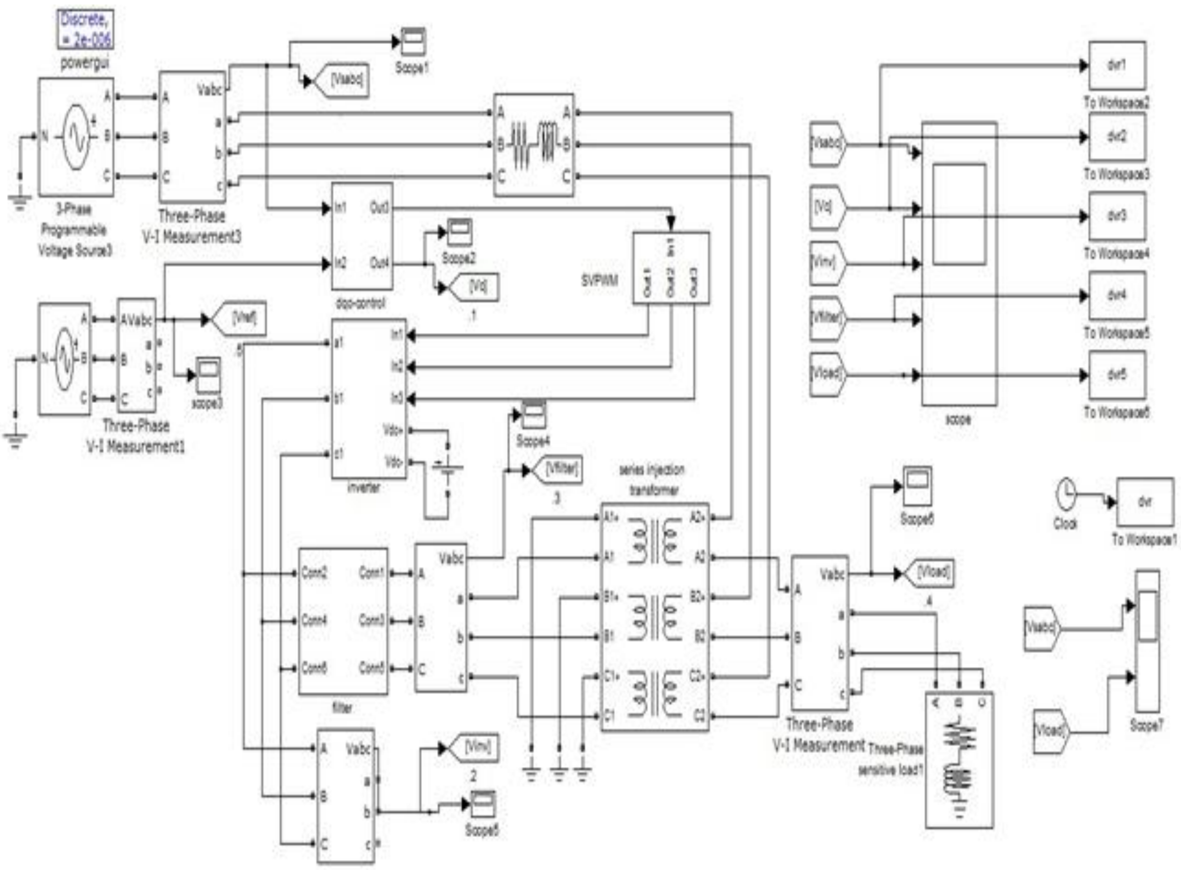

Fig 4.1

4.2 Voltage sags:
4.2.1: SPWM Technique:

The first simulation shows of three phase voltage sag is simulated. The simulation started with supply voltage 20% sagging as shown in Fig 4.2.1 (a) and it also shows a 20% voltage sag initiated at 0.2s and it is kept until 0.8s, with a total voltage sag duration of 0.6s. Figures 4.2.1(b) and 4.2.1(c) shows the voltage injected by DVR and the corresponding load voltage after compensation. As a result of DVR , the load voltage is kept at 1 p.u using SPWM technique.

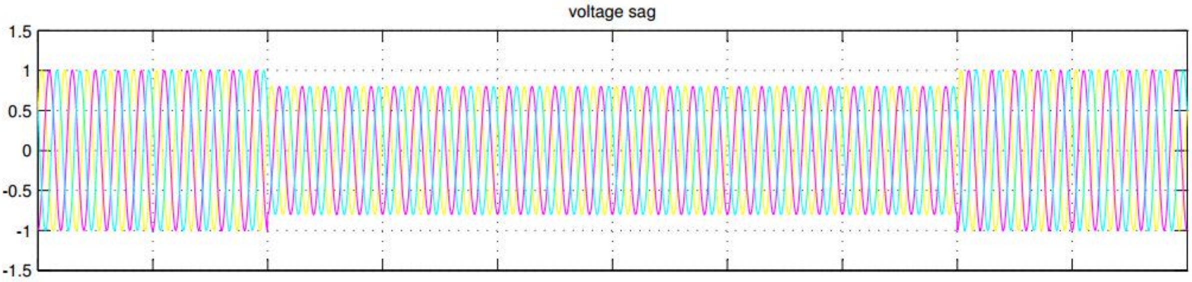

Fig 4.2.1(a): Voltage sag of 0.2 p.u

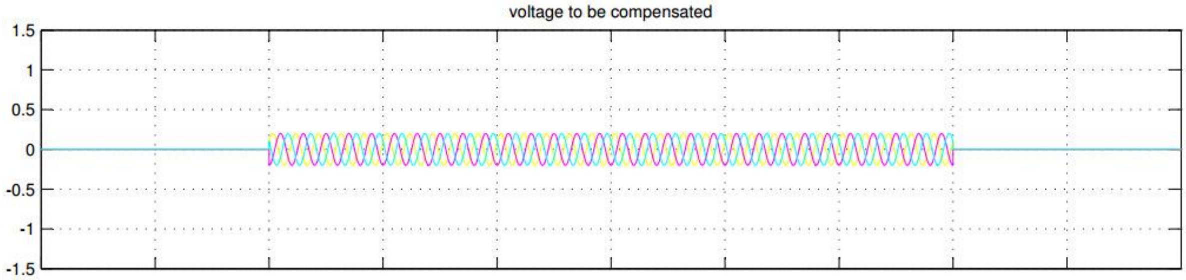

Fig 4.2.1(b): Injected voltage

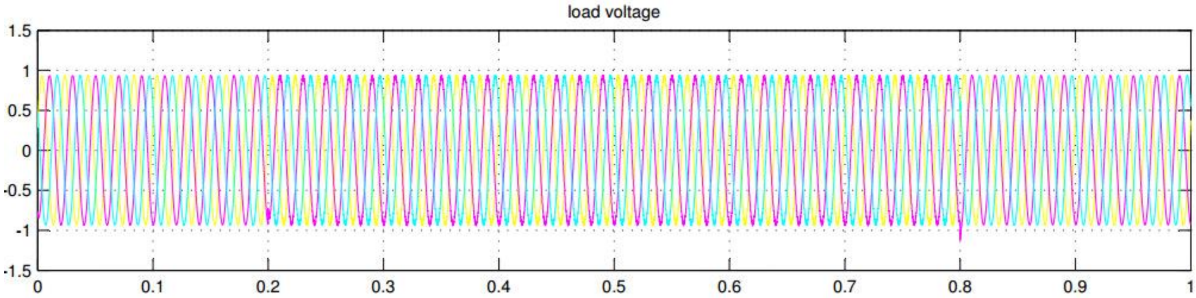

Fig 4.2.1(c): Load voltage after compensation

4.2.2: SVPWM Technique:

The below simulation waveforms shows of three phase voltage sag mitigation. The simulation started with supply voltage 20% sagging as shown in Fig 4.2.2 (a) and it also shows a 20% voltage sag initiated at 0.2s and it is kept until 0.8s, with a total voltage sag duration of 0.6s. Figures 4.2.2(b) and 4.2.2(c) shows the voltage injected by DVR and the corresponding load voltage after compensation. As a result of DVR , the load voltage is kept at 1 p.u using SVPWM technique.

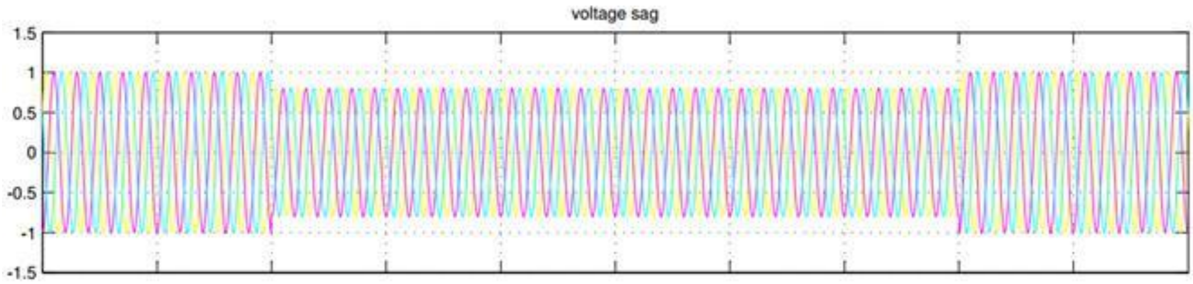

Fig 4.2.2(a): Voltage sag of 0.2 p.u

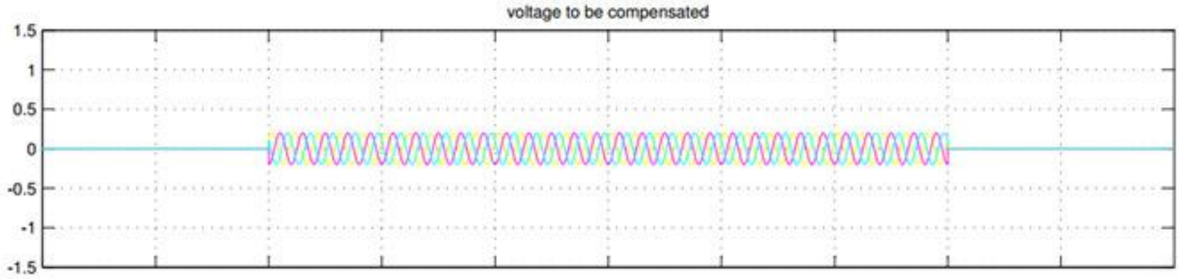

Fig 4.2.2(b): Injected voltage

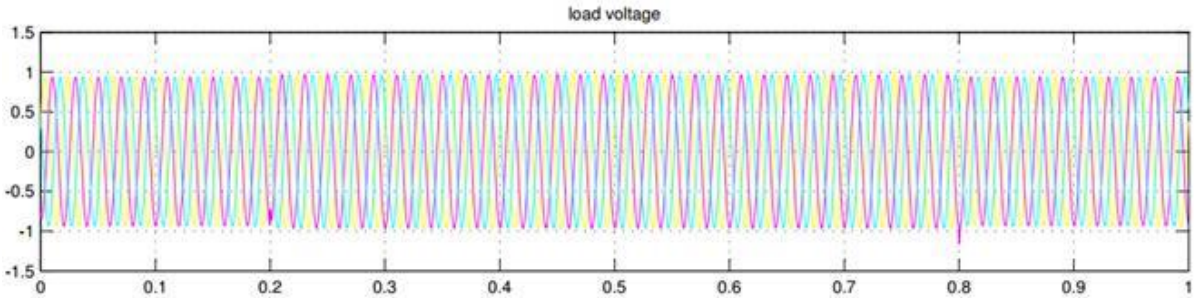

Fig 4.2.2(c): Load voltage after compensation

4.3 Voltage Swells:

4.3.1: SPWM Technique

The first simulation shows of three phase voltage swell is simulated. The simulation started with supply voltage 20% swelling as shown in Fig 4.3.1 (a) and it also shows a 20% voltage swell initiated at 0.2s and it is kept until 0.8s, with a total voltage swell duration of 0.6s. Figures 4.3.1(b) and 4.3.1(c) shows the voltage injected by DVR and the corresponding load voltage after compensation. As a result of DVR , the load voltage is kept at 1 p.u using SPWM technique.

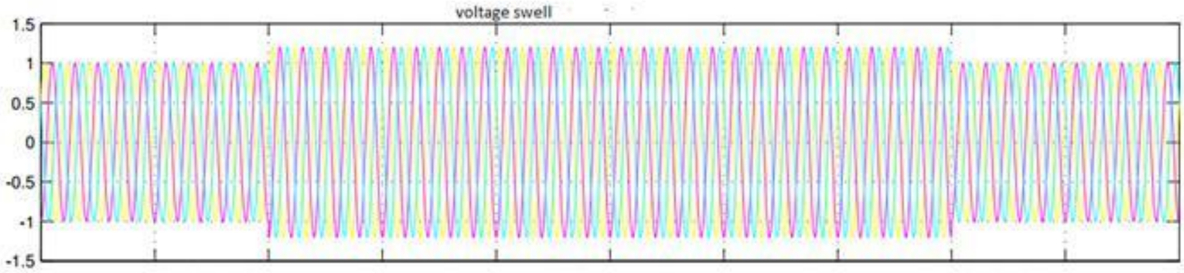

Fig 4.3.1(a): Voltage swell of 0.2 p.u

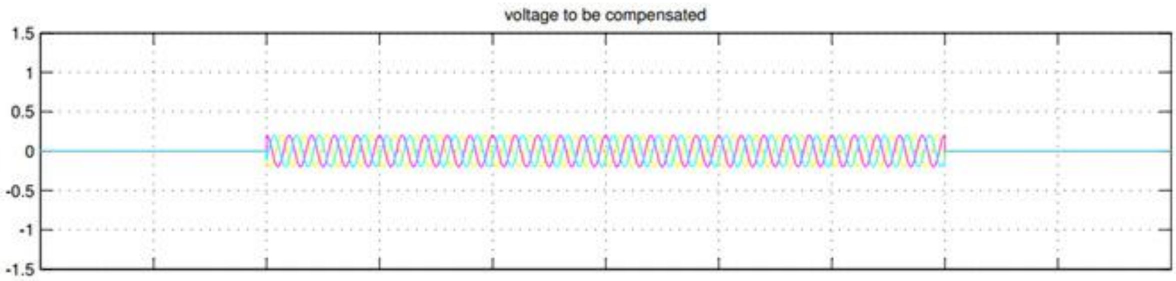

Fig 4.3.1(b): Injected voltage

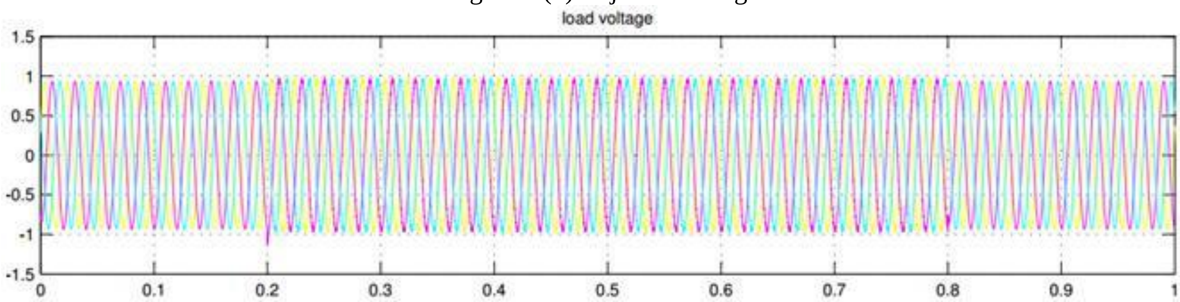

Fig 4.3.1(c): Load voltage after compensation

4.3.2: SVPWM Twchnique

The below simulation waveforms shows of three phase voltage swell mitigation. The simulation started with supply voltage 20% swelling as shown in Fig 4.3.2 (a) and it also shows a 20% voltage swell initiated at 0.2s and it is kept until 0.8s, with a total voltage swell duration of 0.6s. Figures 4.3.2(b) and 4.3.2(c) shows the voltage injected by DVR and the corresponding load voltage after compensation. As a result of DVR , the load voltage is kept at 1 p.u using SVPWM technique.

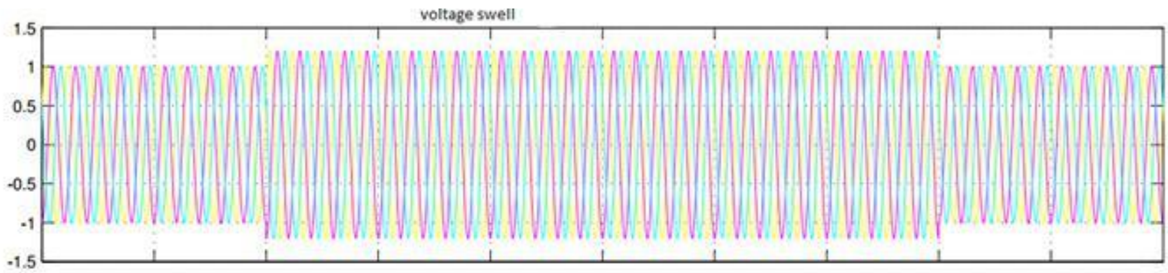

Fig 4.3.2(a): Voltage swell of 0.2 p.u

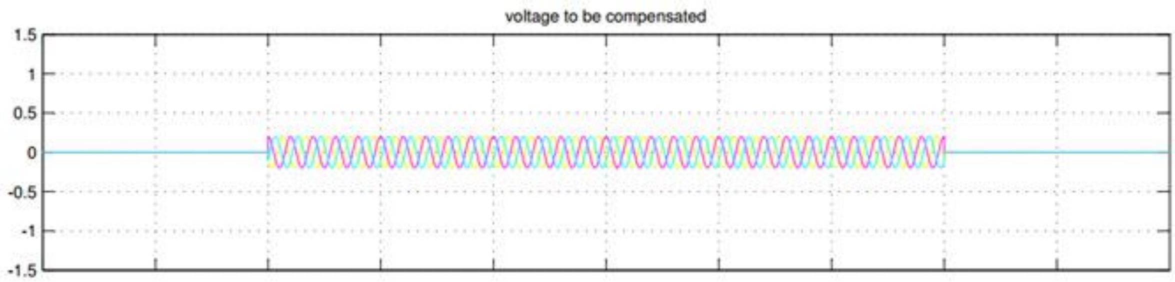

Fig 4.3.2(b): Injected voltage

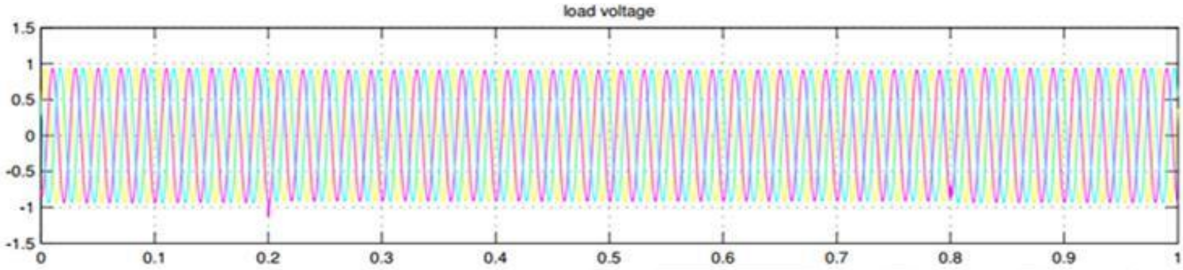

Fig 4.3.2(c): Load voltage after compensation

Table 2: Comparison of THD values in SPWM & SVPWM Techniques

S.No	Waveforms	THD in SPWM		THD in SVPWM	
		Sag	Swell	Sag	Swell
1	Inverter output voltage	163.74	163.56	89.56	89.54
2	Filter output voltage	11.34	4.49	0.35	0.35
3	Source voltage	0.00	0.00	0.00	0.00
4	Load voltage	1.10	1.08	0.09	0.09

From FFT analysis it is clear that the harmonics present in the inverter output voltage and filter output voltage are low in case of space vector pulse width modulation (SVPWM) than the sinusoidal pulse width modulation(SPWM).

V.CONCLUSION

The modeling and simulation of DVR using MATLAB/SIMULINK has been presented. The performance of DVR is studied under voltage Sag and Swell by using SPWM/SVPWM Techniques. From simulation results DVR compensates sags & swells quickly and provides better voltage voltage regulation in both cases. Space vector pulse width modulation effectively restored the voltage of sensitive load to normal and reduced the harmonic distortion in load voltage when compared with sinusoidal PWM. The simulation study reveals that SPWM requires 15% more DC voltage when compared to SVPWM for the same output. For the compensation of same amount of voltage sags & swells SVPWM requires less amount of DC voltage when compared to SPWM. So by using SVPWM technique dc voltage required for inverter is less when compared to sinusoidal PWM technique in order to generate same amount of output. The harmonics content in the output voltage is reduced by using Space Vector PWM technique as compared to SPWM technique.

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Bibliography:

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