International Journal of Research
Available at https://edupediapublications.org/journals
p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 03 Issue 14
October 2016

Voltage Sag Mitigation by IDVR Using SVPWM Technique

K. RATNA SUNIL [1], R. SATHISH KUMAR[2], B. VENKATA PRASANTH[3]
[1]PG Scholar, Dept of EEE, QIS College of Engineering & Technology, Ongole, AP, India,
[2]Associate Professor, Dept of EEE, QIS College of Engineering &Technology, Ongole, AP, India,
[3]Professor & HOD, Dept of EEE, QIS College of Engineering &Technology, Ongole, AP, India,

Abstract- *Power quality is of immense importance in all modern environment where electricity is involved. Power quality can be essentially influenced by important factor like quality service. Power quality problems were categorized by major events like sags, swells, transients, interruptions and harmonics. These problems may cause degradation in services which can cost economic losses to both utility and consumers. The power quality problems originate from various events ranging from switching events at the end user facility or faults on transmission lines. The extensive use of equipment sensitive to voltage deviation has made industrial applications more susceptible to voltage sags and swells. Among these the sags appeared as a top concern. Voltage sags can cause improper functioning and eventual tripping of industrial equipment, resulting in loss of production and hence profit. Voltage sag mitigation can be done using dynamic voltage restorer (DVR) and inter-line dynamic voltage restorer (IDVR). One of the main factors which limit capabilities of DVR in compensating long-duration voltage sags is the amount of stored energy within the restorer. In order to overcome this limitation, IDVR has been proposed where two DVR's each compensating a transmission line by series voltage injection, connected with common DC-link. In this paper, we are concentrating on modelling and simulation of IDVR using SVPWM technique to mitigate voltage in the power line by MATLAB/SIMULINK software.*

Keywords- **Power quality, Interline Dynamic voltage Restorer [IDVR], Multilevel Inverter [MLI], Sinusoidal Pulse width modulation [SPWM], Total harmonic distortion[THD], Space Vector Pulse width modulation[SVPWM]**

I. INTRODUCTION

Power quality is very crucial factor for proper operation of industrial process which contains a voltage sensitive and non-linear load which pollutes the power quality. Power quality is defined as set of parameters defining the properties of power quality as delivered to the user in normal operating condition in terms of continuity of supply and characteristics of voltage in terms of voltage (symmetry, magnitude, and waveform) in international electro technical commission (IEC) [1-3]. In present era the non-linearity in load is increasing which results in changes in power quality equation. There are two major characteristics of load which are responsible for increase in sensitivity of load. One of them is, new power electronic based device which is more sensitive to power quality. Controls of these electronic devices can be affected by momentary voltage sag or relatively major. Transient voltages which resulting in uncontrolled tripping, Malfunctioning of relays or miss-operation of important process. Second characteristic belongs to sensitive loads which are interconnected in extensive networks and automated processes [4-5]. The above two characteristics lead to major power quality problem of voltage sag/swell in distribution system.

This paper introduces the Dynamic Voltage Restorer which one is the best CPD to overcome these problems [6-7]. Series connected DVR works on basic principle of injection of require amount of voltage in transmission line by appropriate value of magnitude and phase angle. That injected voltage is taken out from any storing devices like batteries, flywheels [8-9]. Efficiency and performance of DVR depends on energy stored in storing device. Such DVR cannot perform very efficiently for long duration voltage sag compensation. This paper also introduces interline connection of DVR and it is called as IDVR. DVR includes five main parts are as injecting transformer, converter, filter, control circuit and source unit. Space vector pulse width modulation (SVPWM) technique is used to control the inverting operation. Voltage source inverter is used to convert dc voltage to three phase AC voltage. A fault in system is calculated using park transformation with respect to reference value [10-11].

II. OPERATING PRINCIPLE OF DVR

The main aim of DVR is to regulate the voltage at the load terminals irrespective of sag, distortion or unbalance in the supply voltage. The basic operating principle is to inject a voltage of required magnitude & frequency to restore the load voltage under voltage sag or distortion. Generally, it employs solid state power electronic switches such as GTO, IGBT or IGCT in the VSI, which can be operated in various pulse width modulation techniques such as SPWM (sinusoidal pulse width modulation), MSPWM (multiple sinusoidal pulse width modulation) and SVPWM(Space Vector Pulse Width Modulation). They inject a set of three phase AC voltage in series & synchronism with the distribution system. Basically the voltage sag compensation involves real and reactive power injection to the distribution system. For injection of real power DVR required energy storage device . This energy storage device is necessary to meet real power requirement of the system. Capability of the DVR is decided by this energy storage device. Its limits the capability of DVR during long duration voltage sag. This is overcome in proposed system. In IDVR system when one of the DVR is operated in voltage control mode, then other DVR is operated on power flow control mode to replenish the energy in the common DC-link energy storage dynamically.

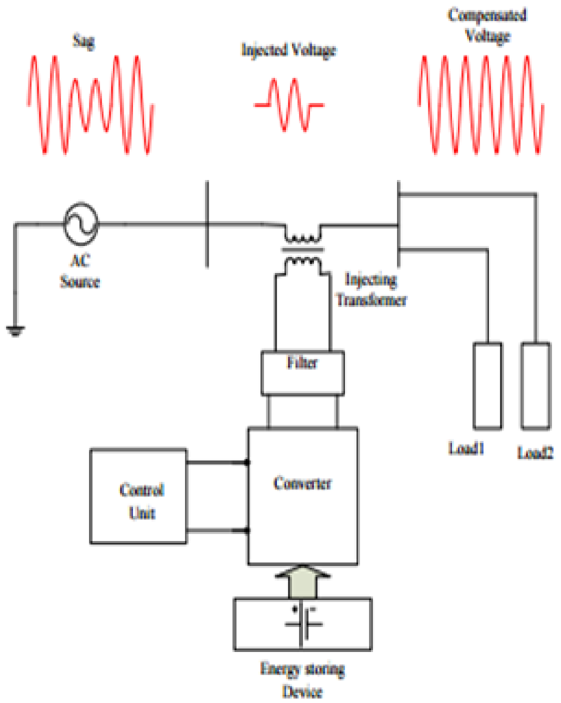

Figure 1. Operating Principle of DVR.

The basic operation of DVR can be explained in mainly three modes such as: one is protection mode, second one is standby mode, and third one is injection/boosting mode.

1. Protection mode: If in any situation the load current is increased more than its permissible value, due to fault condition or short circuit on load side, the dynamic voltage regulator will be isolated from the by the use of bypassing switches S_1 and S_2 as shown in Figure**2.**

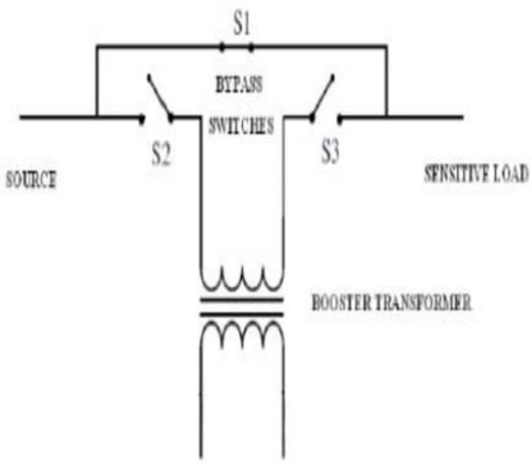

Figure 2. Protection Mode of DVR**.**

2. Standby Mode: In case of this standby mode the boosting transformer secondary winding is short circuited, with this the DVR is unable to inject any compensating values as shown in Figure 3.

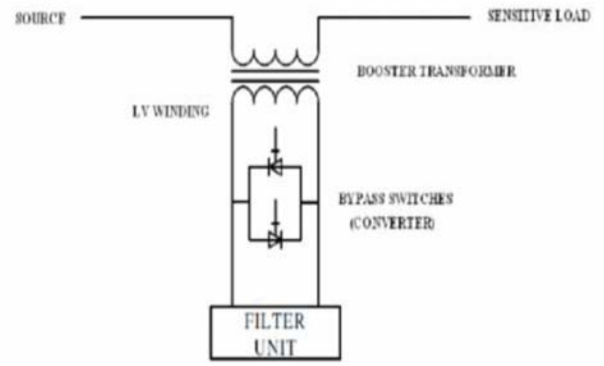

Figure 3. Standby Mode of DVR.

3. Injection/Boost Mode: In this case of injection mode the transformer is called injection transformer and the DVR has the capability of injecting voltage for compensating the power quality problems. In-phase compensation method is used to compensate voltage magnitude. The compensated voltage is in phase with the sagged voltage, therefore this technique minimize the voltage injected by the DVR. This technique is shown in Figure there is phase shift between the voltage before the sag and after the sag. It is recommended for the linear loads.

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 03 Issue 14
October 2016

III. BASIC CONFIGURATION OF DVR

Basically DVR requires five main components for proper operation. These are as fallows.

1. Injecting Transformer
2. Energy Storing Device
3. Voltage Source Converter
4. Filter
5. Control Unit

All above components are shown in Fig.1 and discussed ahead briefly [6].

1. Injecting Transformer

Injecting transformer is used to inject require amount of voltage in magnitude and phase shift. It is used in series with distribution feeder. We can use any one of three phase transformer or three single phase transformer.

2. Energy Storing Device

It is used to supply real amount of power in system. Performance of DVR mostly depends on the stored energy in device. It supplies the required amount of voltage to the converter. Energy storing device could be any of batteries, PV cell, Fly wheel etc.

3. Voltage Source Converter

Input of the converter is connected to DC batteries. Inverter is required to convert DC to AC and this converter is of two types, one is voltage source and other one is current source based. Different control techniques have been used for switching operation of inverter.

4. Filter

It filters out the higher harmonics components. We can connect filter either load side or inverter side of injecting transformer. Inverter side filter eliminates higher order harmonics but there might be voltage drop and phase shift in inverter output side. Load side filter avoids above problems but this position injects higher order current in secondary side.

5. Control Unit

Efficiency of DVR depends on control technique used for inverter. Pulses are generated and these pulses are used for the switching of the inverter. In this paper SVPWM control technique is introduced to generate pulses. DVR operates only when there are differences in load voltage and reference voltage, that difference is measured by PID controller.

IV. INTERLINE DYNAMIC VOLTAGE RESTORER

The IDVR system consists of several DVR's in different feeders, sharing a common DC-link. A two-line IDVR system shown in Fig.4 employs two DVRs are connected to two different feeders where one of the DVRs compensates for voltage swell/sag produced, the other DVR in IDVR system operates in power-flow control mode. The common capacitor connected between the two feeders act as the common DC supply.

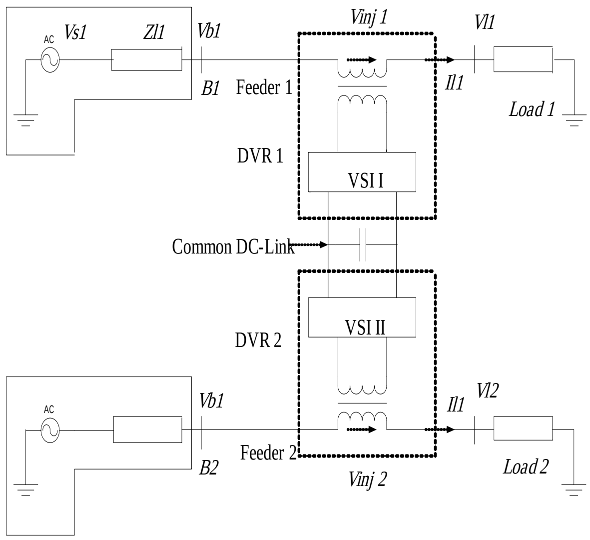

Fig.4. Schematic Diagram of IDVR.

Voltage swell/sag in a transmission system is likely to propagate to larger electrical distance than that in a distribution system. Due to these factors, the two feeders of the IDVR system in Fig 4.are considered to be connected to two different grid substations. It is assumed that the voltage distortion in Feeder1 would have a lesser impact on Feeder 4. The upstream generation transmission system is applied and the two feeders can be considered as two independent sources. These two voltage sources V_{s1} and V_{s2} are connected in series with the line impedances Z_{l1} and Z_{l2} which is in-turn connected to the buses B_1 and B_2 as in Fig.4. The DVR is connected in series with the feeder and the DVR's across different feeders are connected by a common DC-link. The load across each feeder is connected in series to the DVR, where V_{l1} and V_{l2} are the voltages across the load.

The injection of an appropriate voltage needs a certain amount of real and reactive power which must supplied by the DVR. Supply of real power is met by means of an energy storage facility connected in the DC-link. Large capacitors are used as a source of energy storage in most of the DVR's. Generally, capacitors are used to generate reactive power in an AC power system. However, in a DC system, capacitors can be used to store energy. When the energy is drawn from the energy storage capacitors, the capacitor terminal voltage decreases. Hence, large capacitors in the DC-link energy storage are needed to effectively mitigate voltage swell of large depths and long durations. The pulse can be generated using various modulation techniques. In this paper, the pulse for the switch is generated using SPWM

V. PWM TECHNIQUES FOR 3-PHASE VSI

This section describes two types of PWM techniques used to control the 3-phase VSI of a grid connected SPV system.

A. Sinusoidal PWM (SPWM)

The SPWM technique is very simple and very easy to implement. This method produces a sinusoidal waveform by filtering an output pulse waveform by varying width. The required output voltage is achieved by varying the amplitude and frequency of modulating voltage. The pulse width can be changed by changing the amplitude and frequency of reference or modulating voltage. In Fig.3, modulating wave is compared with high frequency triangular wave from. The high switching frequency leads better output sinusoidal wave from. The switching state is changed when sine waveform is intersects with high frequency triangular waveform.

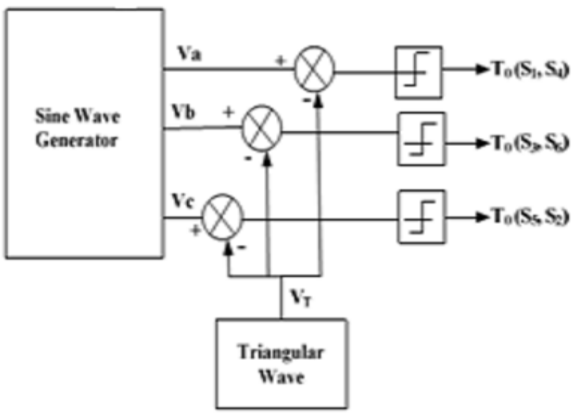

Fig.5. SPWM Control signal Generation.

In 3-phase VSI, the SPWM is achieved by three sinusoidal voltages (Va, Vb, Vc) which are 120 • out of phase with each other are compared with high frequency triangular waveform(V_T), and relative levels of the waveforms are used to control the switching the devices in each phase leg of the inverter.

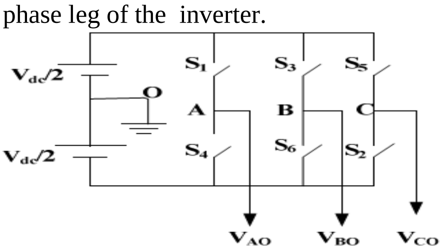

Fig.6. SPWM Inverter.

3-phase VSI having six switches (S_1-S_6) with each phase output is connected to middle of the each inverter leg is shown in Fig.6. The output of the comparator forms the control signal for each leg of the inverter. In one leg, two switches makes a phase and these two switches open and close in a complementary fashion. The total voltage is V_{dc}, therefore the each pole voltage V_{Ao}, V_{Bo}, V_{Co} of the inverter varies between $-V_{dc/2}$and $+V_{dc/2}$. If the sine wave is greater than triangular wave, then upper switch is getting turned ON and lower switch is turned OFF. Based on switching states, positive or negative half DC link voltage is applied to each phase. Usually the switches are controlled in pairs (S_1, S_4), (S_3, S_6) and (S_5, S_2) and the logic is shown in Table I.

S_1 is ON When $V_a > V_T$	S_4 is ON When $V_a > V_T$
S_3 is ON When $V_b > V_T$	S_6 is ON When $V_b > V_T$
S_5 is ON When $V_c > V_T$	S_2 is ON When $V_c > V_T$

TABLE.I Switching States

B. Space Vector Pulse Width Modulation (SVPWM)

SVPWM is employed to generate the desired output voltage vector V in d-q reference frame. For a three phase VSI there are totally eight possible switching patterns and each of them determines a voltage space vector. Fig.7 which show space vector representation, eight voltage space vectors divide the entire vector space into six sectors namely 1-6. Except two zero vectors V_O and V_7, all other active space vectors have same magnitude of 2/3 V_{dc}. In SVPWM, the reference voltage vector should be synthesized by the adjacent vectors of the located sector in order to minimize the switching times and to minimize the current harmonics. The switching function S_X (x=a, b, c) is defined as: If S_X=1, the upper switch is ON and lower switch is OFF. If S_X=0, the upper switch is OFF while the lower switch is ON. There are 8 switch status of three phase inverter corresponding to 8 voltage space vectors as shown in Table1

C. The eight vectors, called the basic space vectors include

Two zero vectors $V_0$and $V_7$and six non-zero V_1-V_6vectors. Two zero vectors have zero magnitude and six non-zero vectors have the same amplitude as shown in Figure 5. The angle between any adjacent two non-zero vectors is 60 degrees.

• The desired reference voltage vector V ref given by the current controller can be approximated by using two adjacent vectors V_X, V_{X+1}(x=1,2,3,4,5,6) and zero vectors

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 03 Issue 14
October 2016

V_0 or V_7 for every PWM and the period TPWM is given in equation (1)

$$T_{PWM}.V_{ref} = T_1.V_X + T_2.V_{X+1} + T_0 + V_0 \quad (1)$$

$$T_1 + T_2 < T_{PWM} \quad (2)$$

• TPWM is considered small with respect to the speed of change of V_{ref} that is the change of V_{ref} can be assumed to be very small within TPWM and therefore the average inverter output will be the same as the average reference voltage.

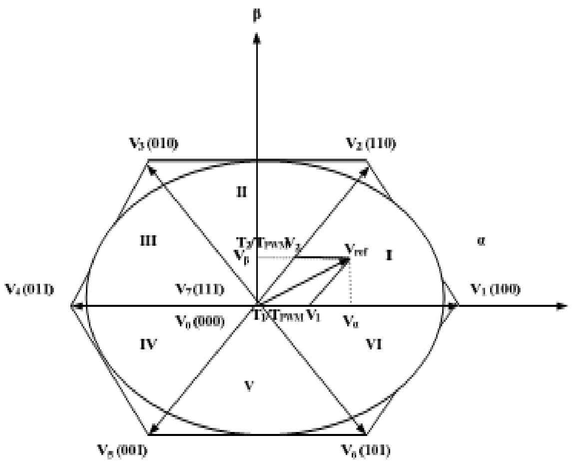

Fig.7. Voltage Space Vector Representation.

TABLE.II. Switching Status of SVPWM for 3-Phase VSI

S_a	S_b	S_c	V_a	V_b	V_c	Vector
0	0	0	0	0	0	V_0(000)
1	0	0	$2/3V_{dc}$	$-1/3V_{dc}$	$-1/3V_{dc}$	V_1(100)
1	1	0	$1/3V_{dc}$	$1/3V_{dc}$	$-2/3V_{dc}$	V_2(110)
0	1	0	$-1/3V_{dc}$	$2/3V_{dc}$	$-1/3V_{dc}$	V_3(010)
0	1	1	$-2/3V_{dc}$	$1/3V_{dc}$	$1/3V_{dc}$	V_4(011)
0	0	1	$-1/3V_{dc}$	$-1/3V_{dc}$	$2/3V_{dc}$	V_5(001)
1	0	1	$1/3V_{dc}$	$-2/3V_{dc}$	$1/3V_{dc}$	V_6(101)
1	1	1	0	0	0	V_7(111)

VI. MATLAB/SIMULATION RESULTS

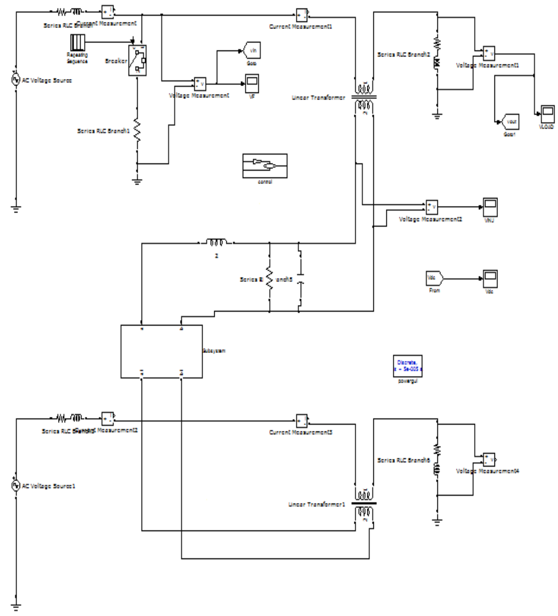

Fig.8.Matlab/Simulation Model of IDVR with SPWM.

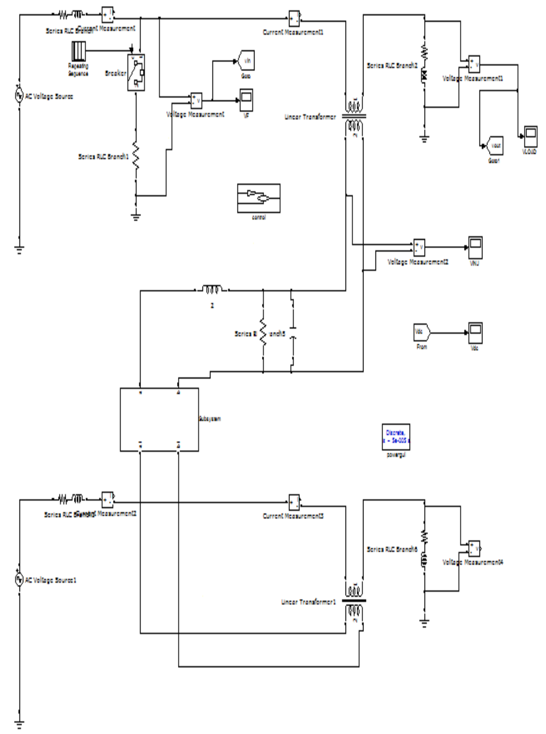

Fig.9.Matlab/Simulation Model of IDVR with SVPWM.

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 03 Issue 14
October 2016

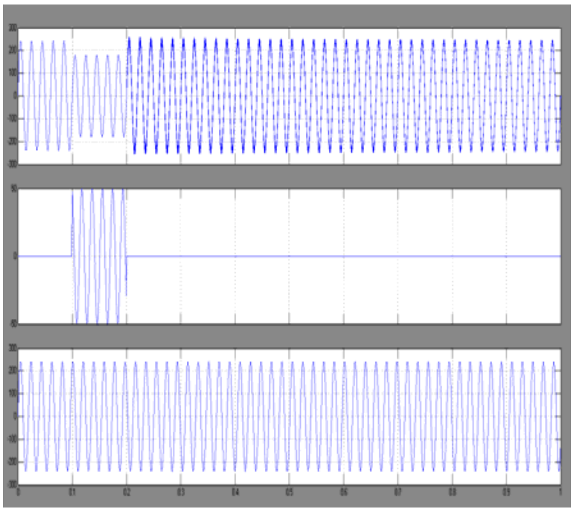

Fig.10 Simulation Results of IDVR Source Voltage, Injected Voltage and Load Voltage with SPWM.

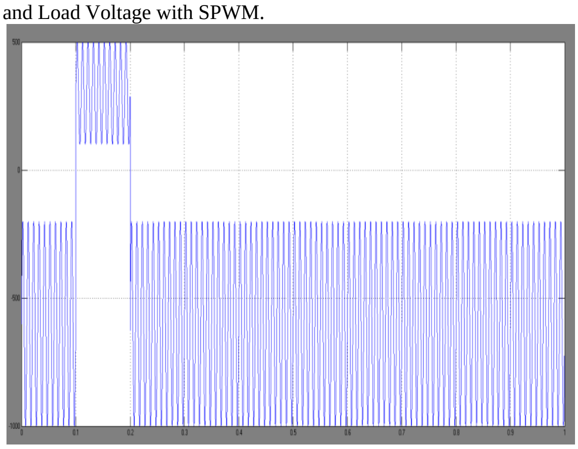

Fig.11. Common DC-Link Voltage for Sag.

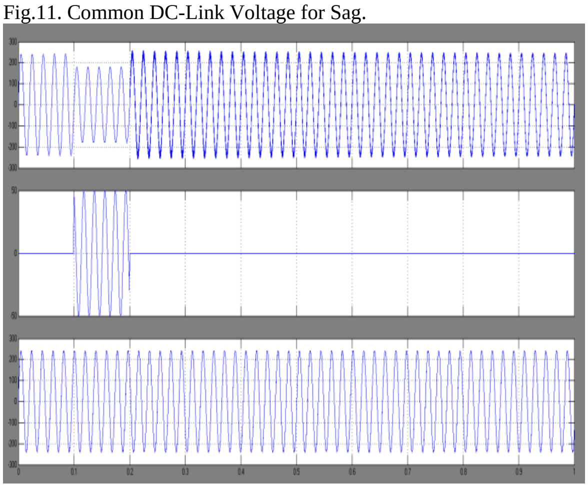

Fig.12.Simulation Results of IDVR Source Voltage, Injected Voltage and Load Voltage with SVPWM

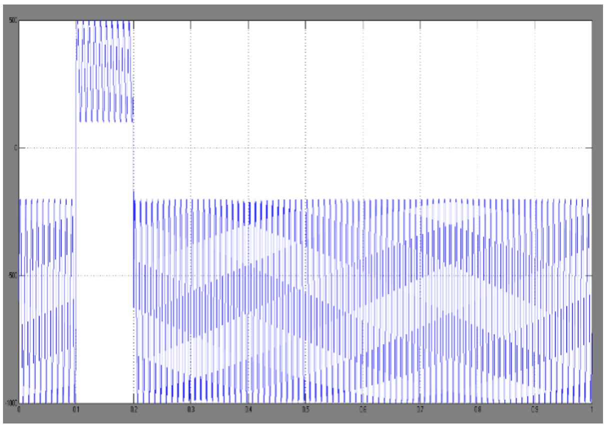

Fig.11.Common DC-Link Voltage for Sag.

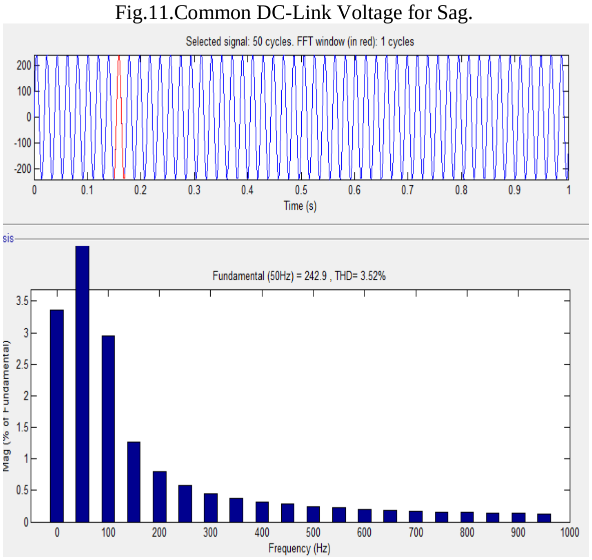

Fig.12.THD for Voltage with SPWM

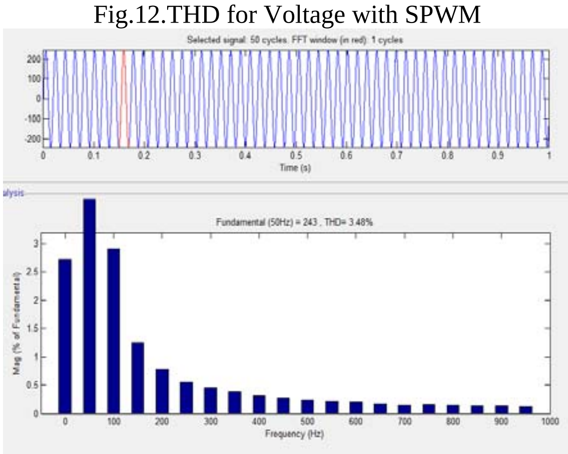

Fig.13.THD for Voltage with SVPWM

VII.CONCLUSION

The modeling and simulation of IDVR system using MATLAB/SIMULIK has been presented. Hence the simulink model of voltage sag compensation in both the SPWM and SVPWM control schemes are modeled and simulated. The respective THD (Total Harmonic Distortion) Voltage Sag Compensation using sinusoidal pulse width modulation 3.87 and space vector pulse width modulation 3.48. The harmonics is comparatively lower for Space Vector Pulse Width Modulation (SVPWM) control scheme than Sinusoidal Pulse Width Modulation (SPWM).
.

REFERENCES

1. Choi S. S, Li B. H, and Vilathgamuwa D. M (2000) "Dynamic voltage restoration with minimum energy injection," IEEE Trans. Power Systems, vol. 15, pp. 51-57.
2. Gajanayake C. J, Vilathgamuwa D. M, and Loh P. C (2005) "Small-signal and signal-flow-graph modelling of switched Z-sourceimpedance network," IEEE Power Electronics Letters, vol. 3, pp. 111-116.
3. Jimichi T, Fujita H., and Akagi H. (2005) "Design and experimentation of a dynamic voltage restorer capable of significantly reducing anenergystorage element," in Conf. Record Industry Applications Conference, 14th IAS Annual Meeting..
4. Loh P. C, Vilathgamuwa D. M, Lai Y. S, Chua G. T, and Li Y (2004) "Pulse-width modulation of Z-source inverters," in Conf.Record IEEE Industry Applications Conference, 39th IAS Annual Meeting.
5. Peng F. Z. (2003) "Z-source inverter," IEEE Trans. Industry Applications, vol.39, pp. 504-510.
6. Sira-Ramirez H and Ortega R (1995) "Passivity-based controllers for the stabilization of DC-to-DC power converters," in Proc.34thIEEEConference on Decision and Control.
7. Usha Rani P. and Rama Reddy S. (2011), „Digital Simulation of an Interline Dynamic Voltage Restorer for Voltage Compensation‟, International conference on Computer, Communication and Electrical Technology ICCCET 2011, 18th& 19th March 2011,National College of Engineering, pp. 133-139 (IEEE Xplore 978-1-4244-9391-3/11)
8. Usha Rani P. and Rama Reddy S. (2011), „Voltage sag / swell compensation in an interline dynamic voltage restorer‟, International conference on Emerging Trends in Electrical and Computer Technology, ICETECT 2011, 23rd& 24th March 2011, St. Xavier's Catholic College of Engineering, pp. 309-314 (IEEE Xplore 978-1-4244-7925-2/11)
9. Gauri S. Sarode, Dr. Paresh J. Shah,Dr. Paresh J. Shah "Modeling and Evaluation of Interline Dynamic Voltage Restorer for Distribution System", INTERNATIONAL JOURNAL OF SCIENCE, SPIRITUALITY, BUSINESS AND TECHNOLOGY (IJSSBT), Vol. 3, No. 2, June 2015 ISSN (Print) 2277—7261.
10. P. USHA RANI 'MODELING AND SIMULATION OF INTERLINE DYNAMIC VOLTAGE RESTORER USING SVPWM TECHNIQUE" ,Journal of Theoretical and Applied Information Technology 10th February 2014. Vol. 60 No.1.
11. Rajesh Damaraju, S.V.N.L. Lalitha "A Fuzzy Controller for Compensation of Voltage SAG/SWELL Problems Using Reduced Rating Dynamic Voltage Restorer", TELKOMNIKA Indonesian Journal of Electrical Engineering Vol. 15, No.3, September 2015, pp. 407 ~ 414 DOI: 10.11591/telkomnika.v15i3.8455.
12. P.Usha Rani "Digital Simulation of an Interline Dynamic Voltage Restorer for Voltage Compensation", JOURNAL OF ENGINEERING RESEARCH AND TECHNOLOGY, VOLUME 1, ISSUE 4, DECEMBER 2014.
13. Gauri S Sarode and Paresh J " Voltage sag Compensation Capability of DVR ",European Journal of Advances in Engineering and Technology 2015, 2(7); 48-55, Research Article. ISSN : 2394 - 658X.

BIOGRAPHY

K Ratna Sunil is pursuing M .Tech at QIS College of Engineering & Technology under JNTU, Kakinada. He received his B.Tech degree from QIS College of Engineering & Technology JNTUK, Kakinada. His current research interests are Power electronics & Power system control.

Sri.R.SathishKumar received B.Tech. in Electrical and Electronics Engineering from Jawaharlal Nehru Technological University, Hyderabad, India, in 2005 and M.Tech in Electrical & Electronics Engineering from Jawaharlal Nehru Technological University, Hyderabad, India, in 2010. Currently, he is working as an Associate Professor in QIS College of Engineering and Technology, Ongole, India. He has published a number of papers in various national & international journals & conferences. His research areas are power system operation & control and economic load dispatch.

Dr. B. Venkata Prasanth received B.Tech. in Electrical & Electronics Engineering from Sri Krishnadevaraya University & M.Tech. Degree in Electrical Power Systems from Jawaharlal Nehru Technological University, Ananthapur, India. He received his Ph.D. in Electrical & Electronics Engineering from Jawaharlal Nehru Technological University, Hyderabad, India. He has got a teaching experience of more than 15 years. Currently, he is working as Professor& Head in QIS College of Engineering and Technology, Ongole, India in the Dept. of Electrical & Electronics Engineering. He has published a number of papers in various national & international journals & conferences. His research interests include application of intelligent controllers to power system control design, power system restructuring, power system economics & optimization.