A New Method for Reducing Voltage Sag Using Interline Dynamic Voltage Restorer

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Abstract: — Power quality is of immense importance in all modern environments where electricity is involved. Power quality can be essentially influenced by important factor like quality service. Power quality problems were categorized by five major events; 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 work, I am 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

DVR is connected in series with load and source. Sudden change in large load or other factors can cause quality problem in system. If system is under voltage sag then there will be lesser magnitude across load as compared to deserving voltage. DVR needs to inject voltage in system to maintain constant voltage across load.

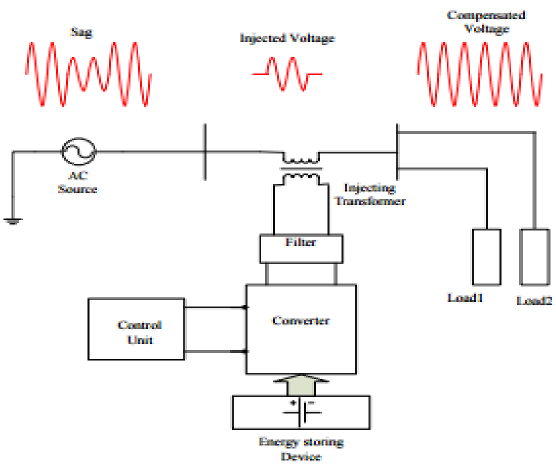

Fig 1. Operating principle of DVR.

Operating principle of DVR is as shown in fig 1. As there is voltage sag from source side, the injecting transformer feeds required amount of voltage from storing device and compensated constant voltage is delivered to the load [6].

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 DVRs in different feeders, sharing a common DC-link. A two-line IDVR system shown in Fig.2 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.

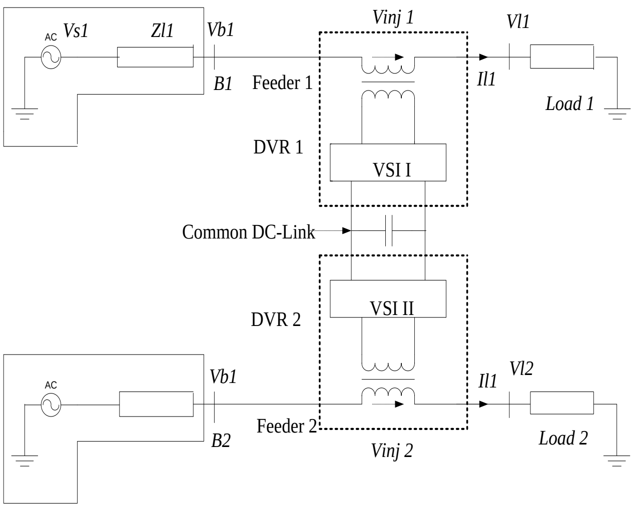

Fig.2. Schematic figure of IDVR.

Voltage swell/sag in a transmission system is likely to propagate to larger electrical distance than that in a

Sup-plied 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 DVRs. 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.

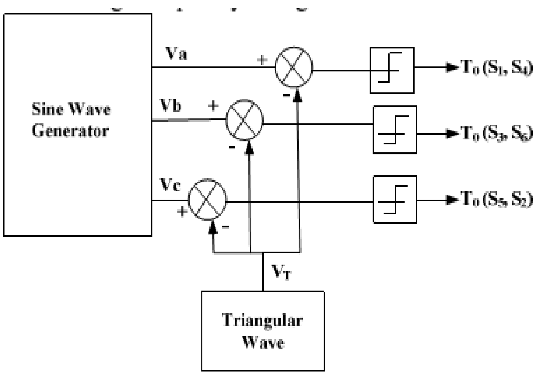

Fig.3. SPWM Control signal Generation.

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(VT), and relative levels of the waveforms are used to control the switching the devices in each phase leg of the inverter.

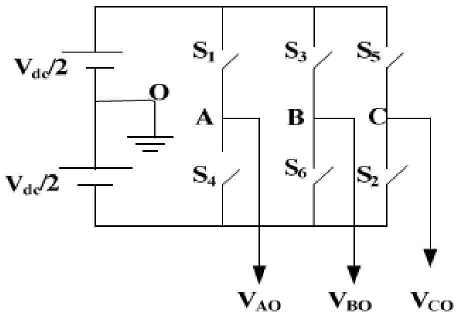

Fig.4. SPWM Inverter.

3-phase VSI having six switches (S1-S6) with each phase output is connected to middle of the each inverter leg is shown in Fig.4. The output of the comparator forms the control signal for each leg of the inverter. In one lag, two switches makes a phase and these two switches open and close in a complementary fashion. The total voltage is Vdc, therefore the each pole voltage Vao, Vbo; Vco of the inverter varies between –Vdc/2and +Vdc/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 (S1, S4), (S3, S6) and (S5, S2) and the logic is shown in Table I.

TABLE.I Switching States

S1 is ON when $V_a > V_T$	S4 is ON when $V_a < V_T$
S3 is ON when $V_b > V_T$	S6 is ON when $V_b < V_T$
S5 is ON when $V_c > V_T$	S2 is ON when $V_c < V_T$

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 VO and V7, all other active space vectors have same magnitude of (2/3) Vdc. 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 Sx(x=a, b, c) is defined as: If Sx=1, the upper switch is ON and lower switch is OFF. If Sx=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 Table

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

Two zero vectors V0and V7and six non-zero V1-V6vectors. 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 Vx, Vx+1(x=1,2,3,4,5,6) and zero vectors V0or V7for every PWM and the period TPWM is given in equation (6)

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

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

• 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.

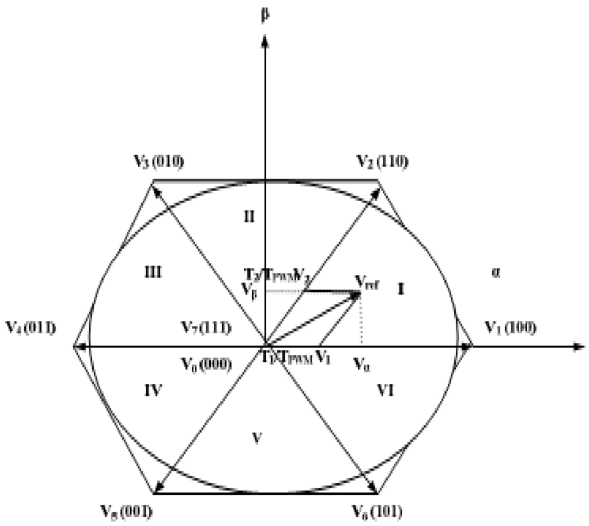

Fig.5. Voltage Space Vector Representation.

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	$2/3V_{dc}$	$-1/3 V_{dc}$	$-1/3 V_{dc}$	$V_1(100)$
1	1	0	$1/3 V_{dc}$	$1/3 V_{dc}$	$-2/3 V_{dc}$	$V_2(110)$
0	1	0	$-1/3 V_{dc}$	$2/3 V_{dc}$	$-1/3 V_{dc}$	$V_3(010)$
0	1	1	$-2/3 V_{dc}$	$1/3 V_{dc}$	1/3 Vdc	$V_4(011)$
0	0	1	$-1/3 V_{dc}$	$-1/3 V_{dc}$	$2/3V_{dc}$	$V_5(001)$
1	0	1	$1/3 V_{dc}$	$-2/3V_{dc}$	$1/3V_{dc}$	$V_6(101)$
1	1	1	0	0	0	$V_7(111)$

VI.MATLAB/SIMULATION RESULTS

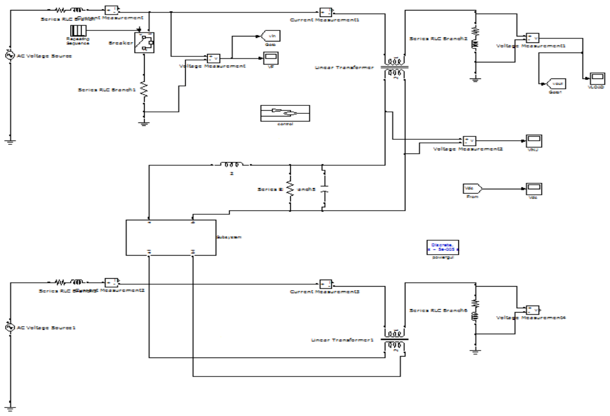

Fig.6.Matlab/Simulation Model of IDVR with SPWM.

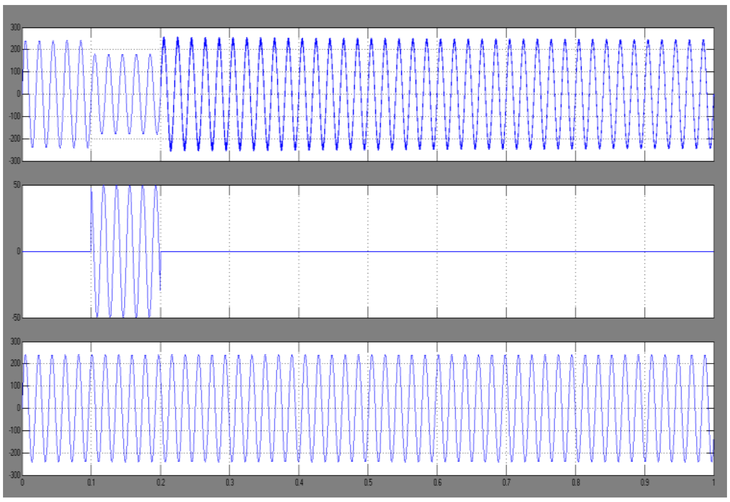

Fig.7.Simulation Results of IDVR Source Voltage, Injected Voltage and Load Voltage with SVPWM.

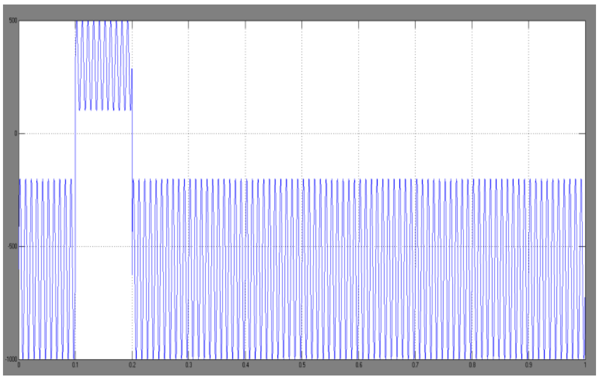

Fig.8.Common DC-Link Voltage for Sag.

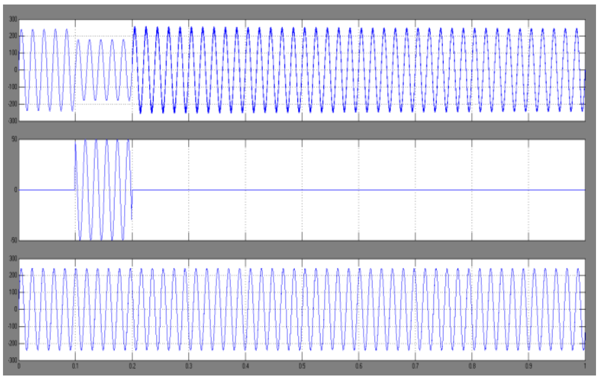

Fig.9.Simulation Results of IDVR Source Voltage, Injected Voltage and Load Voltage with SVPWM.

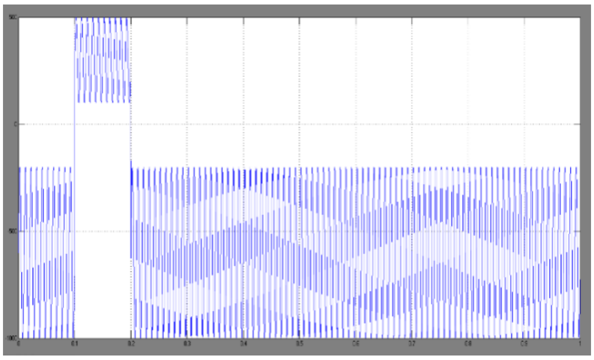

Fig.10.Common DC-Link Voltage for Sag.

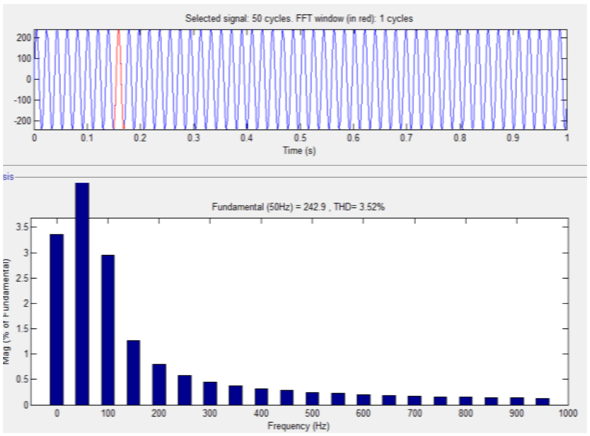

Fig.9.THD for Voltage with SPWM

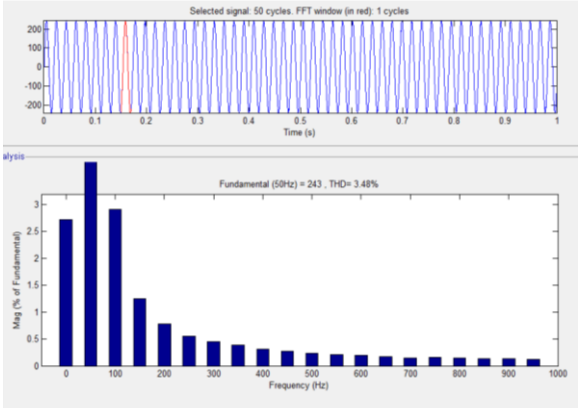

Fig.10.THD for Voltage with SVPWM.

VII.CONCLUSION

The modeling and simulation of IDVR system using MATLAB/SIMULIK has been presented. The simulation results showed clearly the performance of the DVR in mitigating voltage sags. The IDVR handled multi-feeder voltage sag without any difficulties and injected the appropriate voltage component to correct rapidly any anomaly in the supply voltage to keep load voltage balanced and constant at nominal value. The proposed topology mitigates the voltage sag efficiently. The efficiency and the effectiveness in voltage sags compensation showed by the IDVR system makes it an interesting power quality device compared to other custom devices. The results of the MATLAB/SIMULINK simulation results verification also verify the proposed control algorithm based on space vector pulse width modulation technique to generate the pulses for mitigating voltage sag.

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