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MODELING AND SIMULATION OF INTERLINE DYNAMIC VOLTAGE RESTORER USING SVPWM TECHNIQUE

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ABSTRACT

Voltage Deviations, often in the form of voltage sags can cause severe process disruptions and can result in substantial economic loss. The Dynamic Voltage Restorer (DVR), a custom power device, has been used to protect sensitive loads from the effect of voltage sags / swells on the distribution feeder. The DVR's main function is to inject the difference in voltage to the power line and thus maintain the load side voltage at the optimum value. The interline DVR proposed in this work provides a way to replenish DC link energy storage dynamically. The IDVR consists of several DVRs connected to different distribution feeders in the power system. The DVRs in the IDVR system share common energy storage. When one of the DVR compensates for voltage sag appearing in that feeder, the other DVRs replenish the energy in the common DC link dynamically. This paper presents the modeling and closed loop control aspects of the DVR and IDVR systems using Space Vector Pulse Width Modulation technique working against voltage sags by simulation.The proposed DVR and IDVR systems are modeled and simulated using MATLAB/ SIMULINK software. The simulation results show that the control approach performs very effectively and yields excellent compensation for compensating voltage sags.
Keywords: *Dynamic Voltage Restorer (DVR), Interline Dynamic Voltage restorer (IDVR), Space Vector pulse Width modulation (SVPWM)*

1. INTRODUCTION

Voltage sag is a momentary decrease in RMS voltage lasting between half a cycle to a few seconds. It is generally caused by faults in the power system and is characterized by its magnitude and duration. Voltage sag magnitude is defined as the net RMS voltage during voltage sag, which is usually in per unit of the nominal voltage level. The voltage sag magnitude depends on various factors like the type of fault, the location of the fault and the fault impedance. The duration of the voltage sag depends on how fast the fault is cleared by the protective device. In short, voltage sag will last till the fault is cleared.

The DVR is operated in such a fashion that it does not supply or absorb any active power during the steady-state operation [1]. It is desirable to have a minimum VA rating of the DVR, for a given system without compromising compensation capability [2]. Control algorithm for dynamic voltage restorer (DVR) to improve voltage quality problems such as voltage sags/swells in distribution systems has been proposed [3]. The DVR consists of three inverters sharing the same DC link via a capacitor bank. Each inverter has an individual inner control loop for generating the gate signals for the switches [4].

The voltage-restoration process involves real-power injection into the distribution system, the capability of a particular DVR topology, especially for compensating long-duration voltage sags, depends on the energy storage capacity of the DVR [5]. The main factor which limits capabilities of a particular DVR in compensating long-duration voltage sags is the amount of stored energy within the restorer [6]. The modeling and simulation of DVR and IDVR is presented [7 -13].

The literature [1] to [13] does not deal with IDVR system using space vector pulse width modulation technique. An attempt is made in the present work to model IDVR system using the blocks of MATLAB simulink.

2. BASIC PRINCIPLE OF DVR and IDVR

A DVR is a device that injects a controlled voltage V_{inj} in series to the bus voltage by means of a series transformer as depicted in Fig.1. When supply voltage V_s changes, the DVR injects a

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voltage V_{inj} in such a way that the desired voltage magnitude can be maintained. DVR is simply a VSC that produces an ac output voltage and injects in series with supply voltage through a transformer. DVR itself is capable of generating reactive power, but the injected active power must come from the energy storage part of DVR.

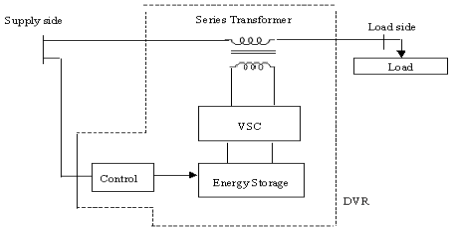

Fig.1. Typical DVR Circuit

The IDVR system employs two or more DVRs connected to a common DC link. A general schematic of the IDVR system with two independent feeders is shown in Fig.2. These two feeders could be of the same or different voltage level. When one of the DVRs compensates for voltage sag, the other DVR in IDVR system operates in power flow control mode to replenish DC link energy storage, which is depleted due to the real power taken by the DVR working in the voltage sag compensation mode. Propagation of voltage sag in one line to the other line can be neglected due to the electrical distance between them and the voltage level difference of two feeders. Once the electrical coupling is neglected they can be considered as two isolated sources V_{s1} and V_{s2} with their source impedances Z_{l1} and Z_{l2}.

In order to establish the power exchange between the two systems, it is assumed that the DVR 1 is mitigating voltage sag appearing in that line and the DVR 2 is controlled to provide real power to the DC link energy storage. As the line II is operating at its normal condition, the load voltage of feeder II should be equal the load bus voltage V_{b2}. Thus the inverter of DVR 2 should be controlled to meet this condition while it is providing real power to the DC link energy storage. The real power, which should be supplied by the DVR 2 to maintain the DC link voltage, is equal to the real power needed to compensate voltage sag in line I and the system power losses including the converter switching losses.

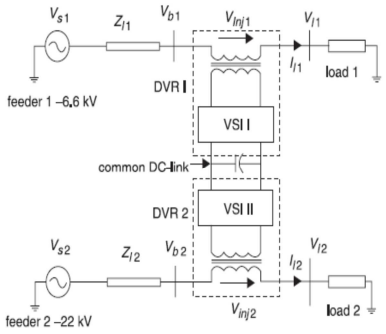

Fig.2. Schematic Diagram Of An IDVR

The dqo transformation or Park's transformation is used in the control of the DVR. The control scheme for the proposed system is based on the comparison of a voltage reference and the measured terminal voltage (V_a, V_b, V_c). The error signal is used as a modulation signal that allows to generate a commutation pattern for the power switches constituting the voltage source converter. The commutation pattern is generated by means of the Space Vector Pulse Width Modulation (SVPWM). Equation (1) defines the transformation from the three phase system a, b, c to the dqo stationary frame.

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \cos\left(\theta-\frac{2\pi}{3}\right) & 1 \\ -\sin(\theta) & -\sin\left(\theta-\frac{2\pi}{3}\right) & 1 \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (1)$$

There are eight possible combinations of on and off patterns for the three upper power switches. The on and off states of the lower power devices are opposite to the upper one, and so are easily determined once the states of the upper power transistors are determined. To implement the space vector PWM, the voltage equations in the *abc* reference frame can be transformed into the stationary *dq* reference frame.

3. SIMULATION OF DVR SYSTEM

The proposed DVR circuit with the Space Vector PWM is shown in Fig.3. Here the error voltage in the dq-frame is used to calculate the resultant reference voltage and the angle α of the space vector 8-sector framework. The angle α is used to obtain the useful sectors, which are utilized to calculate the switching pulses. At any instant, the combination of the upper/lower switch signals will

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give an 'M' wave, which is compared with a ramp signal to give gate pulses to the switches in the converter.

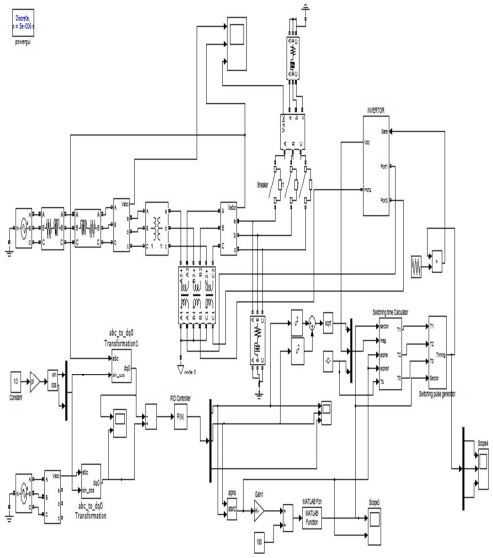

Fig.3 Simulation Circuit Of DVR

Fig.4 shows 28.12% voltage sag initiated at 300ms, and it is kept until 800ms, with a total voltage sag duration of 500ms. Fig.7 (a) and (b) shows the voltage injected by the DVR and the compensated load voltage respectively. As a result of the DVR, the load voltage is kept at the same value throughout the simulation, including the voltage sag period. The THD of the SVPWM system is found to be 6.54%.

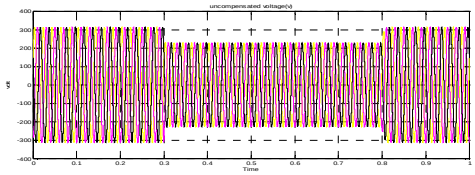

Fig.4 Voltage Sag Of The DVR

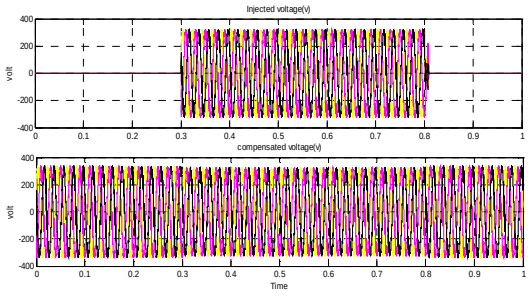

Fig.5 Response Of The DVR To Voltage Sag

4. SIMULATION OF IDVR SYSTEM

Fig.6 shows the configuration of the proposed IDVR design using MATLAB/SIMULINK. Once a voltage disturbance occurs, with the aid of dqo transformation based control scheme, the inverter output can be steered in phase with the incoming AC source while the load is maintained constant. The basic functions of a controller in a IDVR are the detection of voltage sag events in the system; computation of the correcting voltage, generation of trigger pulses to the sinusoidal PWM based DC-AC inverter, correction of any anomalies in the series voltage injection and termination of the trigger pulses when the event has passed. The controller may also be used to shift the DC-AC inverter into rectifier mode to charge the capacitors in the DC energy link in the absence of voltage sags.

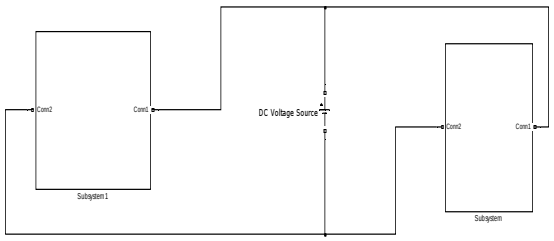

Fig.6 Close Loop Controlled Three Phase IDVR

The subsystem 1 and 2 consists of feeder and DVR. And subsystem 1 is shown in Fig.7. The DVR 1 consists of an inverter, switching time calculator and switching pulse generator. Fig.8 indicates that 27.42% voltage sag is initiated at 300ms and it is kept until 800ms, with a total voltage sag duration of 500ms in the low voltage feeder$_1$.

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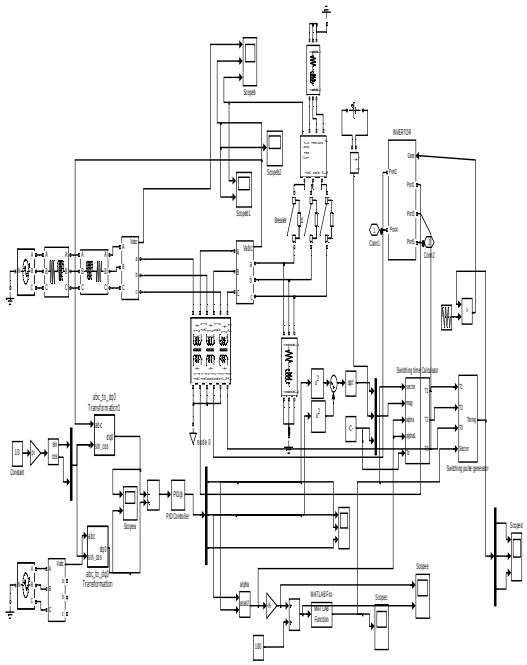

Fig.7 Subsystem 1 Of Three Phase IDVR

Fig.9 (a) and (b) show the voltage injected by the DVR2 and the compensated load voltage respectively. Due to the presence of the IDVR, the load voltage remains constant throughout the voltage sag period.

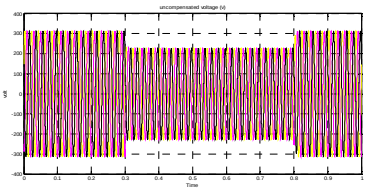

Fig.8 Voltage Sag Of The Three Phase IDVR

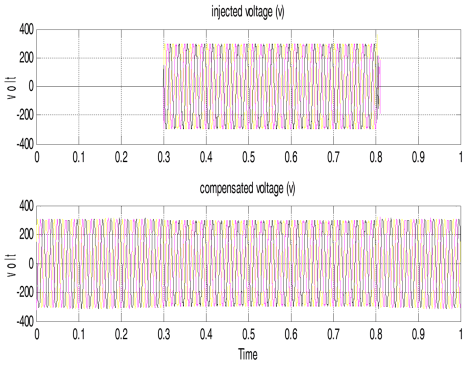

Fig.9 Response Of The Three Phase IDVR

5. CONCLUSION

The MATLAB simulink models are proposed for closed loop DVR and IDVR systems. The simulation of a DVR and IDVR system has been done successfully using these models. IDVR is found to be an effective custom power device for voltage sag mitigation. The impact of voltage sag on sensitive equipment is severe. Simulation results have been presented to demonstrate the efficacy and effectiveness of the proposed DVR and IDVR systems to mitigate long duration voltage sags.

The simulation results indicate that the control strategy compensates for voltage sag with high accuracy. The results show that the control technique is a simple method for voltage sag compensation.

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