DIGITAL SIMULATION OF A DYNAMIC VOLTAGE RESTORER SYSTEM

P. USHA RANI, S. RAMA REDDY

Department of Electrical and Electronics Engineering,
Jerusalem College of Engineering ,Centre for collaborative research with Anna University, Chennai, India.
e-mail: pusharani71@yahoo.com

Abstract: 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. This paper presents the modeling and closed loop control aspects of the DVR system with an H bridge inverter working against voltage sags / swells by simulation. The power circuit of the DVR system with an H bridge inverter with the control techniques used for compensation is explained. The proposed DVR is 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 / swells.

Keywords: Dynamic Voltage Restorer (DVR), Voltage Source Converter (VSC), Total Harmonic Distortion (THD)

INTRODUCTION

A common characteristic of most electronics is that they are sensitive to voltage variations. Computers and other sensitive loads can lower their performance or even shutdown the process they are in control due to those variations. Voltage variations can be classified as disturbances that produce voltages below the nominal value, which are called voltage sags, and disturbances that produce voltages above the nominal value, which are called voltage swells. Voltage sag is defined as a sudden reduction of supply voltage down 90% to 10% of nominal, followed by a recovery after a short period of time. A typical duration of sag is 10ms to 1 minute. Voltage sag can cause loss of production in automated processes since voltage sag can trip a motor or cause its controller to malfunction. Voltage swell is defined as sudden increasing of supply voltage up 110% to 180% in RMS voltage at the fundamental frequency with duration from 10ms to 1 minute. Switching off a large inductive load or energizing a large capacitor bank is atypical system event that causes swells. During power disturbances Dynamic Voltage Restorer (DVR) installed in front of a critical load will appropriately provide correction to that load only. Also DVR cannot provide compensation during full power interruptions.

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

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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 (Agileswari, et al., 2005) .

The structures and control of a dynamic voltage restorer that injects in series with a distribution feeder is described (Arindam and Ledwich, 2001). A detailed analysis of the load voltage compensation for the DVR that is used for enhancing power quality is presented (Boonchiam, et al., 2006) A fast dynamic control scheme for a capacitor-supported single phase dynamic voltage restorer for inductive loads are described (Ngai-man Ho., et al., 2008). A new matrix method, which is able to compute the phase shift and a reduction of the supply voltage much quicker than the Fourier transform or phase locked loop is presented (Fitzer, et al., 2004). A feed forward and state feedback based controller structure for DVR systems is described (Hyosung and Seung-Ki Sul, 2005). A new DVR circuit topology which has the ability to mitigate long duration voltage sags with comparatively small energy storage capacitors are presented (Mahinda Vilathgamuwa and Wijekoon, 2002). The modeling aspects of several types of DVR working against various voltage sags by simulation in PSCAD/EMTDC are presented (Nguyen and Tapan, 2004).

A fast detection method for voltage disturbances is explored. The algorithm is based on the theory that allows a set of three phase voltages be represented as dc voltages in a d-q synchronous rotating frame.(Montero-Hernandez and Enjeti, 2005). The application of the DVR on power distribution systems for mitigation of voltage sags/ swells at critical loads is presented (Boonchiam and Mithlananthan, 2006). A control system based on a repetitive controller to compensate for power quality disturbances is presented (Roncero, et al., 2009).

In this paper, the modeling and control of the DVR for protection against voltage sag / swell is described using the MATLAB package. Simulation results are presented to show the effectiveness of the proposed control method.

This paper is organized as follows: A general description of the DVR circuit topology is presented in section 2. Section 3 presents a control strategy of the DVR, while section 4 presents the DVR system with an H bridge inverter power circuit. The effectiveness of the proposed DVR closed loop control system is evaluated and the simulation results are given in section 5.

2. DVR IN SAG MITIGATION

The Dynamic Voltage Restorer, installed between the supply and a critical load can restore the load voltage to the pre-fault level during a voltage sag as depicted in Fig.1. To restore the load voltage, the DVR should inject the equivalent of the dropped voltage, which represents the difference between the pre-fault and fault voltage through a series connected transformer. Voltage restoration of the DVR involves the injection of active power and energy from the DVR to the distribution system. However, the capability of the energy storage capacitors in the DVR is limited. The DVR Power Circuit can be divided into four main blocks as shown in Fig.2. They are the Energy storage device, the PWM inverter unit, the Filter Circuit and the Series injection transformer.

3.CONTROL STRATEGY

The control strategy is designed using the in-phase compensation technique. Voltage sag is detected as a sudden change in the magnitude of the load voltage. Power Circuit of DVR

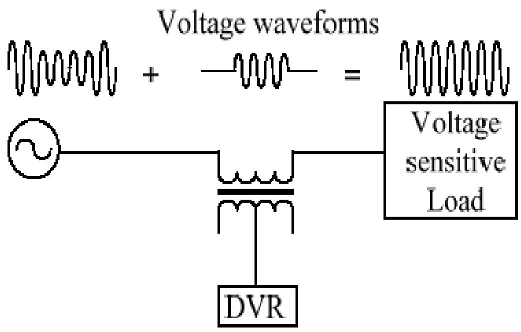

Fig.1. Basic Operation of DVR

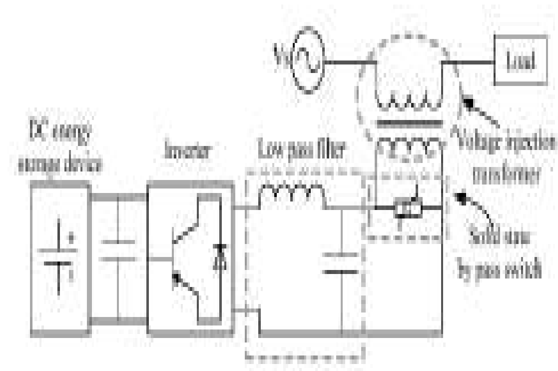

Fig.2. Power Circuit of DVR

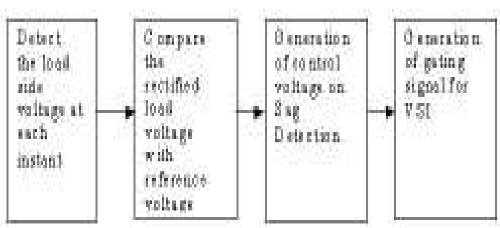

Fig.3. Block Diagram of Control Strategy

To rectify the voltage dip, the difference between the pre-sag voltage and the sag voltage has to be injected into the distribution line.

Fig.3. shows the basic blocks used for the control strategy.

4. DVR POWER CIRCUIT IN SIMULATION

DVR system is simulated using MATLAB and the results are presented here.

4.1. Closed Loop Controlled DVR system with an H bridge inverter

A typical Closed Loop Controlled DVR with an H bridge inverter is used in a simple power system to protect a sensitive load in a large distribution system as presented in Fig.4. Its control system block diagram is shown in Fig.5.

The inverter is a four-pulse switch controlled bridge. The currents follow different directions at outputs depending on the control scheme, eventually supplying AC output power to the critical load during power disturbances.

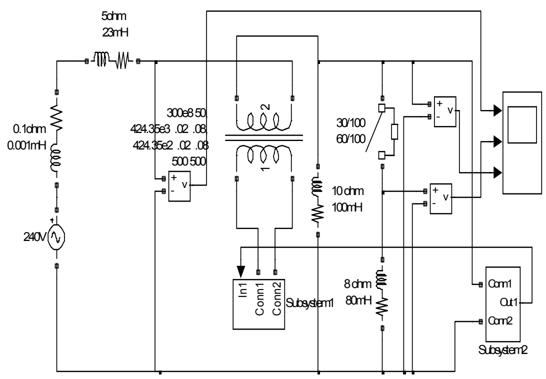

Fig.4. Closed loop DVR with an H-Bridge inverter

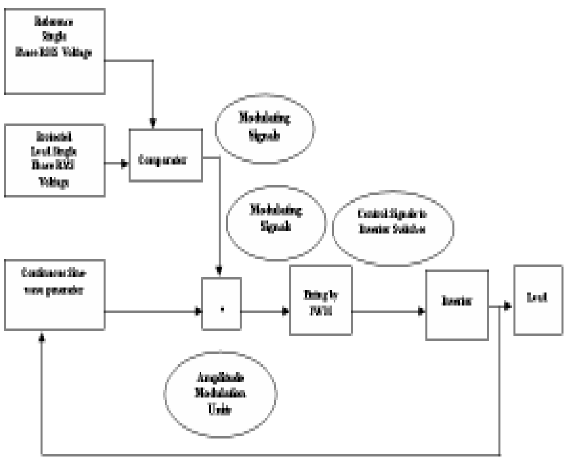

Fig.5. Block diagram of Control system

The control of this bridge lies in the control of the switch firing angles. The time to open and close gates will be determined by the control system. To model a DVR protecting a sensitive load against voltage sags a simple method of using the measurement of a single phase RMS output voltage for controlling signals can be applied. The amplitude modulation is then used. In addition to provide appropriate firing angles to switches, a switching control using the PWM technique is employed.

Subsystem1 is shown in Fig.6. It consists of a full bridge inverter with a filter. Pulse Width Modulation technique was used to control the H bridge inverter. Subsystem2 consists of a rectifier with a capacitor filter as shown in Fig.7.

5. SIMULATION RESULTS

The simulation is done using MATLAB and the results are presented here. Initially the system was subjected to sag of 33 % magnitude and 0.3s duration. Simulation is done and transient performance at sag front and recovery was observed. Fig.8. shows the simulation result for the closed loop DVR system response to the voltage sag.

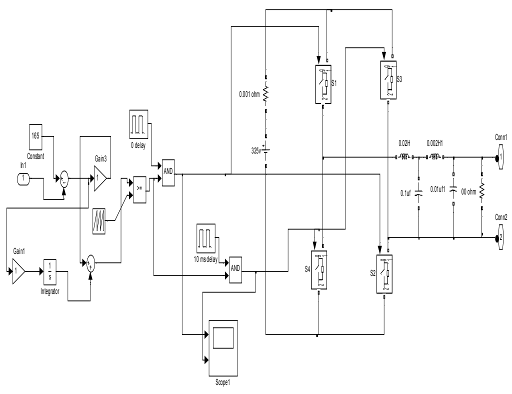

Fig.6. Sub System 1 of closed loop DVR with an H-Bridge inverter

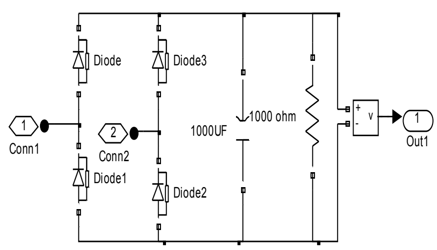

Fig.7. Sub System 2 of closed loop DVR with an H-Bridge inverter

The first graph shows the input supply voltage. The second graph indicates the injected voltage and the third graph shows the compensated load voltage after voltage injection.

The system was subjected to swell of 116 % magnitude and 0.3s duration. Simulation is done and transient performance at swell front and recovery was observed. Fig.9. shows the response of the closed loop DVR system to the voltage swell. The first graph shows the sag in voltage. The second graph indicates the injected voltage and the third graph shows the compensated load voltage after voltage injection. The driving pulses of the inverter switches are shown in Fig.10. The output of the inverter with and without filter is shown in Fig.11. The Fig.12. shows the FFT analysis of closed loop DVR system. The THD value is 4.93%.

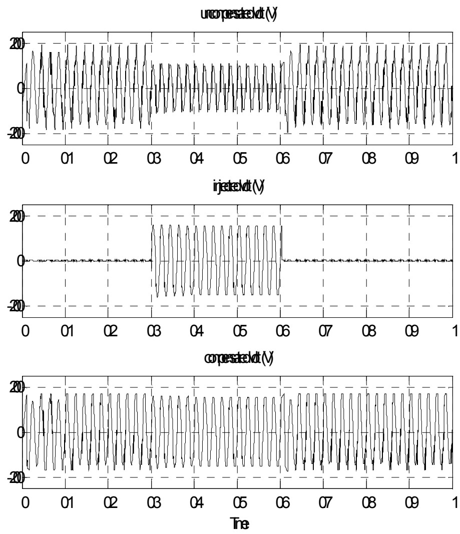

Fig.8. DVR response to voltage sag

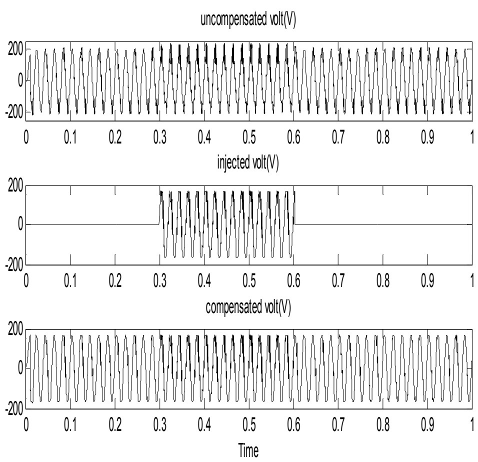

Fig.9. DVR response to voltage swell

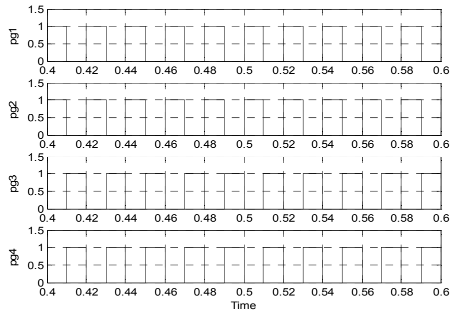

Fig.10. Driving pulses of inverter switches

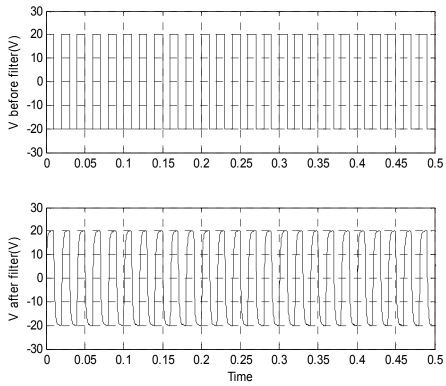

Fig.11. Inverter output with & without filter

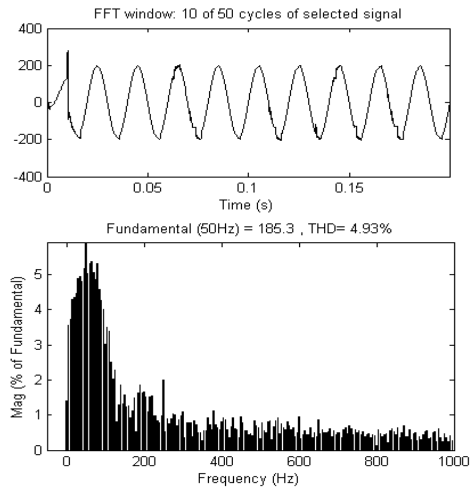

Fig.12. FFT analysis for the output of DVR

CONCLUSION

The modelling and simulation of a DVR system using MATLAB has been presented. DVR is an effective custom power device for voltage sag / swell mitigation. The impact of voltage sag on sensitive equipment is severe. Therefore, DVR is considered to be an efficient solution due to its low cost, small size and fast response.

The simulation results indicate that the implemented control strategy compensates for voltage sags / swells with high accuracy. The results show that the control technique is simple and efficient method for voltage sag / swell compensation.

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