Z- Source Inverter based Dynamic Voltage Restorer for the Mitigation of Voltage Sag/Swell

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ABSTRACT

This paper uses super capacitor as the energy storage device for the DVR to compensate voltage sag, voltage swell and harmonics due to addition of nonlinear load in the distribution line. Based on this topology, DVR consist of super capacitor, z source inverter and injection transformer. Super capacitor produces the necessary dc voltage which is given as the input voltage to the z-source inverter; provide the necessary injecting voltage, which has to be restored. A new topology based on Z-source inverter is presented in order to enhance the voltage restoration property of dynamic voltage restorer. Z-source inverter would ensure a constant DC voltage across the DC-link during the process of voltage compensation. The modeling of Z-source based dynamic voltage restorer is carried out component wise and their performances are analyzed using MATLAB software.

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1. INTRODUCTION

Power quality problems can originate at the supply system, or the customer's plant or even a neighboring installation which could propagate via the supply. Disturbance Effect Overvoltage, Unbalance Motor heating Neutral-ground voltage Digital device malfunction Interruption Complete shutdown Sag Variable speed drive& computer trip-out Swell Overstress insulation Fluctuations Light flicker. Voltage sag/sell is most important power quality problems challenging the utility industry can be compensated and power is injected into the distribution system. By injecting voltage with a phase advance with respect to the sustained source-side voltage, reactive power can be utilized to help voltage restoration [1]. Dynamic Voltage Restorer, which consists of a set of series and shunt converters connected back-to-back, three series transformers, and a dc capacitor installed on the common dc link [3]. The Pulse-width modulation of Z-source inverter has recently been proposed as an alternative power conversion concept as they have both voltage buck and boost capabilities.

The Z-source converter employs a unique X-shaped impedance network on its dc side for achieving both voltage buck and boost capabilities this unique features that cannot be obtained in the traditional voltage-source and current source converters. The proposed system is able to compensate long and significantly large voltage sags [2], [5] and [9]. Passivity-based dynamical feedback controllers can be derived for the indirect stabilization of the average output voltage. The derived controllers are based on a suitable stabilizing "damping injection" scheme [7]. Transformer less self-charging dynamic voltage restorer series compensation device used to mitigate voltage sags. A detailed analysis on the control of the restorer for voltage sag mitigation and dc link voltage regulation are presented [8]. Installation of the world's first Dynamic Voltage Restorer (DVR) on a major US. Utility system to protect a critical customer plant load from power system voltage disturbances. The installed system at an automated yarn manufacturing and weaving factory provides protection from disturbances [10].

In this paper the modeling and control of voltage sag/swell compensation using Z-Source inverter based dynamic voltage restorer are simulated using MATLAB software. The simulation results are presented to show the effectiveness of the proposed control method.

2. DYNAMIC VOLTAGE RESTORER

The Dynamic Voltage Restorer (DVR), is also referred to as Series Voltage Booster (SVB) or the Static Series Compensator (SSC), is a device utilized solid state power electronic components, and it is connected in series with Distribution circuit. The DVR consist of an Injection/Booster transformer, a Harmonic Filter, a Voltage Source Converter (Power converter), DC charging circuit and Control and Protection circuit as shown in the block diagram of DVR in fig.1. The first DVR was installed in North Carolina, for the rug manufacturing industry [11]. Another was installed to a large dairy food processing plant in Australia [1 3]. Its primary function is to rapidly boost up the voltage at load side in case disturbance to that load. There are various circuit topologies and control scheme are used to implement the DVR. It basically consists of, Battery energy storage, Voltage Source Inverter, Passive Filter, Injection/ Booster Transformer as shown in Figure 1.

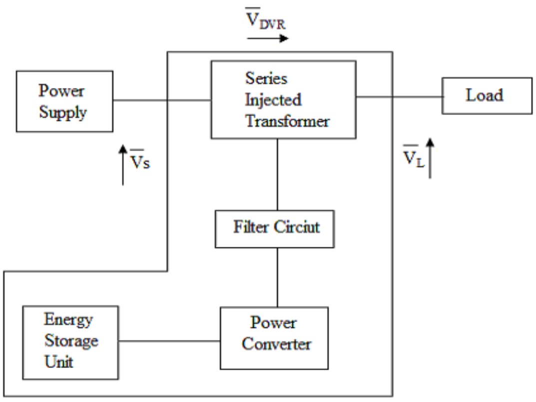

Figure 1. Schematic diagram of DVR.

The basic function of the DVR is to detect any voltage sag/swell occurred in the power line and injects the balance voltage from the DVR. This is achieved either by absorbing or injecting active or reactive power [9].

2.1. DC energy Storage device

It is used to supply the real power requirement for the compensation during voltage sag. Lead-acid batteries, Super Conducting Magnetic Energy Storage (SMES), Flywheels and Super capacitors can be used as the storage devices. For DC drives such as capacitors, batteries and SMES, DC to AC conversion (inverters) are needed to deliver power, whereas for flywheel, AC to AC conversion is required [4, 5, and 8]. The maximum compensation ability of DVR particular for voltage sag is dependent on the active power supplied by the energy storage devices.

2.2. Voltage Source Inverter (VSI)

The basic function VSI is to convert DC voltage supplied by the energy storage device to an AC voltage. This is coupled to an injection transformer to the main system. Thus a VSI with low voltage rating is sufficient [4, 8].

2.3. Passive Filter

It is used to convert PWM pulse waveform in to sinusoidal waveform. It consists of an inductor and a capacitor. It can be placed either high voltage side or low voltage side of the injection transformer. By placing it inverter side higher order harmonics are prevented from passing through the voltage transformer. And it will reduce stress on the injection transformer. When the filter is placed on the high voltage side, the higher order harmonic current do penetrate to the secondary side of the transformer, a higher rating of the transformer is required [4,8].

2.4. Voltage Injection Transformer

The basic function is to increase the voltage supplied by the filtered VSI output to the desired level. The high voltage side of the injection transformer is connected in series to the distribution line and low voltage side is connected to the power circuit of the DVR. In this study single phase injection transformer is used. For three has DVR, three single phase transformer can be connected either in delta/open or star/open configuration.

2.5. By-pass Switch

The DVR is series connected device, if fault current that occur due to fault in the downstream will flow through the inverter circuit [10]. The power electronic component are rated to the load current hence to protect the inverter from higher current, a by-pass switch is used and it is located between the inverter and the isolating transformer.

3. DVR OPERATING STATES

- During the normal operation
  Under normal working condition DVR is not injecting any voltage to the system. If the energy device is fully charged then the DVR operates in standby mode or in the self-charging mode.
- During a Voltage sag/swell
  By supplying the real power from the energy storage device together with the reactive power, the DVR injects the difference between the pre-sag and sag voltage [6].
- Fault in the downstream of the power line
  In this case, by-pass switch is operated and provide alternative path for the high fault currents. If this high fault current flows through the inverter, it may damage the sensitive power electronic component.

4. EXISTING VOLTAGE SAG/SWELL MITIGATION TECHNIQUE

In most of the published work on DVR , Reference voltage generation are achieved using pqr power theory, dq transformation [12], fuzzy logic control , sliding mode control, Artificial neural network and software PLL. Generally open loop feed forward control is preferred to meet the fast compensation requirement .The presence of passive LC filter, saturation of series injection transformer and the voltage drop across the inductor affect the performance of DVR in open loop control. The Load voltage may not be compensated to the desired value in open loop feed forward control. Closed loop control can reduce the damping oscillation caused by the switching harmonics LC filter but not catching up with fast dynamic response. In the dqo transformation method, the quantities are expressed as the instantaneous space vectors. First three phase voltages (Va, Vb, Vc) are converted to stationary reference frame $V\alpha$ and $V\beta$ and then it is converted to d-q-o reference. During a fault these dc values will drop and the difference between the pre-sag and sagged value will form an error signal. This error signal is then converted back to $V\alpha$ and $V\beta$ which is again modulated using space vector modulation to produce the required pulse to switch on the inverter thus restoring the load voltage .This method is applicable only to three phase system. The computations are instantaneous but incur time delays in filtering dc quantity.

5. PROPOSED COMPENSATION TECHNIQUE

The basic functions of a controller in a DVR are the (i) detection of voltage sag/swell events in the system (ii) computation of the correcting voltage and (iii) generation of trigger pulses to the sinusoidal PWM based DC-AC inverter. In order to mitigate the simulated voltage sag / swell a Discrete PWM-based control scheme is implemented. This control system only measures the rms voltage at load point and exerts voltage angle control as follows: an error signal is obtained by comparing the reference voltage with the rms voltage measured at the load point. The PI controller processes the error signal and generates the required angle δ to drive the error to zero. In the PWM generators, the sinusoidal signal, Vcontrol, is phase modulated by means of the angle δ or delta .The modulated signal, Vcontrol, is compared against a triangular signal (carrier) in order to generate the switching signals of the VSC valves. The main parameters of the sinusoidal PWM scheme are the amplitude modulation index, ma, of signal V control, and the frequency modulation index, mf, of the triangular signal. The amplitude index ma is kept fixed at 1 pu, in order to obtain the highest

fundamental voltage component at the controller output. It should be noted that, an assumption of balanced network and operating conditions are made.
The modulating angle δ or delta is applied to the PWM generators in phase A, whereas the angles for phase B and C are shifted by 240° or -120° and 120° respectively.

$$Va = Sin\ (\omega t + \delta) \tag{1}$$

$$Vb = Sin\ (\omega t + \delta - 2\pi/3) \tag{2}$$

$$Vc = Sin\ (\omega t + \delta + 2\pi/3) \tag{3}$$

It can be seen that the control implementation is kept very simple by using only voltage measurements as feedback variable in the control scheme. The speed of response and robustness of the control scheme are clearly shown in the simulation results. Since custom power is a relatively low power application, PWM methods offer a more flexible option than the fundamental frequency switching (FFS) methods favored in FACTS applications. Besides, high switching frequencies can be used to improve the efficiency of the converter, without incurring significant switching losses.

6. Z-SOURCE INVERTER

Z-source inverter has X-shaped impedance network on its DC side, which interfaces the source and inverter H-bridge. It facilitates both voltage-buck and boost capabilities. The Impedance network composed of split inductors and two capacitors. The supply can be DC voltage source or DC current source or AC source. Z-source inverter can be of current source type or voltage source type. Fig. 2 shows the general block diagram of Z-Source inverter.

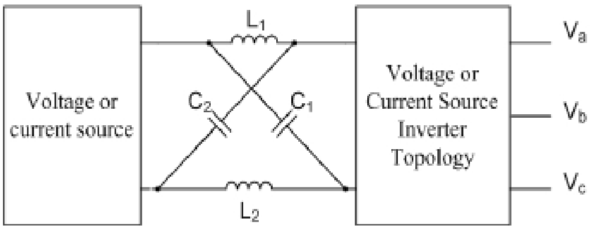

Figure 2. Block diagram of Z-Source inverter.

Z-source inverter operation is controlled by multiple pulse-width modulation. The output of the Z-Source inverter is controlled by using pulse width modulation, generated by comparing a triangular wave signal with an adjustable DC reference and hence the duty cycle of the switching pulse could be varied to synthesize the required conversion. A stream of pulse width modulation is produced to control the switch as shown in the Figure 3.

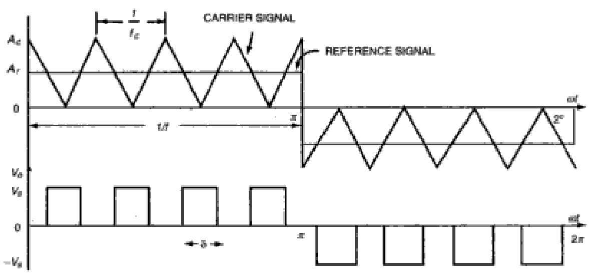

Figure 3. Pulse Width Modulation.

7. MATLAB/SIMULINK RESULTS

To verify the adopted control system, the total system of DVR was developed using the MATLAB/SIMULINK. As show in the below figures the simulation results during voltage sag/ swell with the proposed control scheme. Voltage sag and swell are simulated by temporary connection of different impedances at the supply side bus.

7.1. Voltage Swell

The three phase voltage swell is simulated for 0.5 m sec from t=0msec to t=0.5 m sec as shown in Figure 5.The DVR regulate the load voltage to the reference voltage by injecting appropriate voltage component (negative voltage magnitude).

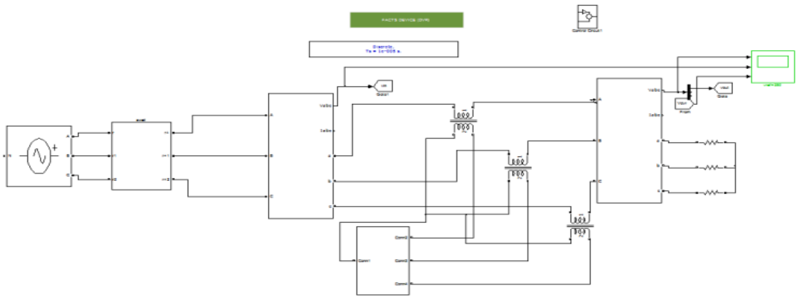

Figure 4. Simulation circuit of Voltage swell compensation using DVR.

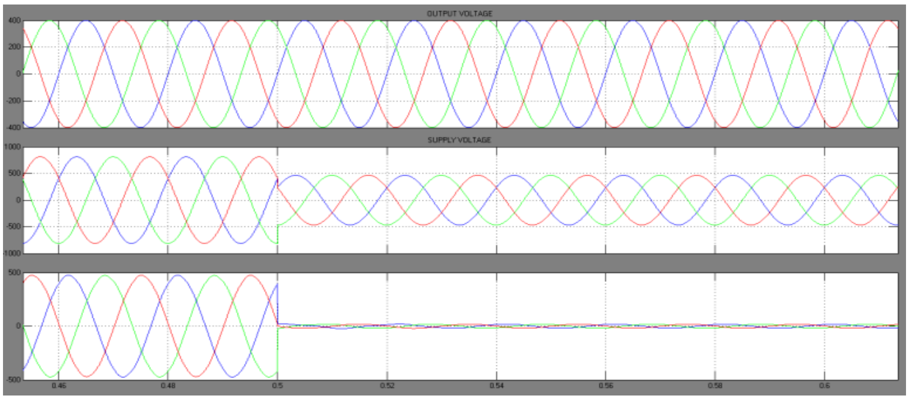

Figure 5. Simulation results of Voltage swell compensation using DVR.

7.2. Voltage Sag

The three phase voltage sag is simulated for 0.5 m sec from t= 1.5 m sec to t=2 m sec as shown in Figure 7. As in the case of voltage swell, the DVR injects appropriate voltage to regulate the load voltage to reference voltage.

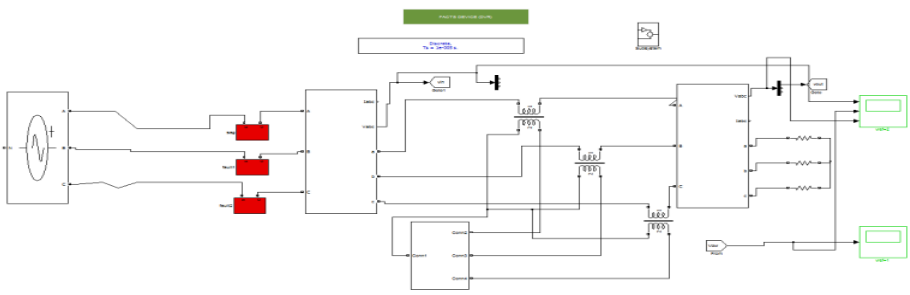

Figure 6.Simulation circuit of Voltage sag compensation using DVR.

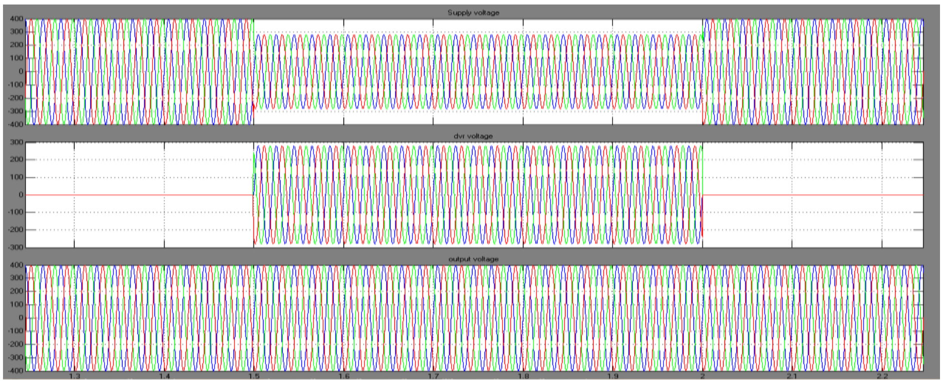

Figure 7. Simulation results of Voltage sag compensation using DVR.

7.3. Voltage Swell

The three phase voltage swell is simulated for 0.5 m sec from t=0msec to t=0.5 m sec as shown in Figure 9.The injected voltage swell and the load voltage.The Z-Source inverter regulate the load voltage to the reference voltage by injecting appropriate voltage component .

7.4. Voltage Sag

The three phase voltage sag is simulated for 0.5 m sec from t= 1.5 m sec to t=2 m sec as shown in Figure 10. As in the case of voltage swell, the Z-Source inverter injects appropriate voltage to regulate the load voltage to reference voltage.

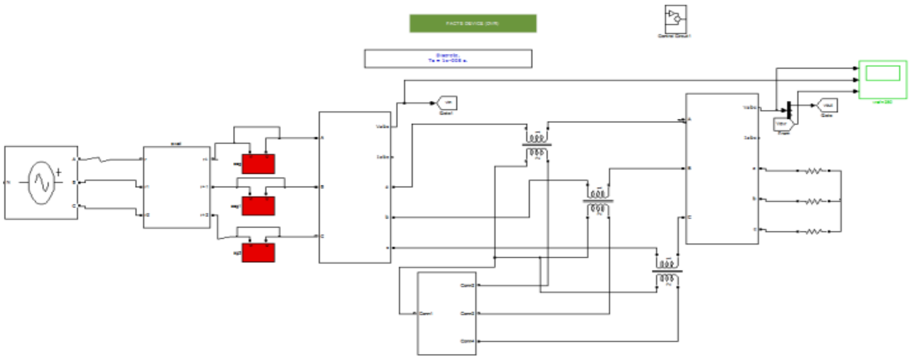

Figure 8. MATLAB/Simulink model of three faze Z-Source inverter.

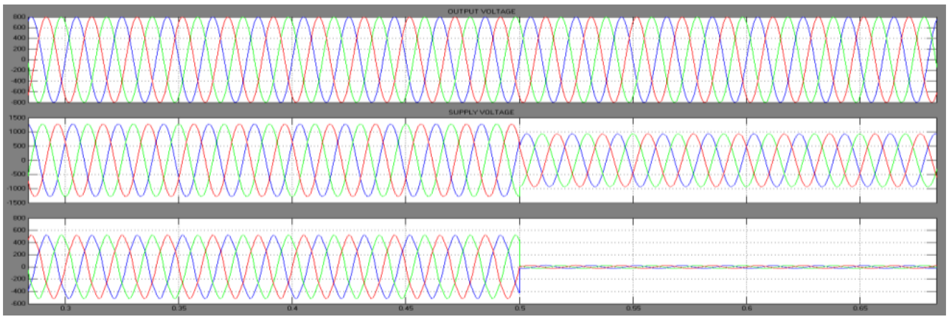

Figure 9. Simulation results of voltage swell compensation three phase Z-Source inverter.

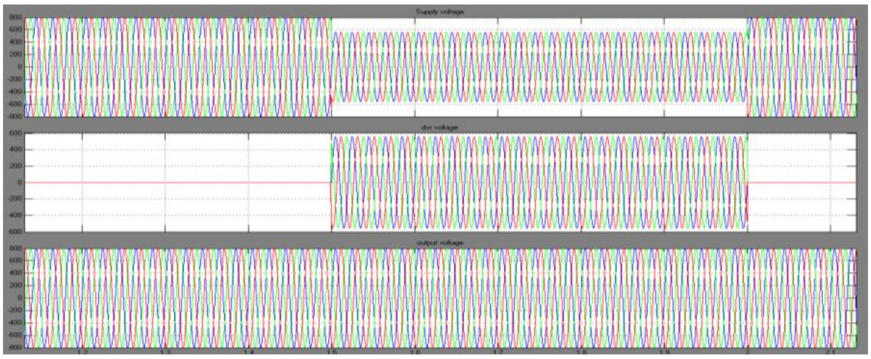

Figure 10. Simulation results of voltage sag compensation three faze Z-Source inverter.

The simulation results illustrates that the proposed Z-Source inverter control scheme restoring DCvoltage
Across the DC-link during the voltage is very effectively. The voltage swell and sag mitigation is performed with a smooth, stable and rapid DVR response.

8. CONCLUSION

This paper has presented a Z-Source inverter control scheme for a constant DC voltage across the DC-link during the process of voltage compentation.Z-Source based Dynamic Voltage Restorer to improve the system response and injection capability for the mitigation of voltage sag/swell. As opposed to fundamental frequency switching schemes already available in the MATLAB/SIMULINK, this PWM control scheme requires only rms value of the voltage. In this paper voltage sag/swell compensation using three phase Z-Source inverter based Dynamic Voltage Restorer is considered. It is observed that throughout fault condition the power factor at input side is maintained unity and the system output voltage is maintained constant throughout the fault condition. The simulation results show that this control technique compensates for the voltage sag/swell and its excellent performances.

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