Quasi-Z-source Inverter based Dynamic Voltage Restorer

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Abstract-   DVR is a series connected custom power device, which is considered to be a cost effective alternative when compared with other commercially available voltage sag compensation devices. This paper presents a quasi Z-source inverter based dynamic voltage restorer and compares the size of the energy storage requirement of q-ZSI inverter with traditional VSI. The q-ZSI fed DVR has the unique advantages of wide range of voltage gain, lower component rating and constant dc current from the source. Analysis, Simulation and results are presented to demonstrate the proposed concept.

Keywords – DVR, qZSI, VSI

I. INTRODUCTION

Power quality is a major concern for electricity suppliers, equipment manufacturers and customers as sensitive equipment and non-linear loads are becoming common in both the industrial sectors and the domestic environment. Power Quality problems [1] encompass a wide range of disturbances such as voltage sags/swells, flicker, harmonics distortion, impulse transient, and interruptions.

Voltage sag occurs when there is a disturbance due to a fault that causes a reduction in voltage for a short period. The voltage sag as defined by IEEE Standard 1159, IEEE Recommended Practice for Monitoring Electric Power Quality, is "a decrease in RMS voltage or current at the power frequency for durations from 0.5 cycles to 1 minute [2]. The DVR maintains the load voltage by injecting voltages whose magnitude and phase angle can be regulated [3]. These voltages are injected in synchronism with the distribution system voltage. Different studies have been performed to evaluate the performance or propose control strategies for DVR to improve its performance [4-7].

In the conventional VSI and CSI based DVR, ac output voltage is limited below dc voltage and additional converters are required to meet desired ac output above dc input. The upper and lower devices of each phase leg cannot be gated simultaneously otherwise shoot through will occur and destroy the device [8]. In Z-source based topology, output voltage amplitude is not limited to DC sources voltage summation similar to traditional cascaded multilevel inverters and can be boosted with Z network shoot-through state control, therefore in the renewable sources supported DVR, other DC/DC converters are not needed and DVR is more reliable against short circuit. Recently proposed quasi-Z-source inverters (qZSIs) have some new attractive advantages more suitable for application in PV systems [9-10].

In this paper, a new topology of quasi Z-source inverter (qZSI) based DVR is proposed. In the proposed system, the size of energy storage element is decreased in comparison with the conventional systems, lower component   rating and harmonic factor. The simulation results of conventional VSI based DVR and quasi-Z-source based DVR are compared.

II.CONVENTIONAL DVR SYSTEM

DVR is a custom power device that injects voltage into the system in series to regulate the load side voltage.

The main function of the DVR is to monitor the load voltage waveform constantly and if any sag or surge occurs, the balance (or excess) voltage is injected to (or absorbed from) the load voltage. To achieve the above functionality a reference voltage waveform has to be created which is similar in magnitude and phase angle to that of the supply voltage.

In this proposal in-phase compensating techniques of DVR and efficient control method PI controller is selected according to the load and energy storage unit requirement.

A schematic diagram of the DVR incorporated into a distribution network is shown in Fig. l. In the Fig., V_S is the source voltage, V_{dvr} is the series injected voltage of the DVR, I is the load current V_L is the load voltage. The restorer typically consists of an injection transformer, the secondary winding of which is connected in series with the distribution line. A voltage-sourced PWM inverter bridge is connected to the primary of the injection transformer and an energy storage device is connected at the dc-link of the inverter bridge. The inverter bridge output is filtered by using an LC filter. The injection of an appropriate V_{dvr} during a voltage disturbance requires a certain amount of real and reactive power supply from the DVR.
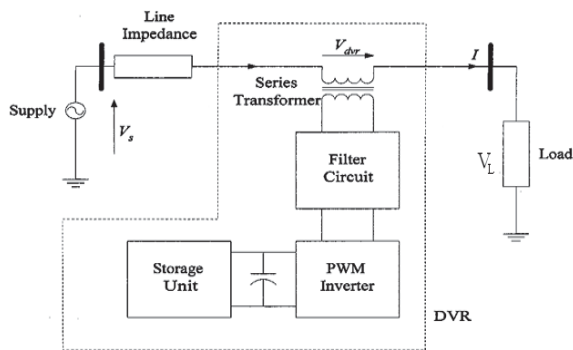

Figure 1. Basic Block Diagram of DVR

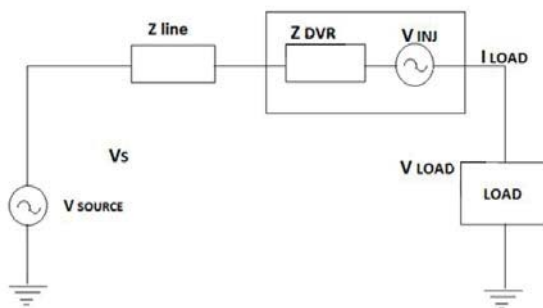The equivalent circuit of DVR is shown in Fig 2.

Figure 2. Equivalent circuit

Now the injected voltage of DVR can be written as

$$V_{dvr} = V_L + Z_L I_L - V_S \text{ -------- (1)}$$

A fault current in the grid can lead to a reduced magnitude of the voltage at the Point of Common Coupling. Under these circumstances, the DVR generates a compensating voltage corresponding to the estimated magnitude of voltage variation. This compensating voltage is injected to the distribution system via an injection transformer and it stabilizes the load side voltage.The voltage sag is detected and calculated error voltage is controlled and compared with triangular waveform to produce PWM signals as shown in Fig 3 . The modulation index is always m≤ 1.The pulses switch on the power devices and required voltage is injected. The injected voltage is less than dc voltage of energy storage element.
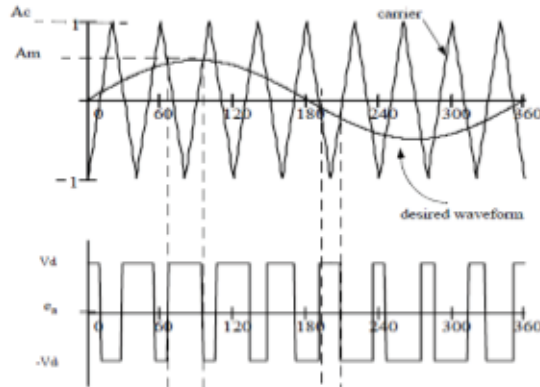
Figure 3. SPWM control for VSI

III. PROPOSED DVR SYSTEM

In proposed DVR system, PWM inverter is replaced by quasi-Z-source Inverter as shown in Fig 4. The qZSI has two types of operational states at the dc side: nonshoot-through states and shoot-through state. The LC and diode network connected to inverter bridge modifies the operation of the circuit, allowing the shoot through state.
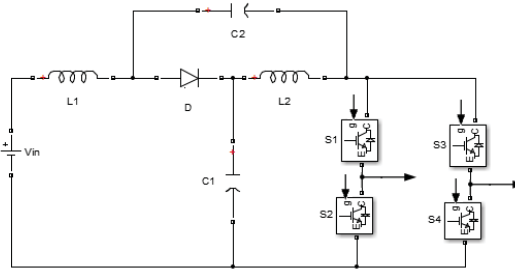

Figure 4. Circuit diagram of quasi-ZSI

The major difference in qZSI compared to ZSI is it draws continuous current from the source and voltage on capacitor C_2 is greatly reduced.

During a switching cycle T, non-shoot-through states intervals is T1 and shoot through period its interval is T_0.

During non shoot-through state,

$V_{L1}= V_{in}-V_{C1}$, $V_{L2}= -V_{C2}$ and   (2)

$V_{dc} = V_{C1}-V_{L2}=V_{C1}+V_{C2}$, $V_D=0$ (3)

During shoot through state,

$V_{L1}= V_{C2}+V_{in}$, $V_{L2}=V_{C1}$ and   (4)

$V_{dc} = 0$, $V_D=V_{C1}+V_{C2}$ (5)

At steady state, average value of inductors over one switching cycle is zero. Applying this peak dc link voltage across inverter Bridge is

$$\hat{V}_{dc}= \frac{1}{1-2\frac{T_0}{T}}V_{in} =BV_{in}   \quad (6)$$

The peak inverter output voltage in boost mode is given by

$$\hat{V}_0 =\frac{\hat{V}_{dc}}{2}.M =\frac{V_{in}}{2}BM \qquad (7)$$

To control the shoot-through states, two reference signals (Up and Un) are introduced as shown in Fig.5 . If the triangular waveform is greater than Up or lower than Un, the inverter switches turn into the shoot-through state. Thus, in the proposed shoot-through PWM control method, to reduce the current stress of the switches, the shoot-

through states are created by simultaneously turning ON all inverter switches. During the shoot-through states, the voltage across inverter bridge drops to zero.
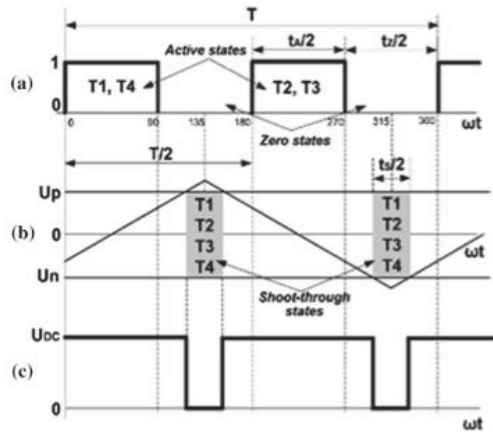

Figure 5. PWM technique of qZSI

Since the dc voltage is getting boosted, the output of inverter can be boosted even though the size of storage of element is reduced. In qZSI, the input current is continuous, lower capacitor rating and less EMI problems.

IV. SIMULATION AND RESULTS

The simulation of VSI based and qZSI based DVR are carried out. Single phase test system is considered. Sag is generated by applying a fault in the line during interval 0.1-0.2 s. The 50% sag is detected and error signal is controlled and sine PWM pulses are generated so that inverter produces missing voltage. The fig 6 shows SIMULINK model of VSI based DVR. The sag is detected during interval 0.1-0.2s and rms value of the input is reduced to120V. The controller takes the action on error signal and SPWM pulses for inverters are produced by comparing the triangular wave with reference wave. The inverter gives the missing voltage 120V and the constant DC input required is 230V. The figure 7 shows compensated load voltage and injected voltage is observed to be 120V.
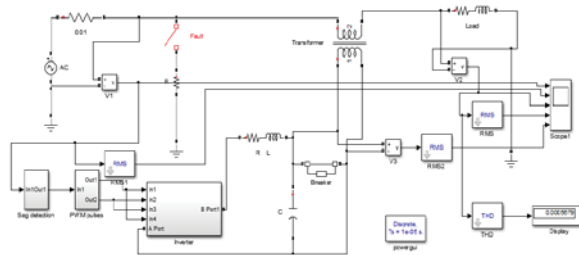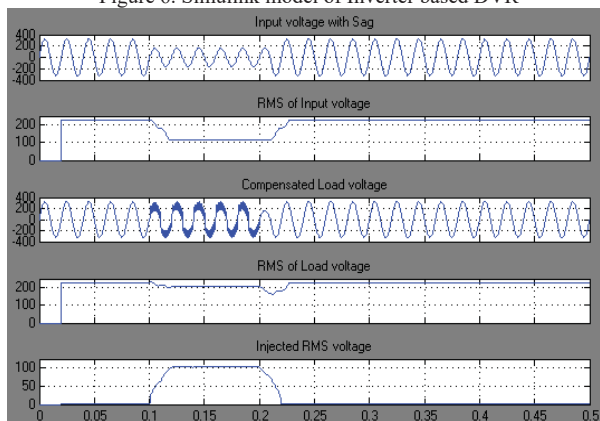

Figure 6. Simulink model of Inverter based DVR

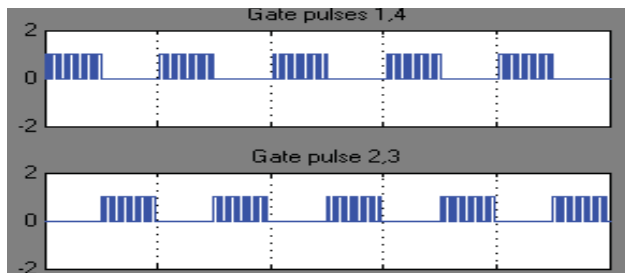Figure 7. Compensated load voltage and injection voltage waveforms in VSI

Figure8: PWM pulses in VSI

In the proposed system, the VSI inverter is replaced by quasi-Z source inverter as shown in Fig.9 L1=L2=5mH; C1=C2=470µF.The sag is detected during 0.1-0.2s and the error signal is generated and pulses are generated during shoot through states also.

If the triangular waveform is greater than V_p and V_n, shoot through state exists and input dc voltage is boosted by use of impedance network then the inverter output is also boosted. The inverter gives 120V for 50% sag and input DC required is 60V. The figure 10 shows compensated load voltage and RMS value of output. The gate pulses are also shown in Fig11.
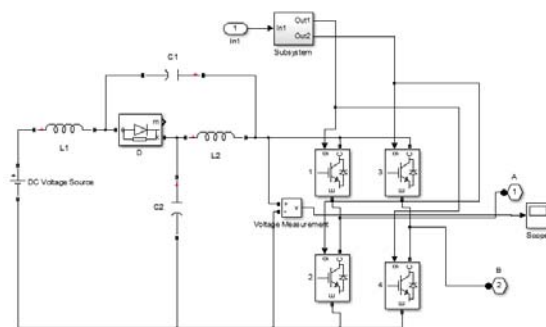

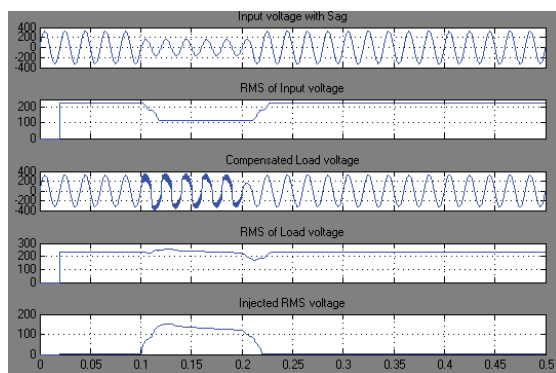Figure 9. Simulink model of q-ZSI

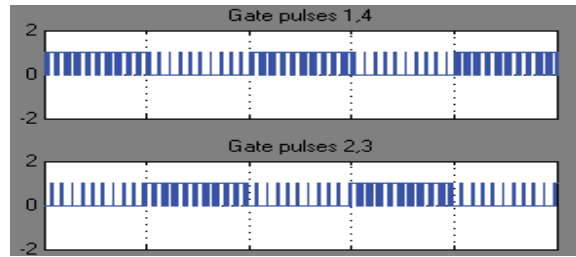Figure 10. Compensated load and injection voltage waveforms in q-ZSI

Figure 11. Gate pulses for q-ZSI

V..CONCLUSION

In this paper conventional system of Dynamic Voltage Restorer techniques were studied and a new method has been proposed which is more efficient and cost-effective since the size of DC storage element requirement is reduced. The proposed qZSI has merits such as wide range of gain, continuous input current, reduced component stress and lower component rating. The Simulation results show that qZSI based DVR is effective than conventional system. The proposed qZSI can be used in PV power generation and PV power can be utilised for power quality problems.

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