Abstract—Dynamic Voltage Restorer (DVR) is a custom power device used in power distribution networks to protect consumers from sudden sags and swells in grid voltage. On the basis of recent developments in impedance source (Z-source) inverters the present paper proposes an integration of quasi-Z-source inverter (QZSI) with a built-in high frequency transformer. New type LCCT-Z-Source inverters are presented. Proposed inverters characterize continuous input current, improved relationship between boost coefficient and modulation index and improved EMI performance. Application of four element (Inductor - Capacitor - Capacitor - Transformer) LCCT impedance network provides higher voltage gain than obtained in quasi-Z-source inverter. The advantage of proposed topology over other recently developed Z-source inverters is that two built-in capacitors block DC currents in transformer windings and prevents core saturation. Simulation results are shown to verify the proposed topologies.

Keywords— DVR, Voltage sag and swell, Modified ZSI.

I. INTRODUCTION

THE voltage sag / swell is the most common power quality related problem among the industries. Such voltage sag / swell have a major impact on the performance of the microprocessor based loads as well as the sensitive loads. In a power line voltage sags / swells can occur as a result of load switching, motor starting, faults, lighting, non-linear loads, intermittent loads, etc., IEEE 519-1992 and IEEE 1159-1995 describe the Voltage sags / swells as shown in Table I and within which controlling equipment should be connected together with the critical loads as corrective measures [1].

DVR is a commercially available cost effective device, which is capable of addressing the above voltage sag problem effectively.

II. DYNAMIC VOLTAGE RESTORERS

A DVR is a device that injects a dynamically controlled voltage \( V_{inj}(t) \) in series to the bus voltage by means of a booster transformer as depicted in Figure 1. The amplitudes of the injected phase voltages are controlled such as to eliminate any detrimental effects of a bus fault to the load voltage \( V_L(t) \). This means that any differential voltage caused by transient disturbances in the AC feeder will be compensated by an equivalent voltage generated by the converter and injected on the medium voltage level through the booster transformer. The DVR works independent of the type of fault or any event that happens in the system, provided that the whole system remains connected to the supply grid, i.e. the line breaker does not trip. For most of the time the DVR has, virtually, "nothing to do," except monitoring the bus voltage. This means it does not inject any voltage \( V_{inj}(t)=0 \) independent of the load current. Therefore, it is suggested to particularly focus on the losses of a DVR during normal operation. Two specific features addressing this loss issue have been implemented in its design, which are a transformer design with low impedance, and the semiconductor devices used for switching.

![Fig 1(a) Schematic diagram of DVR System](image1)

![Fig 1(b). Equivalent circuit of DVR](image2)

Mathematically expressed, the injection satisfies

\[
V_L(t) = V_s(t) + V_{mg}(t)
\]

(1)

Where \( V_L(t) \) is the load voltage, \( V_s(t) \) is the sagged supply.
voltage and \( V_{\text{inj}(t)} \) is the voltage injected by the mitigation device as shown in Fig. 2. Under nominal voltage conditions, the load power on each phase is given by

\[
S_l = I_l V_{l*} = P_l - j Q_l
\]

Where \( I \) is the load current, and, \( P_L \) and \( Q_L \) are the active and reactive power taken by the load respectively during a sag. When the mitigation device is active and restores the voltage back to normal, the following applies to each phase

\[
S_l = P_l - j Q_l = (P_s - j Q_s) + (P_{\text{inj}} - j Q_{\text{inj}})
\]

where the sag subscript refers to the sagged supply quantities. The inject subscript refers to quantities injected by the mitigation device.

### III. MODIFIED Z-SOURCE INVERTER

Z-source inverters (ZSI) are one-stage energy processing buck-boost inverters that contain unique passive input circuits (impedance networks) and utilize the shoot-through of the inverter bridge to boost DC input voltage. The impedance network of ZSI serves as power storage and guarantees double filtration grade at the input of the inverter. The ZSI topology features a DC link consisting of asymmetrical lattice network with two inductors and two capacitors. Two topologies of three-phase ZSI and modified ZSI are shown in Fig. 2a and Fig. 2b.

![Z-source Inverter](image1)

![Modified Z-source Inverter](image2)

The voltage gain \( G \) mentioned in the introduction of ZSI can be written as

\[
G = \frac{V_{\text{out}}}{V_{\text{DC}/2}} = M.
\]

where \( V_{\text{out}} \) denotes amplitude of AC output line-to-line voltage. Using the maximum constant boost control (MCBC) the boost factor \( B \) can be defined as:

\[
B = 1/(1-2D)
\]

### IV. DESIGN OF DVR

The aim of the control scheme is to maintain constant voltage magnitude at the point where a sensitive load is connected under system disturbances. The control system only measures the r.m.s voltage at the load point, i.e., no reactive power measurements are required. The proposed control scheme based on comparison of actual supply voltage and desired load voltage. The error is determined dynamically based on difference between desired and measured value. In the control scheme the actual voltage is measured and also the desired voltage. These voltages are converted in \( dq_0 \) with the Parks transformation

\[
f_{dq_0} = K_s f_{abc}
\]

Where \( f_{dq_0} = (f_d f_q f_o) \)

\[
K_s = \frac{2}{3}
\]

\[
\left[ \begin{array}{ccc}
\cos \theta & \cos(\theta - (2\pi/3)) & \cos(\theta + (2\pi/3)) \\
\sin \theta & \sin(\theta - (2\pi/3)) & \sin(\theta + (2\pi/3)) \\
1 & 1 & 1 \\
-\frac{1}{2} & -\frac{1}{2} & -\frac{1}{2}
\end{array} \right]
\]

\[
\omega = d\theta/dt
\]

The control system employs abc to \( dq_0 \) transformation to \( dq_0 \) voltages. During normal condition and symmetrical condition, the voltage will be constant and \( d \)-voltage is unity in p.u. and \( q \)-voltage is zero in p.u. but during the abnormal conditions it varies. After comparison \( d \)-voltage and \( q \) voltage with the desired voltage error \( d \) and error \( q \) is generated. These error component is converted into abc component using \( dq_0 \) to abc transformation. Phase Locked Loop (PLL) is used to generate unit sinusoidal wave in phase with main voltage. This abc components are given to generate three phase Pulse using Pulse Width Modulation (PWM) technique. Proposed control technique block is shown in figure(3)

![Control block diagram for DVR](image3)

### V. OPERATION OF SIMULATION MODEL

The model of proposed dynamic voltage restorer is prepared in simulink shown in figure(4). DVR is connecting in series in the distribution system. Programmable voltage source is used as a supply voltage to simulate the voltage sag /swells. This source is responsible to generate the variation in the supply voltage. The primary side of injecting transformer is supplied by voltage sourced converter. The proposed abc to \( dq_0 \) converter, which is given in figure: 3, compares the reference voltage with actual measured voltage of DVR then accordingly generate switching pulse of voltage source converter. A virtual PLL block is used and sin-cos is given to abc to \( dq_0 \) and \( dq_0 \) to abc converter. The switching pulses are applied to three phase 6 – pulse MOSFET based converter. The switching frequency is set on 20 kHz and sample time is 0.5 microseconds.
VI. SIMULATION RESULTS

The performance of the designed DVR as shown in Figure(3) and figure(4) is evaluated using Matlab/Simulink. Investigation on the DVR performance can be observed through testing under various disturbances condition on the grid voltage. The system parameters are listed in appendix.

It is assumed that the voltage magnitude of the load must be set at 1 pu during the voltage disturbance. A case of voltage sag with 20% depth and duration of 100ms is initiated at t=0.2 as shown in Fig.5(a). The DVR can compensate the dropped voltage immediately. Fig. 5(b), (c) show the DVR injected voltage and sensitive load voltage, respectively. The simulation is carried out for a balanced voltage swell, the source voltage increases to 1.2 pu from 0.2 s to 0.3 s as shown in Fig. 6(a). The DVR can compensate the dropped voltage immediately. Fig. 6(b), (c) show the DVR injected voltage and sensitive load voltage, respectively.

VII. CONCLUSION

This paper has proposed the modeling and simulation of DVR using simulink in MATLAB. The simple abc to dqo based control technique used. The performance of DVR is studied under voltage sag/swells. The simulation results show that the DVR compensates the voltage disturbances such as sag and swell quickly and provides excellent voltage regulation. For high switching frequencies expected in future applications (e.g. 200 kHz silicon carbide SiC JFETs, SiC MOSFETs and SiC Schottky Diodes) the proposed LCCT-ZSI can be further developed using integrated planar passive technology.

REFERENCES

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