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Analysis of Three Topologies of Dynamic Voltage Restorer to Mitigate Power Quality Issues

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ABSTRACT

Power quality has become a major concern of the modern industries in the present era. Voltage sags/swells are considered as the most significant power quality problems because of increasing complexity in the power system. To overcome these problems, Custom Power Devices (CPD) is connected closer to the load end. One of those devices is Dynamic Voltage Restorer (DVR) which is a series connected most efficient and effective modern CPD used in power distribution network. The main function of the DVR is to monitor the load voltage constantly and if any sag or swell occurs, it can quickly mitigate by injecting the balance (or excess) voltage to the load voltage. The primary advantage of the DVR is keeping the users always on-line with high quality constant voltage to maintain the continuity of production. In this paper the three different topologies of DVR, Voltage Source Inverter (VSI) based DVR, Z Source Inverter (ZSI) based DVR and Z source AC-AC converters based DVR have been analyzed and simulated to mitigate the voltage sag/swell. Comparisons are made between these topologies that can be realized with a minimum amount of energy storage, with the energy taken from the grid.

Key words- ***Custom Power Devices, Dynamic Voltage Restorer, Voltage Source Inverter***

1. INTRODUCTION

Over the last thirty years or so, the amount of equipment containing electronics has increased dramatically. Such equipment can both cause and be affected by electromagnetic disturbances. A disturbance that affects a process control computer in a large industrial complex could easily result in shutdown of the process. The lost production and product loss/recycling during start-up represent a large cost to the business. Similarly, a protection relay affected by a disturbance through conduction or radiation from nearby conductors could trip a feeder or substation, causing loss of supply to a large number of consumers. At the other end of the scale, a domestic user of a PC has to re-boot the PC due to a transient voltage dip, causing annoyance to that and other similarly affected users. Therefore, transporters and users of electrical energy have become much more interested in the nature and frequency of disturbances in the power supply. The topic has become known by the title of Power Quality. The main reasons for concern with power quality (PQ) are as following [1]:

- End user devices become more sensitive to PQ due to many Microprocessor based controls.
- Complexity of industrial processes: the re-startup is very costly.
- Large computer systems in many businesses facilities
- Power electronics equipment used for enhancing system Stability, operation and efficiency. They are major source of bad PQ and are vulnerable to bad PQ as well.
- Deregulation of the power industry
- Complex interconnection of systems, which results in more
- Severe consequences if any one component fails.
- Continuous development of high performance equipment: Such equipment is more susceptible to power disturbances.

Carrier based PWM methods utilize the per carrier cycle volt second balance principle to program a desirable inverter output voltage waveform. According to this principle, a sequence of inverter switching states is generated over a carrier cycle in a manner that for each phase the average value of the rectangular pulse output voltage approaches its reference (sine) voltage value. Therefore, a detailed modulator study requires knowledge of both microscopic (per carrier cycle) and macroscopic (over a fundamental cycle) behavior.

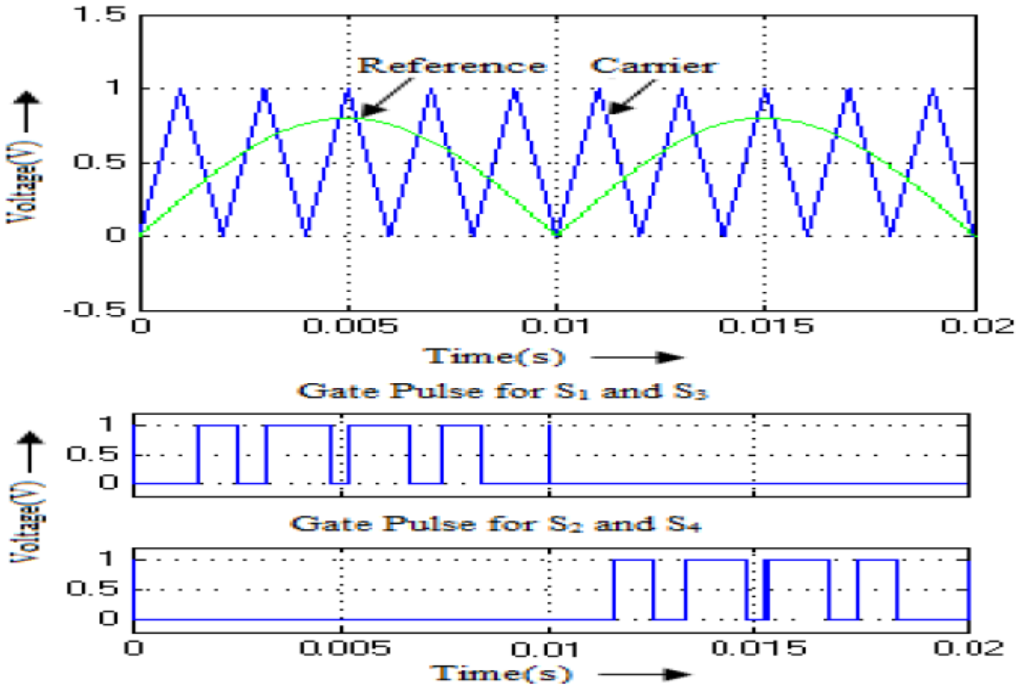

Figure 1: SPWM- Carrier and reference waveforms and gate pulses

In the SPWM method as shown in Figure 1, the reference modulation wave is compared with a triangular carrier wave and the intersections decide the switching instants. Within every carrier cycle, the average value of the output voltage becomes equal to the reference value.

Particularly in the digital implementation, which employs the regular sampling technique, this result becomes obvious as the reference volt-sec precisely equals the output volt sec Sastry, J. et al. [1], a single-stage bridgeless ac-dc PFC converter using a lossless passive snubber and valley switching is proposed. A. K. Sadigh et al. [2], in this paper, a single-phase single-stage isolated zero current switched (ZCS) current-fed full-bridge ac/dc converter is proposed for IGBT-based high-power power factor correction (PFC) applications. S. Bala, et al. [3], this paper presents the design and implementation of a hybrid controller for AC to DC power factor correction (PFC) converter. S. Lee. Et al. [4], resistance emulation using one cycle control (OCC) has been used extensively in single-phase full-bridge boost rectifiers. this paper presents the design and implementation of a hybrid controller for AC to DC power factor correction (PFC) converter. Blanes, et al. [5], this paper proposes an improved modulated carrier control for single-phase shunt active power filter, which eliminates harmonic and reactive currents at ac sources drawn by nonlinear loads. D. V. Ghodke et al. [6], a new auxiliary circuit for an ac-dc single-stage power-factor-corrected (SSPFC) full-bridge-type converter is proposed in this paper.

The SPWM technique is commonly used in industrial applications. The gating signals are generated by comparing a sine reference signal with a triangular carrier wave. Figure 1 shows the generation of gating signals of Single Phase Full Bridge (SPFB) VSI.

1.1 Performance Indices related to PWM-VSI

The output of inverter is a non-sinusoidal periodic waveform. The quality of the output wave is weighed by the theory developed by Joseph Fourier, the French physicist and mathematician [1]. Fourier series decomposes any periodic waveform into the superposition of a direct component with a fundamental pure sine wave component, together with pure sine waves known as harmonics at frequencies, which are integral multiples of the fundamental. The magnitude of harmonics decreases with increase in the order of the harmonics. The performance indices related to PWM-VSI are;

Harmonic Factor (HF) is the measure of individual harmonic contribution and the HF of nth harmonic is given by

$$HF_n = \frac{V_n}{V_1} \tag{1}$$

Lower Order Harmonics (LOH): The low frequency harmonics closers to the fundamental which has amplitude greater than 3% of the fundamental component. LOH are also called as sub carrier harmonics.

Dead band: The band available in frequency spectrum between fundamental component and first dominant harmonics.

Dominant harmonics: For noise interference purposes, only the “dominant harmonics”, that is the harmonics that are higher than 90% of the highest harmonic components are considered. In drive applications, the harmonics of magnitude greater than 5% of fundamental is considered as dominant harmonics [2].

Total Harmonic Distortion (THD): THD is degree of measure of closeness of the considered waveform with the pure sinusoidal one in shape. It is defined as:

$$\mathrm{THD_v} = \sqrt{\sum_{n=2}^{m}\left(\frac{V_n}{V_1}\right)^2} \times 100\% \quad \frac{\sqrt{\sum_{n=2}^{m} V_n{}^2}}{V_1} \times 100\%$$

$$\mathrm{THD_i} = \sqrt{\sum_{n=2}^{m}\left(\frac{I_n}{I_1}\right)^2} \times 100\% \quad \frac{\sqrt{\sum_{n=2}^{m} I_n{}^2}}{I_1} \times 100\% \qquad (2)$$

Where, V1 (I1) is the rms value of fundamental harmonic voltage (current) and Vn (In) is the rms value of the nth order harmonic voltage (current) [3].

Harmonic Spread Factor (HSF): It is figure of merit for identifying the spreading capability of a PWM method. Spreading effect play a major role in deciding the magnitudes of both mechanical vibrations and acoustical noise of drive system. Appraising the harmonic spread effect of the different PWM strategies, a simple quality indicator would be useful [4]. For this purpose, the concept of statistical deviation can be employed and the HSF is defined as follows:

$$\mathrm{HSF} = \sqrt{\frac{1}{n}\sum_{j>1}^{n}(H_j - H_0)^2} \qquad (3)$$

$$H_0 = \frac{1}{n}\sum_{j>1}^{n}(H_j) \qquad (4)$$

Where, 'n' is total number of frequency components considered, 'H_j' is amplitude of j^{th} harmonics and 'H_0' is average value of all components.

Power Spectral Density (PSD): PSD shows the strength of the variations in energy as a function of frequency. In other words, it shows at which frequencies variations are strong and at which frequencies variations are weak. The unit of PSD is energy per frequency and the total energy within a specific frequency range is calculated by integrating PSD within that frequency range [5].

2. *STRUCTURE OF DVR*

DVR is a series connected device located between sensitive load and grid in system. It detects both voltage sag/swell problems and injects controlled voltage to system. Additionally, it can be used for harmonics compensation and transient reduction in voltage and fault current limitations in available literature. To perform these processes, DVR injects a controlled voltage in series with the supply voltage in phase via injection transformer to restore the power quality. The basic structure of a conventional DVR is shown in Figure 2.

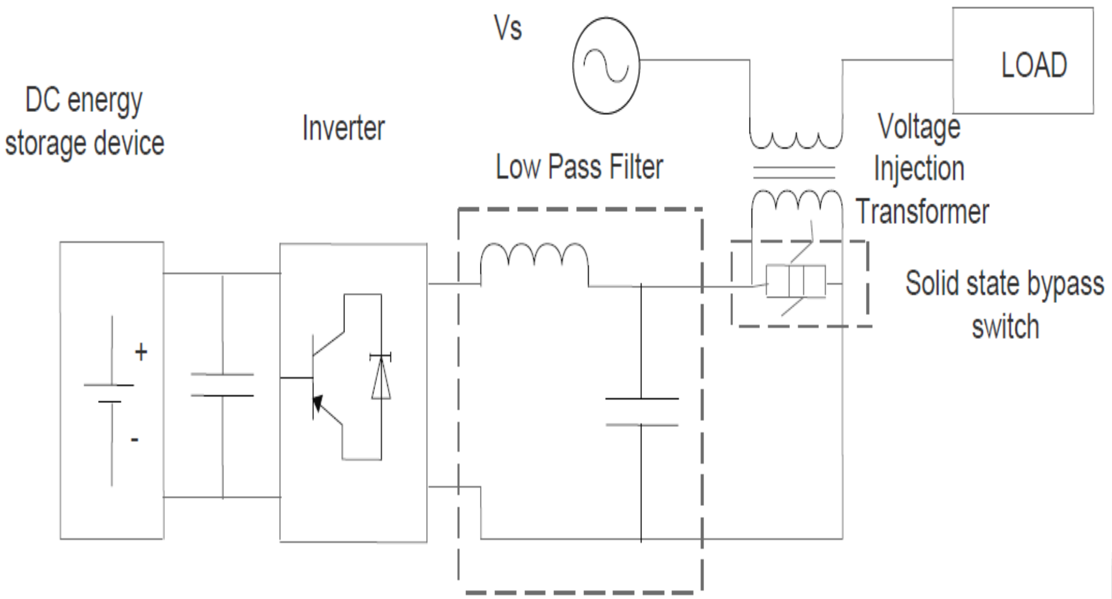

Figure 2: Basic structure of a conventional DVR

It can be divided into four categories: inverter, DC-link capacitor, filter and injection transformer. An inverter system is used to convert dc storage into ac form.

Passive filter is responsible for eliminating the unwanted harmonic components generated in inverter. In this way, it converts inverter PWM output to sinusoidal waveform. Another component, energy storage unit such as batteries, super capacitors, SMES etc. is used to provide energy requirement in DC form. Lastly, transformer injects controlled voltage and provides isolation between load and the system [6].

3. MATHEMATICAL MODELING OF Z SOURCE INVERTER

The Figure 3 shows the general structure of Impedance Source Inverter. It uses a unique LC Impedance Network (or circuit) to couple the inverter main circuit to connect the DC power source, load or another converter. The DC source/or load can be either a voltage or a current source or load. Therefore the DC source can be a battery, diode rectifier, thyristor converter, an inductor, a capacitor or a combination of those. Switches used in the converter can be a combination of switching devices and diodes such as the anti parallel combinations and the series combinations etc.

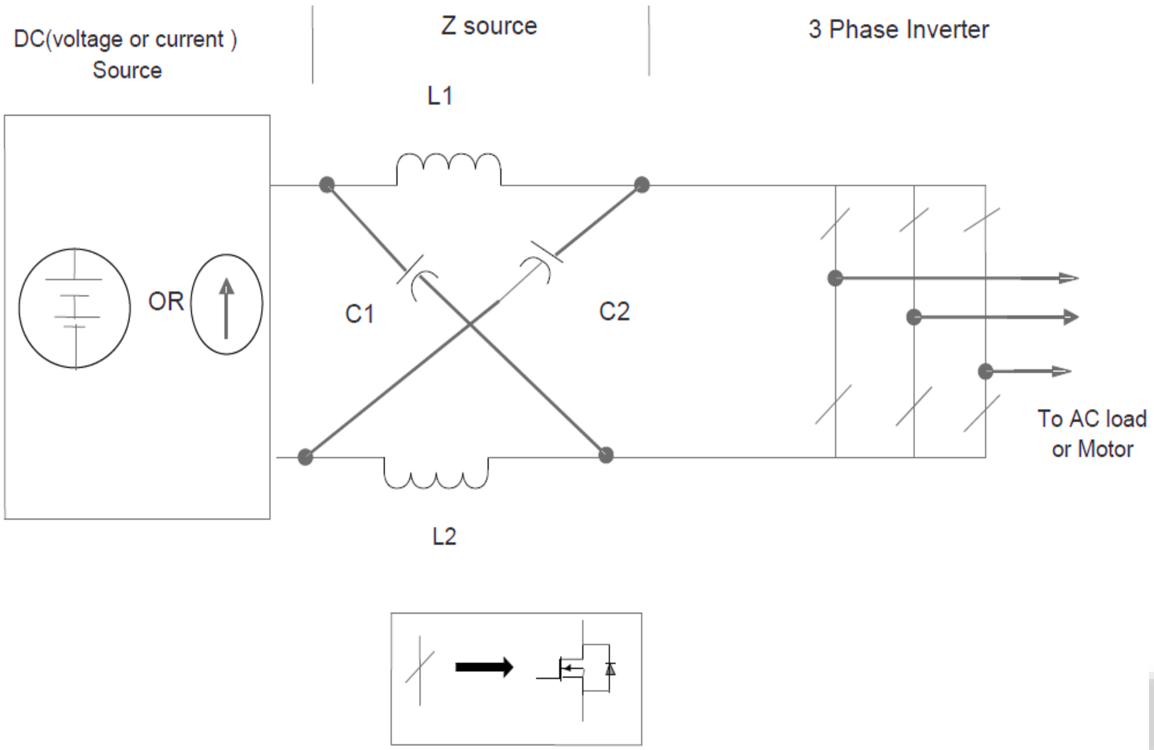

Figure 3: The general structure of Impedance Source Inverter

This inverter has unique features compared with the Voltage and Current Source Inverters

The three phase impedance source inverter bridge has nine permissible switching states unlike the traditional voltage source inverter that has eight switching states.

- The six active vectors when the dc voltage is connected across the load.
- Two zero vectors when the load terminals are shorted through either the upper or lower three devices, respectively.
- One more zero state (or vector) when the load terminals are shorted through both the upper and lower devices of any one of the phase leg (i.e., both devices are gated on), any two phase legs, or all three phase legs. This shoot-through zero state gives the special buck-boost feature to the inverter.
- This shoot-through zero state is forbidden in the traditional Voltage Source Inverter. This shoot-through zero state can be produced in seven different ways: shoot-through via any one phase leg combinations of any two phase leg all three phase legs.

In this state the circuit can be described by the following equations.

$$Vi = 0 \quad (5)$$

$$VL = VC \quad (6)$$

$$Vd = 2VC \quad (7)$$

Where Vd is the input dc voltage and Vi is the average dc link voltage Now consider the inverter is operating in active states for an interval of T1 during a switching cycle T. The equivalent circuit of ZSI in this mode is as shown is Figure 4

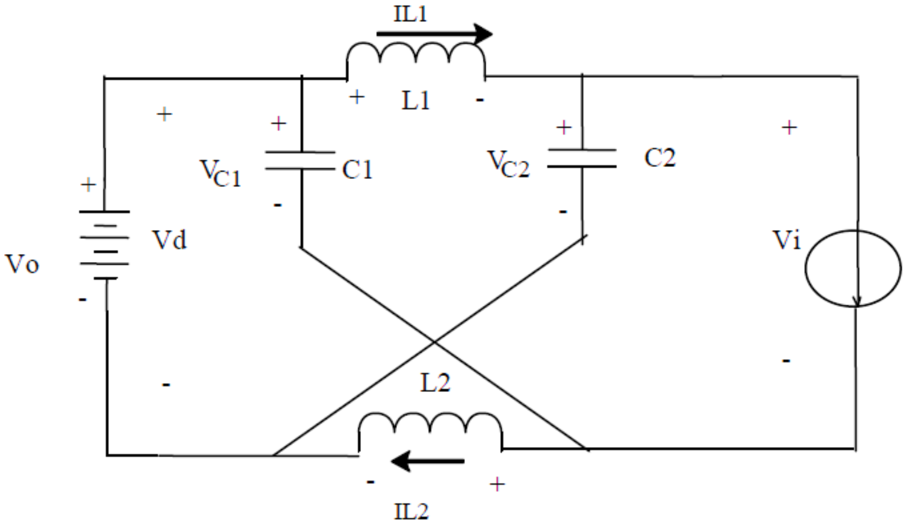

Figure 4: Equivalent circuit of ZSI in active states

4. RESULTS AND ANALYSIS

The basic functions of a controller in a DVR are the detection of voltage sag/swell 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/swells. The dqo transformation or Park’s transformation is used to control of DVR. The dqo method gives the sag depth and phase shift information with start and end times. The quantities are expressed as the instantaneous space vectors. Firstly convert the voltage from abc reference frame to d-q-o reference. For simplicity zero phase sequence components is ignored. Figure 5 illustrates a flow chart of the feed forward dqo transformation for voltage sags/swells detection. The detection is carried out in each of the three phases.

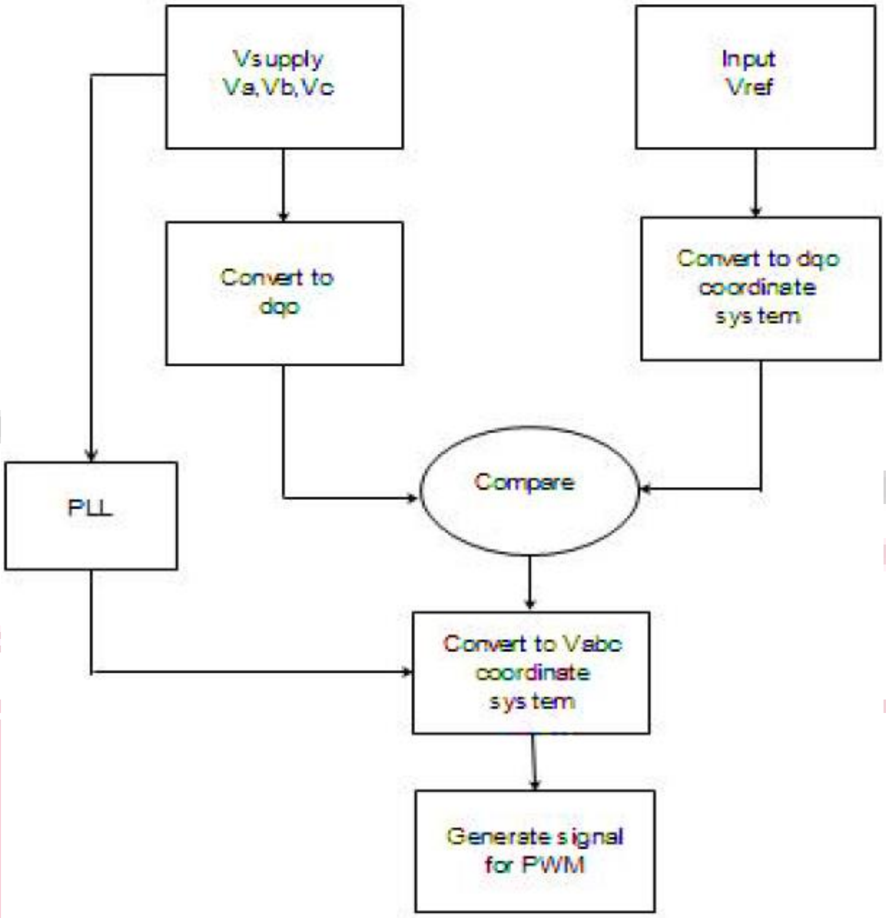

Figure 5: Flow chart of feed forward control technique for DVR based on dqo transformation

The control scheme for the proposed system is based on the comparison of a voltage reference and the measured terminal voltage (Va,Vb,Vc).The voltage sags is detected when the supply drops below 90% of the reference value whereas voltage swells is detected when supply voltage increases up to 25% of the reference value. The error signal is used as a modulation signal that allows to generate a commutation pattern for the power switches (MOSFET) constituting the voltage source converter. The commutation pattern is generated by means of the sinusoidal pulse width modulation technique (SPWM); voltages are controlled through the modulation. The block diagram of the phase locked loop (PLL) is illustrated in Figure 5. The PLL circuit is used to generate a unit sinusoidal wave in phase with mains voltage.

The simulation shows the DVR performance during a voltage swell condition. The supply voltage swell is generated as shown in Figure 6 as observed from this figure the amplitude of supply voltage is increased about 50 % from its nominal voltage and the corresponding input current is as shown in Figure 7.

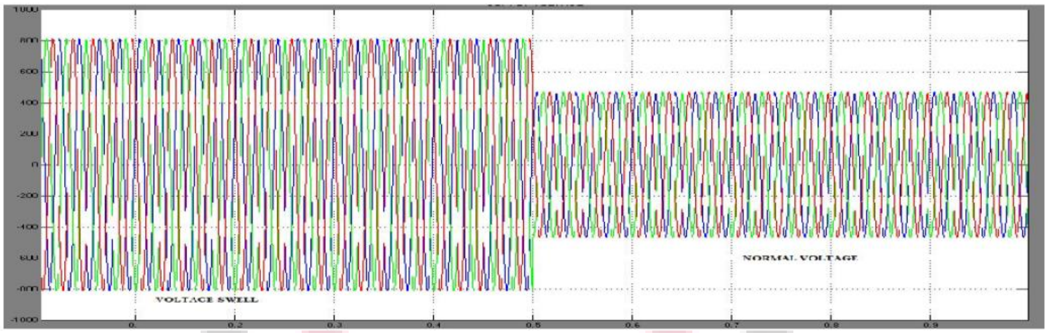

Figure 6: Supply Voltage during Swell in VSI based DVR

The Figure 7 shows the injected voltage by the DVR. The Figure 8 and 9 show the compensated load voltage and the corresponding load current respectively. As seen from the results, the load voltage is kept at the nominal value with the help of the DVR. Similar to the case of voltage sag, the DVR reacts quickly to inject the appropriate voltage component (negative voltage magnitude) to correct the supply voltage.

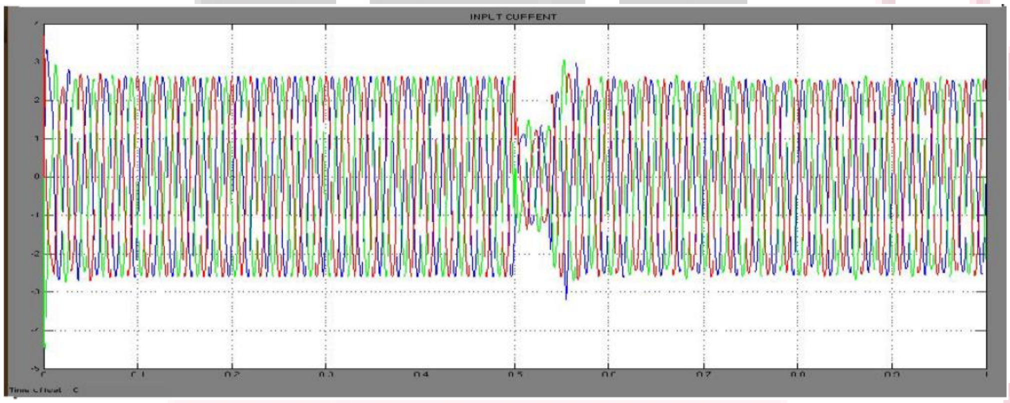

Figure 7: Supply current during Swell in VSI based DVR

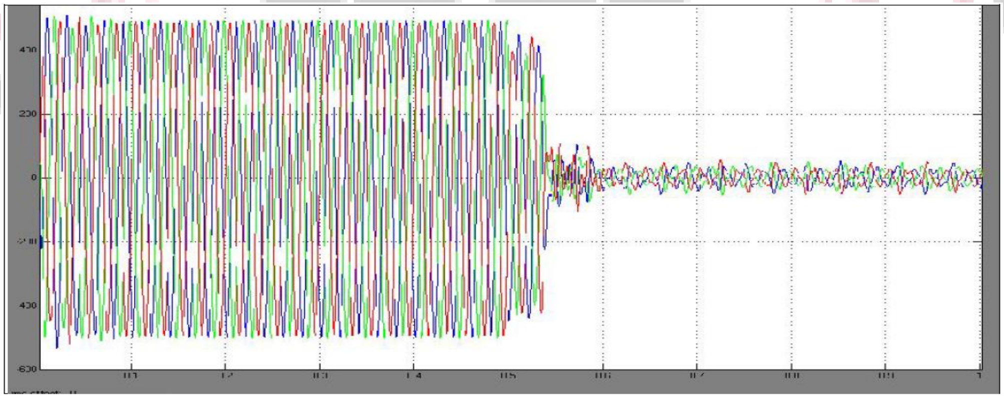

Figure 8: Voltage Injected by VSI based DVR during Swell

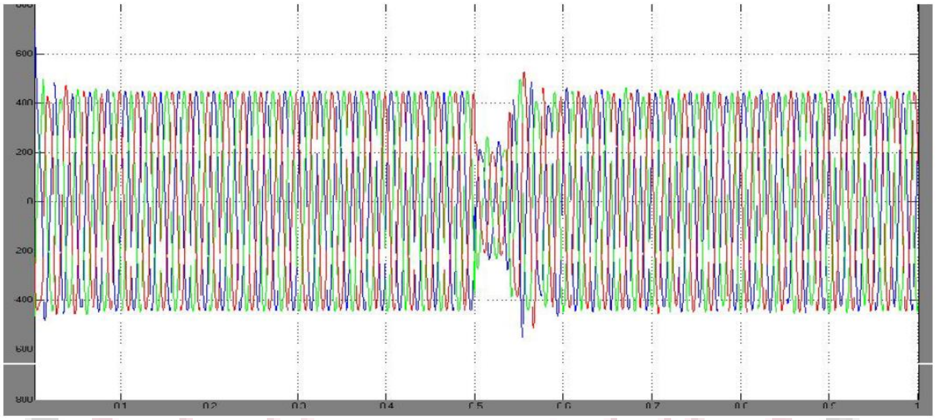

Figure 9: Compensated Load Voltage in VSI based DVR

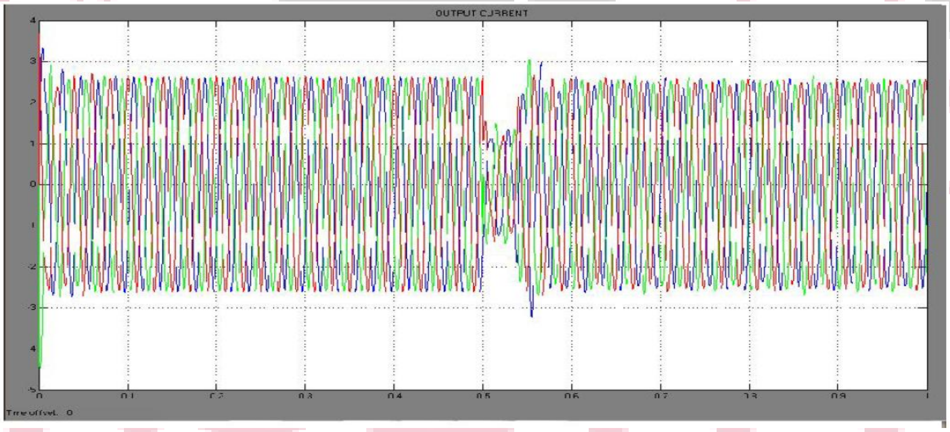

Figure 10: Compensated Load Current in VSI based DVR

The performance of three levels and three phrase AC-DC converter with the modulation techniques and both the simulation and experimental results show improvement in the drive performance.

From the above simulated work, it is clear that a small injected voltage will be present during normal operation. As a future work and a further development an additional control can be added to neutralize the injected voltage component during the normal operation, by generating a similar sinusoidal waveform with a phase shift of 1800 which is basically the drop across the DVR internal impedance.

5. CONCLUSION

It is also proved from the simulation results; the impedance source inverter can be used in buck as well as boost mode of operation. However, the above two configuration of DVR has two main drawbacks which are the need of an energy storage device that could be quickly operated and existence of harmonics in the system during the fault period. To overcome these drawbacks finally the new configuration of Z source AC-AC converter based DVR has been proposed and verified by simulations. The new developed control strategy was integrated to adjust the reference signal for the system. The three phase Z source AC-AC converter has been introduced to perform the direct AC-AC conversion. Hence this system does not require any battery energy storage devices. The bidirectional switches have been used which is able to block the voltage and conduct current in both directions. The proposed system provides output voltage which can be bucked/boosted and in-phase /out of phase with the supply voltage.

REFERENCES

[1] Sastry, J., Bala, S. "Considerations for the design of power electronic modules for hybrid distribution transformers," Energy Conversion Congress and Exposition (ECCE), IEEE, On page(s): 1422 – 1428, 2013.

[2] A. K. Sadigh and K. M. Smedley, “Review of voltage compensation methods in dynamic voltage restorer (DVR),” in Proc. IEEE Power Energy Soc. Gen. Meet., pp. 1–8, Jul. 2012.

[3] S. Bala, D. Das, E. Aeloiza, A. Maitra, and S. Rajagopalan, “Hybrid distribution transformer: Concept development and field demonstration,” in Proc. IEEE Energy Convers. Congr. Expo, pp. 4061– 4068, 2012.

[4] S. Lee., H. Cha, and B. Han, “A new single-phase voltage sag/swell compensator using direct power conversion,” in Proc. Energy Conversion Congress and Exposition, pp 2704 – 2710, 2009.

[5] Blanes, JM, Garrigos, A, Carrasco, JA, Weinberg, AH, Maset, E, Sanchis-Kilders, E, Ejea, JB & Ferreres, A, “Two-stage MPPT power regulator for satellite electrical propulsion system”, IEEE Transactions on Aerospace and Electronics Systems, vol. 47, Issue 3, March 2011.

[6] D. V. Ghodke, “One-cycle-controlled bidirectional AC to DC converter with constant power factor”, IEEE Transaction Industry Electron, Vol. 56, Issue 05, May 2009.