DINAMIC VOLTAGE RESTORER BASED ON Z-SOURCE INVERTER

Jo Joy

Assistant Professor, Dept. of Electrical and Electronics Engineering,
SAINTGITS College of Engineering, Kottayam(India)

ABSTRACT

This paper presents the modeling and simulation of a dynamic voltage restorer as a voltage sag/swell mitigation device in electrical power distribution networks. The dynamic voltage restorer, with its excellent dynamic capabilities, when installed between the supply and a critical load feeder, can compensate for voltage sags/swells, restoring line voltage to its nominal value within few milliseconds and hence avoiding any power disruption to the load. 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. The simulation results shows that the control technique is very effective and yields excellent compensation for voltage sag/swell mitigation.

***Keywords*: Z-Source Inverter (ZSI), Current Source Inverter (CSI), Voltage Source Inverter (VSI), Electromagnetic Interference (EMI), Shoot-Through, DVR.**

I. INTRODUCTION

Modern power systems are complex networks, where hundreds of generating stations and thousands of load centers are interconnected through long power transmission and distribution networks. The main concern of customer is the quality and reliability of power supply at various load centers. Even though power generation in most well-developed countries is fairly reliable, the quality of supply is not. Power distribution system should ideally provide their customers an uninterrupted flow of energy with smooth sinusoidal voltage at the contracted magnitude and frequency. However, in practice power system especially the distribution system, have numerous nonlinear loads, which are significantly affect the quality of power supply. As a result, the purity of waveform of supply lost. This ends up producing many power quality problems.

Apart from non-linear loads, some system events, both usual (capacitor switching, motor starting) and unusual (faults) could also inflict power quality problems. The consequence of power quality problems could range from a simple nuisance flicker in electric lamps to a loss of thousands of rupees due to power shutdown. A power quality problem is defined as any manifested problem in voltage or current of leading to frequency deviations that result in failure or miss operation of customer equipment. Power quality problems associated with an extensive number of electromagnetic phenomena in power systems with broad ranges of time frames such as long duration variations, short duration variations and other disturbances. Short duration variations are mainly caused by either fault conditions or energisation distance related to impedance type of grounding and connection of transformer between the faulted location and node, there can be temporary load of voltage reduction (sag) or voltage rise (swell) at different nodes of the system.

Voltage sag is defined as a sudden reduction in supply voltage to between 90% and 10% of the nominal value, followed by a recovery after a short interval. The standard duration of sag is between 10 milliseconds and 1 minute. Voltage sag can cause loss in production in automated processes since voltage sag can trip a motor or cause its controller to malfunction. Voltage swell is defined as sudden increase in supply between 110% and 180% of the nominal value of the duration of 10 milliseconds to 1 minute. Switching off a large inductive load or energizing a large capacitor bank is a typical system event that causes swells. To compensate the sag/swell in a system, appropriate devices need to be installed at suitable locations.

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 [4].

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.

II. DYNAMIC VOLTAGE RESTORER

Dynamic voltage restorer was originally proposed to compensate for voltage disturbances on distribution systems. A typical DVR scheme is shown in Fig. 1. The restoration is based on injecting AC voltages in series with the incoming three-phase network, the purpose of which is to improve voltage quality by adjustment in voltage magnitude, waveshape, and phase shift. These are important voltage attributes as they can affect the performance of the load equipment. Voltage restoration involves energy injection into the distribution systems and this determines the capacity of the energy storage device required in the restoration scheme.

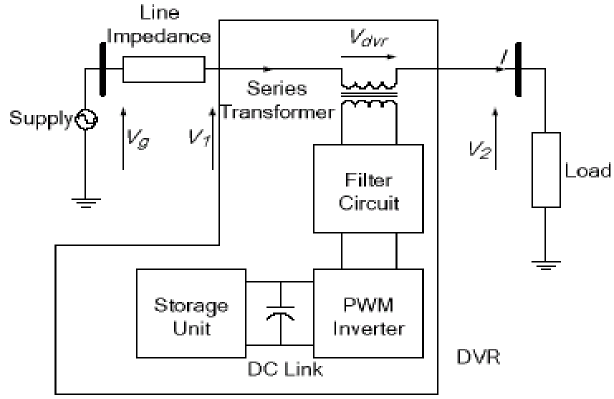

Figure.1. Block Diagram of General DVR Circuit

In the Fig. 1, V_g is the source voltage, V_1 is the incoming supply voltage before compensation, V_2 is the load voltage after compensation, is the series injected voltage of the DVR and I is the line current. The restorer typically consists of an injection transformer, the secondary winding of which is connected in series with the distribution line, a pulse-width modulated (PWM) voltage source inverter (VSI) bridge connected to the primary of the injection transformer and an energy storage device connected at the dc-link of the inverter bridge. The series injected voltage of the DVR, V_{dvr}, is synthesized by modulating pulse widths of the inverter-bridge switches. The injection of an appropriate V_{dvr} in the face of an up-stream voltage disturbance requires a certain amount of real and reactive power supply from the DVR. The reactive power requirement is generated by the inverter.

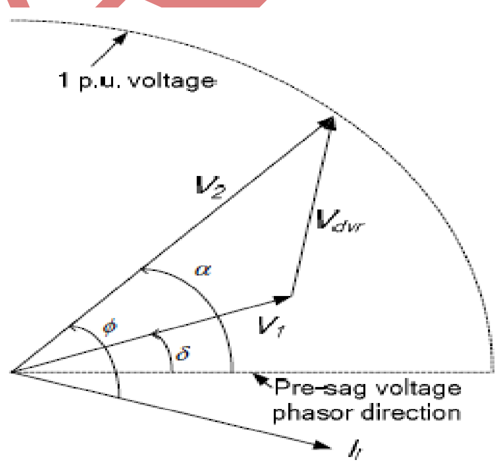

Figure.2. Vector Diagram of Voltage Injection Method

Widely used in present DVR control is the so-called in phase voltage injection technique where the load voltage V2 is assumed to be in-phase with the pre-sag voltage. As the DVR is required to inject active power into the distribution line during the period of compensation, the capacity of the energy storage unit can become a limiting factor in the disturbance compensation process. In particular, if capacitors are used as energy storage, the DC-link voltage will decrease with the dwindling storage energy during compensation.

The corresponding phasor diagram describing the electrical conditions during voltage sag is depicted, where only the affected phase is shown for clarity. Let the voltage quantities Il, φ, δ and α represent the load current, load power factor angle, supply voltage phase angle and load voltage advance angle respectively. Although there is a phase advancement of α in the load voltage with respect to the pre-sag voltage in Fig. 2, only in-phase compensation where the injected voltage is in phase with the supply voltage (α = δ) is considered.

III. Z-SOURCE INVERTER

To overcome the above problems of the traditional V-source and I-source converters, the impedance-source (or impedance-fed) power converter (abbreviated as Z-source converter) and its control method for implementing dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion are used. Fig. 3 shows the general Z-source converter structure proposed. It employs a unique impedance network (or circuit) to couple the converter main circuit to the power source, load, or another converter, for providing unique features that cannot be observed in the traditional V- and I-source converters where a capacitor and inductor are used, respectively.

The Z-source converter overcomes the above-mentioned conceptual and theoretical barriers and limitations of the traditional V-source converter and I-source converter and provides a novel power conversion concept. In Fig. 3, a two-port network that consists of a split-inductor L1 and L2 and capacitors C1 and C2connected in X shape is employed to provide an impedance source (Z-source) coupling the converter (or inverter) to the dc 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, fuel cell, 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 combination and, the series combination. The inductance L1 and L2 can be provided through a split inductor or two separate inductors.

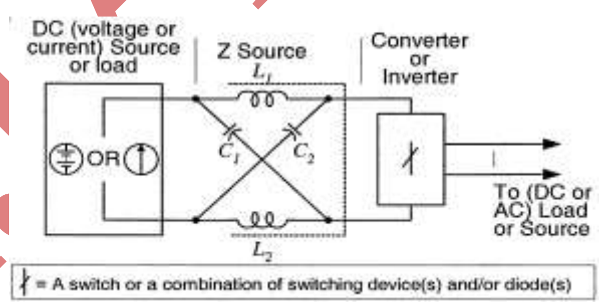

Figure.3. General Structure Of Z-Source Inverter

The Z-source concept can be applied to all dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion. Impedance network is a two port network. Usually one pair represents the input and other represents the output. This network also called as lattice network. Lattice network is the one of the common four terminal two port network. The lattice network is used in filter sections and is also used as attenuators. Lattice networks are sometimes used in preference to ladder structure in some special applications. This lattice network that consists of split inductors L1 and L2 and capacitors C1 and C2 connected in X-shape. The three phase impedance source inverter bridge has nine switching states unlike the traditional voltage source inverter that has eight switching states. The impedance source inverter bridge has one extra zero state, when the load terminals are shorted through both upper and lower devices of any one phase leg or all three phase legs. This shoot through zero state is forbidden in the VSI, because it would cause a shoot- through. This network makes the shoot through zero state possible. This state provides the unique buck-boost feature to the inverter. The equivalent switching frequency from the impedance source network is six times the switching frequency of the main inverter, which greatly reduces the required inductance of the Impedance source network. The equivalent circuit of the Impedance source inverter is shown in Fig. 4. The impedance source network is a combination of two inductors and two capacitors. This combined circuit, the Impedance Source Network is the energy storage or filtering element for the Impedance Source inverter. This impedance source network provides a second order filter. This is more effective to suppress voltage and current ripples. The inductor and capacitor requirement should be smaller compared to traditional inverters.

When the two inductors (L1 and L2) are small and approach zero, the Impedance source network reduces to two capacitors (C1 andC2) in parallel and becomes traditional voltage source. Similarly, when the two capacitors (C1 and C2) are small and approach zero, the Impedance Source Network reduces to two inductors (L1 and L2) in series and becomes a traditional current source. Therefore considering additional filtering and energy storage by the capacitors, the impedance source network should require less inductance and smaller size compared with the traditional current source inverters.

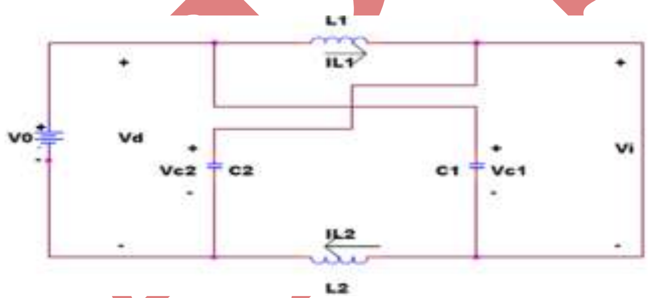

Figure. 4. Equivalent circuit of the Impedance Source Inverter

The advantages of Z-source inverter are follows:

- It can produce any desired output ac voltage, even greater than the line voltage
- Provides ride –through during voltage sags without any additional circuits and energy storage;
- minimizes the motor ratings to deliver a required power;
- Reduces in-rush and harmonic current.
- The Impedance source technology can be applied to the entire spectrum of power conversion.

IV. VOLTAGE SAG COMPENSATION IN DVR SYSTEM

In order to meet the requirement of constant voltage control, closed loop operation is performed for the desired value of the voltage according to the need. The Simulink model of closed loop control of voltage sag compensation in a DVR system is shown in the Fig. 5. Initially the system was subjected to 25% voltage sag at t=300ms and remains up to t=700ms with the total voltage sag duration of 400ms, in a run time of 1000ms.

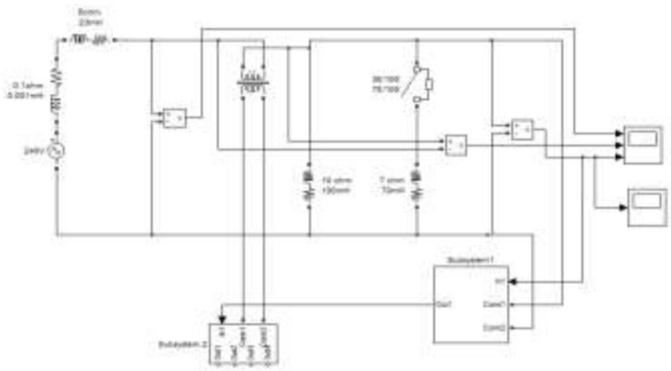

Figure. 5. Closed Loop Control of Voltage Sag Compensation in a DVR System

Fig. 6 shows the subsystem 1 of the closed loop DVR system. It contains the PI controller. The AC output voltage is rectified to DC supply and then a reference voltage is given for the error. This error is sent to the PI controller. The saturator value is given as pulses for controlling the Z-Source inverter.

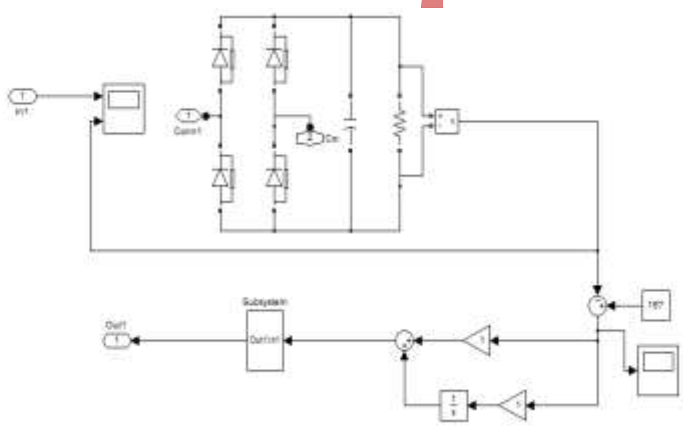

Figure. 6. Subsystems 1 of Closed Loop Control of Voltage Sag Compensation in a DVR System

In the Fig. 7, subsystem 2 contains the Z-Source inverter which is being controlled by the PI controller. The Z-Source starts conducting when it obtains the pulse from the saturator. Fig. 8 shows the output waveform of closed loop control of voltage sag compensation. Fig. 8.A shows the uncompensated AC voltage with 25% sag. Fig. 8.B shows the injected DVR voltage. Fig. 8.C gives the compensated output voltage

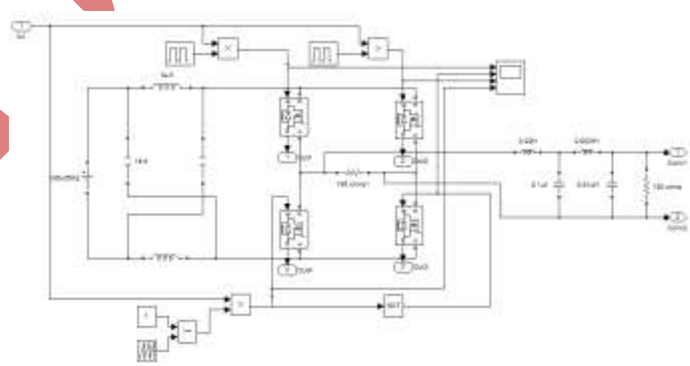

Figure.7. Subsystem 2 of Closed Loop Control of Voltage Sag Compensation in a DVR System

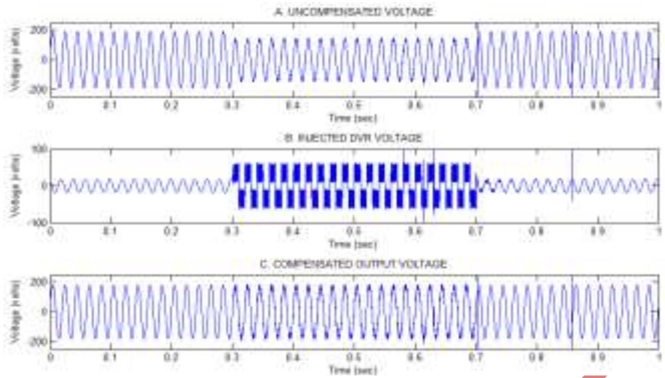

Figure. 8. Simulation results of Closed Loop Control DVR under 25% sag (A.Uncompensated Voltage, B. Injected DVR Voltage, C. Compensated Voltage)

In Fig. 9, the Fast Fourier Transform (FFT) analysis is performed for the compensated output voltage. Here the Total Harmonic Distortion (THD) value is 7.21%. The simulation was done under transient performance at the sag front and recovery was observed. The load voltage is maintained at the same value throughout the simulation including the voltage period. Thus voltage sag compensation using closed loop control is simulated.

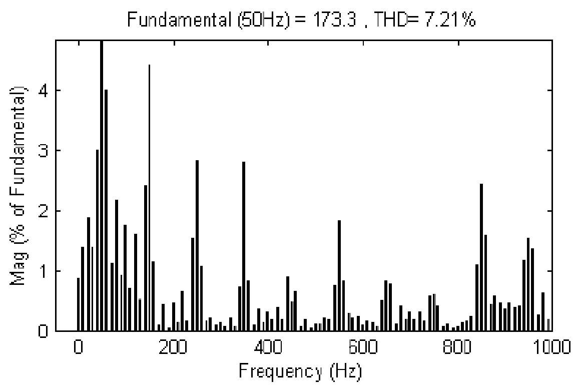

Figure.9. FFT Analysis of Closed Loop Control of Voltage Sag Compensation in a DVR System

V. VOLTAGE SWELL COMPENSATION IN DVR SYSTEM

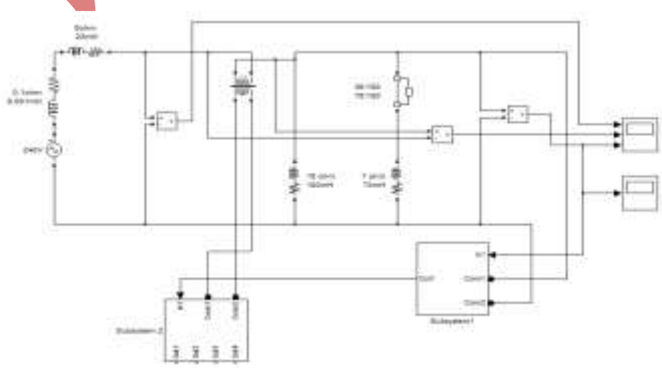

Figure. 10. Closed Loop Control of Voltage Swell Compensation in a DVR System

The Simulink model of closed loop control of voltage swell compensation in a DVR system is shown in the Fig. 10. Initially the system was subjected to 30% voltage swell at t=300ms and remains up to t=700ms with the total voltage swell duration of 400ms, in a run time of 1000ms.

Fig. 11 shows the subsystem 1 of the closed loop DVR system. It contains the PI controller. The AC output voltage is rectified to DC supply and then a reference voltage is given for the error. This error is sent to the PI controller. Value is set in the saturator for giving the pulses for controlling the Z-Source inverter. Multiple pulses are given to the Z-Source for boosting operation. In this case multiple pulses are given to the switch 2 and 4 of the inverter.

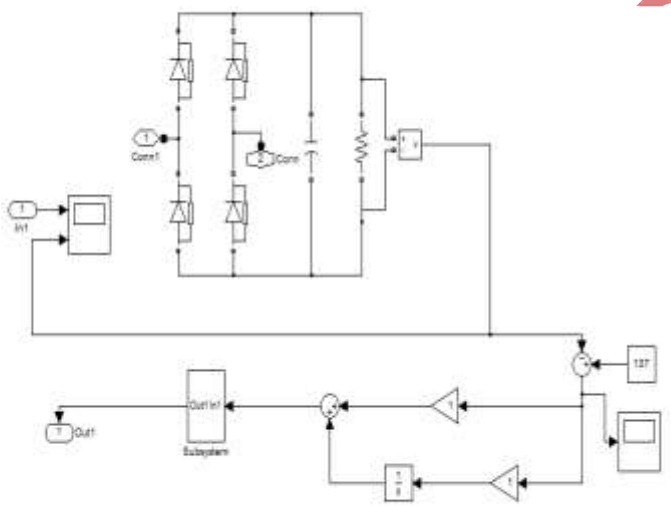

Figure. 11. Subsystem 1 of Closed Loop Control of Voltage Swell Compensation in a DVR System

In the Fig. 12, subsystem 2 has the Z-Source inverter which is being controlled by the PI controller. The Z-Source starts conducting when it obtains the pulse from the saturator. Fig. 13 shows the output waveform of closed loop control of voltage swell compensation. Fig. 13.A shows the uncompensated AC voltage with 30% swell. Fig. 13.B is the injected DVR voltage. Fig. 13.C shows the compensated output voltage.

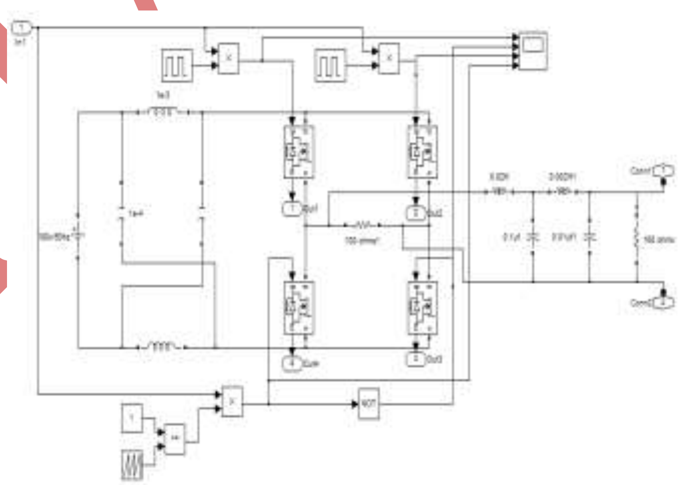

Figure. 12. Subsystem 2 of Closed Loop Control of Voltage Swell Compensation in a DVR System

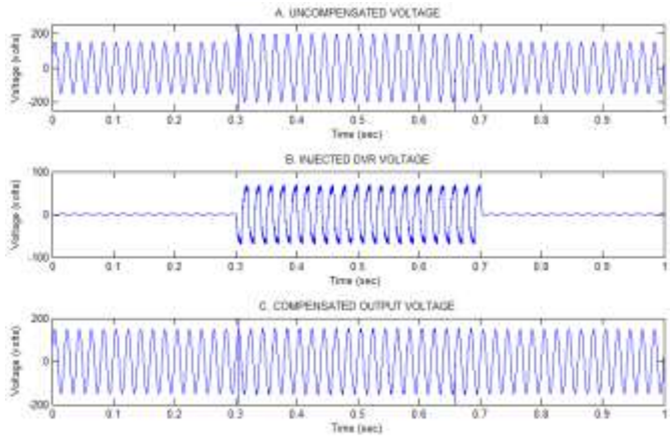

Figure. 13. Simulation results of Closed Loop Control DVR with 30% swell

(A. Uncompensated Voltage, B. Injected DVR Voltage, C. Compensated Voltage)

In Fig. 14, FFT analysis is performed for the compensated output voltage. Here the THD value is 6.92%. The simulation was done under transient performance at the swell front and recovery was observed. The load voltage is maintained at the same value throughout the simulation. Thus voltage swell compensation using closed loop control is simulated.

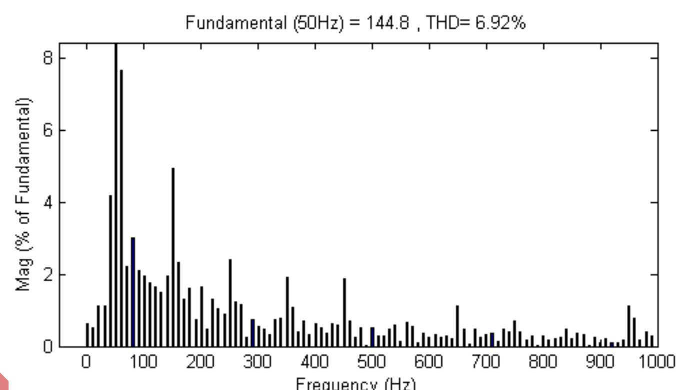

Figure. 14. FFT Analysis of Closed Loop Control of Voltage Swell Compensation in a DVR System

VI. CONCLUSION

In this paper voltage sag/swell compensation using Z-Source inverter based Dynamic Voltage Restorer is considered. The control technique is designed using in-phase compensation and used a closed loop control system to detect the magnitude error between voltages during pre-sag and sag periods. The modeling and simulation of closed loop control of voltage sag/swell mitigation were carried out using MATLAB software.

The simulation results show that the developed control technique with proposed single phase DVR is simple and efficient. From the simulation results it was observed that dynamic voltage restorer compensates 25% of voltage sag and 30% of voltage swell.

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