A series connected Dynamic Voltage Restorer Used in Power Distribution Network

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ABSTRACT

In Z source AC-AC converter based DVR, the AC-AC converter has been employed to perform a direct AC-AC conversion. The Z source network can produce any desired output voltage which is a greater or lesser voltage than the line voltage. Hence it enhances the voltage restoration capability of DVR. This new converter has unique features of providing a larger range of output ac voltage with buck-boost, reversing or maintaining phase angle, reducing in – rush and harmonic current and improving reliability. The proposed topology and the existing topology are simulated under voltage sag/swell using MATLAB / Simulink and the simulation results are compared to show that the proposed system effectively compensates the voltage sag/swell. The present work is an effort towards analyzing the different multi-pulse AC to DC converters in solving the harmonic problem in a three phase converter system.

Key words- DVR, Voltage Source Inverter (VSI) based DVR, Z Source Inverter

1. INTRODUCTION

The main objective of Power distribution systems is to provide uninterrupted flow of energy with constant magnitude level sinusoidal voltage and frequency to their customers. The modern manufacturing and process equipment which operates at high efficiency require high quality power for the successful operation of their machines.

The failure of required quality power can cause complete shutdown of the industries which will make a major financial loss to the industry concerned.. In practice, power systems, especially the distribution system has numerous non-linear loads which produce power quality problems such as voltage sag and swell, flicker, harmonics, distortion, impulse transient and interruptions [1]. Among these, two power quality problems such as voltage sag and swell have been identified a major concern to the customers .The voltage sag and swell have major impact on the performance of the microprocessor based loads as well as the sensitive loads. Though there are many different methods to mitigate voltage sag and swell, but the use of a custom Power device is considered to be the most efficient method. The term custom power pertains to the use of power electronics controllers in a distribution system specially to deal with various power quality problems. Dynamic Voltage Restorer (DVR) is one of the most efficient and effective modern custom power device used in power distribution networks. DVR is series connected solid state device that injects voltage into the system in order to regulate the load side voltage [2]. It is normally installed in the distribution system between the supply and the critical load feeder at the point of common coupling (PCC). Other than voltage sag and swell compensation, DVR can also have other features like: line voltage harmonics compensation, reduction of transients in voltage and fault current limitations.

The dc output voltage of a rectifier should be as ripple free as possible therefore, a large capacitor is connected as a filter on the dc side. This capacitor gets charged to a value close to the peak of the ac input voltage. As a consequence the current through the rectifier is very large near the peak of the 50Hz ac input voltage and it does not flow continuously; that is, it becomes zero for finite durations during each half-cycle of the line frequency. These rectifiers draw highly distorted current from the utility. Now and even more so in the future, harmonic standards and guidelines will limit the amount of current distortion allowed into the utility and simple diode rectifiers may not be allowed. In the past few years a lot of work has been done for the reduction of Total Harmonic Distortion (THD) using different concepts and applications. This work deals with the reduction of Total Harmonic Distortion using multi-pulse AC to DC conversion scheme. The results are obtained for both uncontrolled and controlled converters. The three-phase multi-pulse AC to DC conversion system employs a phase-shifting transformer and a three phase converter between the supply and load side of the system. Every such converter provides 6-pulse AC to DC Conversion, so in order to produce more sets of 6-pulse systems, a uniform phase-shift is required and hence with proper phase-shifting angles, 12, 18, 24 and 30, and higher pulse systems can be produced. Different rectifiers are used for conversion of AC supply into DC supply. For uncontrolled conversion, diodes have been preferred, while for the controlled conversion, thyristers are used. The performance improvement of multi-pulse converter is achieved in terms of total harmonics distortion in supply current, DC voltage ripples and form factor. All the simulations have been done for similar ratings of load, for all the multi-pulse converters configurations, so as to represent a fair comparison among controlled and uncontrolled continuations of multi-pulse converters. The present work is an effort towards analyzing the different multi-pulse AC to DC converters in solving the harmonic problem in a three phase converter system. The effect of increasing the number of pulses on the performance of AC to DC converters has been analyzed. For performance comparison the total harmonic distortion is considered. The effects of load variation on multi-pulse AC to DC converters have also been investigated. Multi-pulse methods involve multiple converters connected so that the harmonics generated by one converter is cancelled by harmonics produced by other converters. By this means, certain harmonics related to number of converters are eliminated from the power source. In multi-pulse converters, reduction of AC input line current harmonics is important as regards to the impact of the converter on the power system.

1.1 VOLTAGE SAG

Voltage sag is defined as the reduction of R.M.S voltage to a value between 10- 90% and lasting for duration of half a cycle to one minute. Voltage sags are mostly caused by system faults and starting of induction motor of large rating. It may be also caused by switching operations associated with a temporary disconnection of supply, the flow of heavy current associated with the starting of a large electric motors or the flow of fault currents or the transfer of load from one power source to another. These events may emanate from customers’ systems or from the public supply network. The main cause of momentary voltage dips is probably the lightning strike. Each of these cases may cause sag with a special characteristics (magnitude and duration). Figure 1.1 shows a waveform depicting voltage sags.

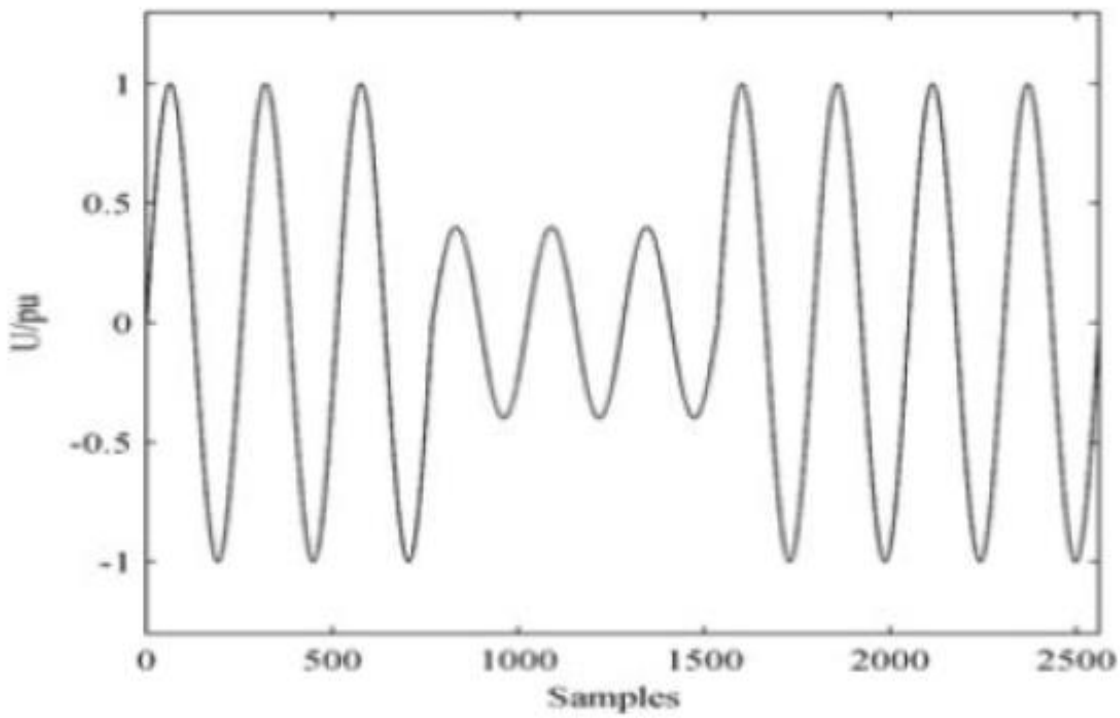

Figure 1: Voltage sag waveform

- The possible effects of voltage sags are:
- Extinction of discharge lamps
- Malfunctions of electrical low-voltage devices
- Computer system crash
- Tripping of contactors.

With the development of more electric aircraft, the aviation power capacity is increasing. Meanwhile, power electronic devices have been more widely used in aircraft power system, which brought harmonic, reactive and imbalance problems to aircraft grid. These problems will seriously affect the quality of the aircraft power supply, degrade performance and service life of power generation equipment and electrical equipment, and even threaten the safe operation of the entire aircraft electrical system. Therefore, to solve the aircraft grid harmonic, reactive and unbalanced problems, and ensure the quality of aircraft power supply system, the maintenance of the maintain the stability and reliability of the power system has become a hot issue in aircraft power research. Harmonic has the variety and complexity in advanced aircraft and current harmonic reduction methods are insufficient. The source and harm of aircraft grid harmonic, the current common harmonic reduction methods and its problems are to be analyzed. The application of active power filter in aircraft grid harmonic reduction, and the prospective development and research orientation of this new method are to be discussed. The main harmonic source of power system is the generator and inverter. In actual operation of brushless alternator, magnetic field distribution is not exactly sinusoidal, thus the induced electromotive force is not an ideal sine wave, and the output voltage contains a certain content of harmonic. The frequency and amplitude of this harmonic depends only on the structure and operation of the generator itself, substantially independent of the external load, and can be seen as a harmonic voltage source (Emadi 2000).

VSCF power system adopts inverter to convert variable frequency AC into constant frequency AC. There are two kinds of the inverters: AC-AC inverter and AC-DC-AC inverter. As the AC-AC inverter adopts phase control, its harmonic component is very complex. In addition to containing the integer harmonic content, it also contains inter-harmonics (Penget al 1993). AC-DC- AC inverter converts DC power into AC power first and then reverse, the process of rectification and inversion will produce a lot of harmonic. The main harmonic source in power distribution systems is the vertoro. A typical vertoro consists of three-phase step-down transformer and diode Rectifier Bridge. With the development of power electronic technology, large number of electronic vector is used. Electronic vertoro is actually a DC converter isolated, and there is a rectifier circuit at its input end.

1.2 VOLTAGE SWELL

Voltage Swell is defined as an increase in R.M.S voltage between 110 % to 180% at the power frequency for durations from 0.5 cycles to 1 min. They appear on the switching off of a large load; energizing a capacitor bank; or voltage increase of the un faulted phases during a single line-to ground fault. Figure 1.2 shows a waveform of voltage swell.

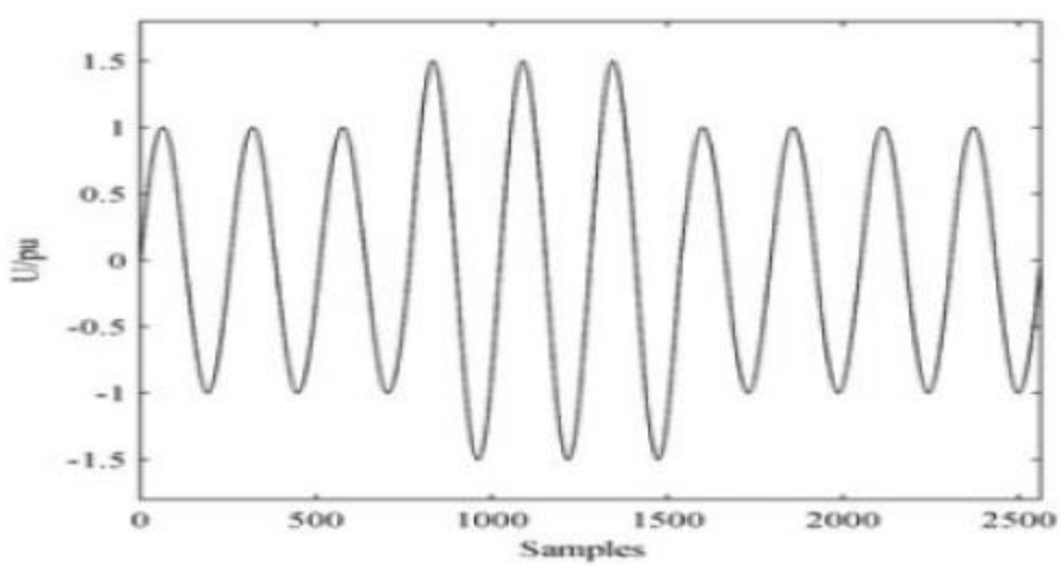

Figure 2 Voltage swell waveform

On account of the strict prerequisite of energy quality at the info air conditioning mains, a few benchmarks have been produced and implemented on the purchasers. In view of the seriousness of energy quality issues some different choices, for example, detached channels, Active Filters (AFs), and cross breed channels alongside customary rectifiers have been broadly grown, particularly in extensive rating and as of now existing establishments. Notwithstanding, these channels are very expensive, cumbersome and have sensible misfortunes, which decrease general proficiency of the total frameworks. Indeed, even now and again the rating of converter utilized as a part of dynamic channels is near the rating of the heap. Under such conditions, it is viewed as better choice to utilize such converters as an inalienable piece of the arrangement of AC-DC change, which gives lessened size, high productivity, and very much controlled and directed DC to give agreeable and adaptable operation of the framework. It is viewed as an opportune endeavor to introduce a wide point of view on the status of air conditioning dc converters innovation for the designers utilizing them and managing power quality issues.

The converters are classified into several subcategories .The first one is general on power quality standards, other options, texts and some surveys and comparative topology publications. The second and third categories are on unidirectional and bidirectional power flow ac-dc converters. These converters are further sub classified as boost, buck, buck boost, multilevel and multi pulse ac-dc converters. The total number of configurations of these converters is divided into ten categories.

1.3 BASIC PWM STRATEGY AND PERFORMANCE INDICES

PWM has become an accepted control strategy and is preferred in almost all power conversion systems. It is an operation performed on ‘raw’ voltage and current waveforms to shape their spectra in a way beneficial to a particular application. Spectra shaping involves the creation of a ‘dead band’ between wanted and unwanted components. This may drastically increase the switching frequency of the devices and may even de-rate them. A PWM strategy should aim at a wide range of linear operation, minimum number of switching, reduced content of Lower Order Harmonics (LOH) and lowered distortion in both voltage and current waveforms. A control strategy should be designed in such a way that the system offers an output voltage spectrum as shown in Figure 1.

Past four decades variety of PWM techniques suitable for the demands have been developed and discussed. The basic method is called Sinusoidal Pulse Width Modulation (SPWM) (Ned Mohan 2003), where the angular width of the pulses varies in sine fashion. SPWM technique enjoys an assortment of advantages such as high output quality, less THD, low distortion and low rating filter component.

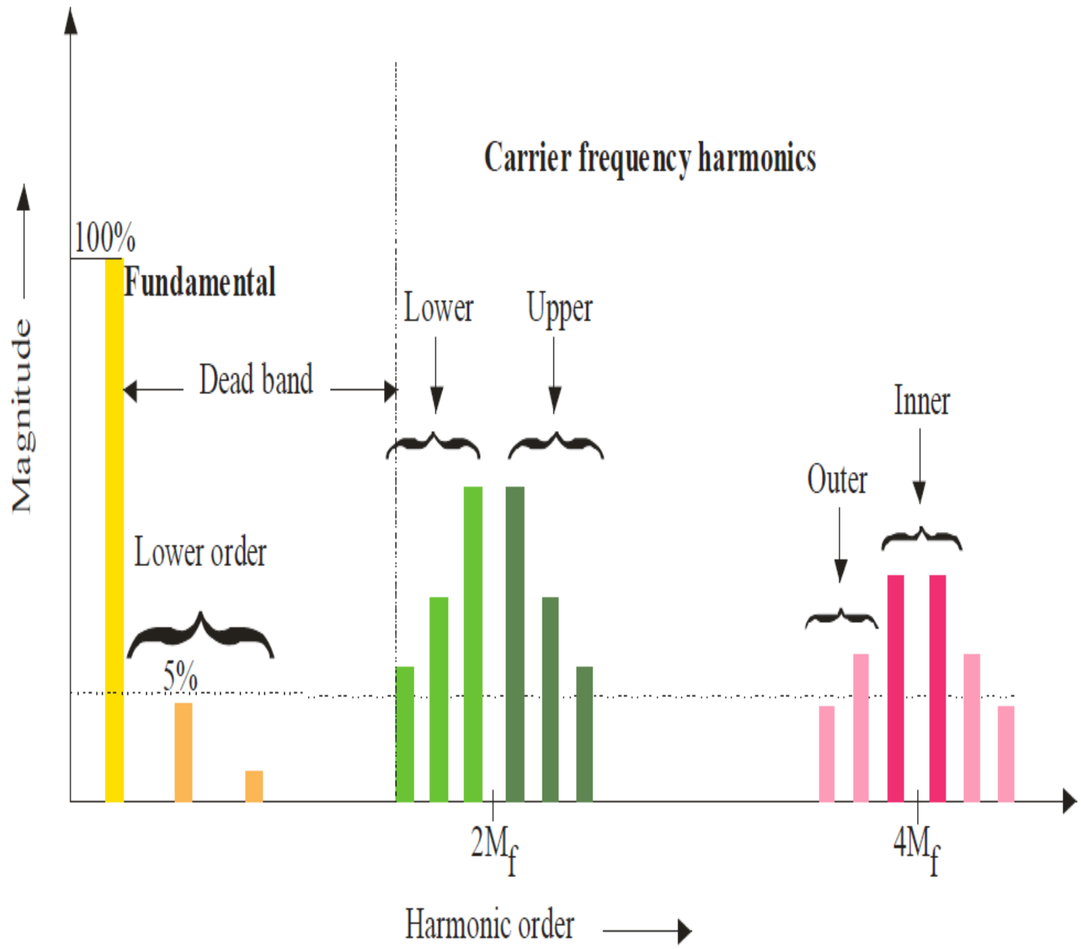

Figure 3: Desired frequency spectrum in a PWM converter

Reported VSI-PWM strategies are different in concept and performance, and designed towards achieving any one of the following objectives.

- Reduced THD
- Easy to predict the position of dominant harmonic
- Distribution of harmonic power
- Feasibility of accurate digital implementation
- Control over the harmonic spectrum

2. *PROPOSED METHODOLOGY*

In many references, Voltage source inverter (VSI) is used due to the appropriate output voltage with low harmonics level. The main defect of VSI is its reducing characteristics whose maximum output voltage is limited by DC link voltage. This means that the compensation ability of DVR decreases when the DC link voltage falls due to energy reduction in energy storage element. A DC-DC boost converter application between inverter and the energy storage element is proposed. Using boost converter leads to an increase in size, price and integration of system. In it is proposed to apply a Z-source inverter (ZSI) instead of VSI. Z-source inverter is a new converter with some special advantages, presented recently as a substitution to conventional converters.

The unique features to the Z-Source Inverter are:

- The ZSI provides the buck-boost function by one-stage conversion.
- In this technology unwanted on and off by EMI noise will not destroy the converter.
- The ZSI has the advantages of both VSI and Current Source Inverter (CSI).
- It solves the problems of the traditional converters.
- The ZSI has low or no in-rush current as compared to the VSI and CSI.
- Due to low losses efficiency of the system is improved.

2.1. DVR Using Z Source Inverter

As shown in Figure 2, DVR is composed of a Z source inverter, an energy storage element, LC filter, and a transformer. Vs is the source voltage, VL is the load voltage after compensation, Vdvr is the series injected voltage of the DVR. The function of the DVR is to injecting three single phase AC voltages in series with the three phase incoming network voltages during sag, compensating for the difference between faulty and nominal voltages. All three phases of the injected voltages are of controllable amplitude and phase. The series injected voltage of the DVR (Vdvr) is synthesized by modulating pulse widths of the inverter bridge switches. The injection of an appropriate Vdvr in the voltage disturbance requires a certain amount of real and reactive power supply from the DVR. This enables full voltage restoration during sag.

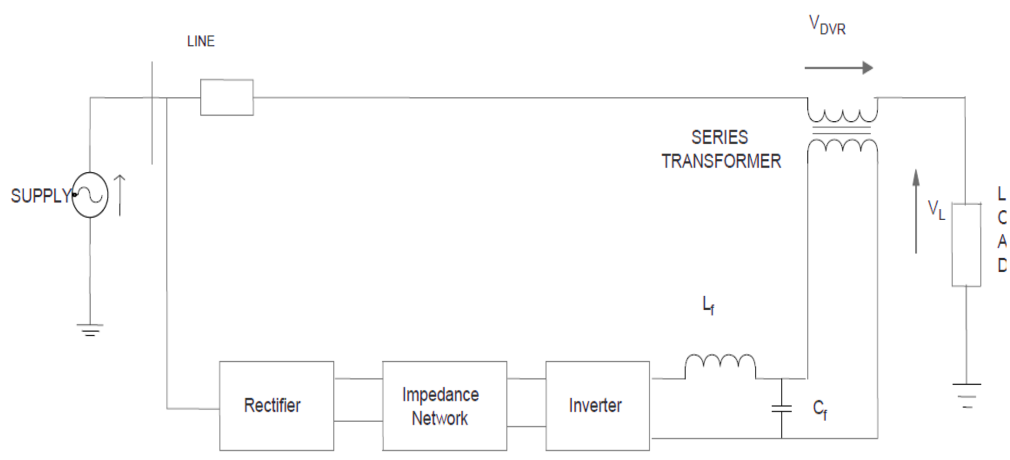

Figure 4: Z-source based structure of DVR

During normal condition, the DVR operates in a standby mode with low loss. In this condition (no sag) the low voltage side of the booster transformer is shorted either by solid state bypass switch or by switching one of the inverter legs and it functions as a short-circuited current transformer. Since no ZSI switching takes place, the DVR produces conduction losses only.

These losses should be kept as low as possible so as not to cause steady state power loss. The required energy during sags has to be supplied by an energy source. The necessary amount of energy that must be delivered by the energy source depends on load MVA requirement, control strategy applied, deepest sag to be protected. Under normal conditions, the short circuit impedance of the injection transformer determines the voltage drop across the DVR.

Generally Pulse-Width Modulated Voltage Source Inverter (PWM VSI) is used. The most common inverter topologies are the two- or three-level three-phase converter where the dc-side capacitor(s) is connected alternately to all ac phases. The inverter configuration, switching and output waveforms for the fundamental switching are shown in Figure 5.

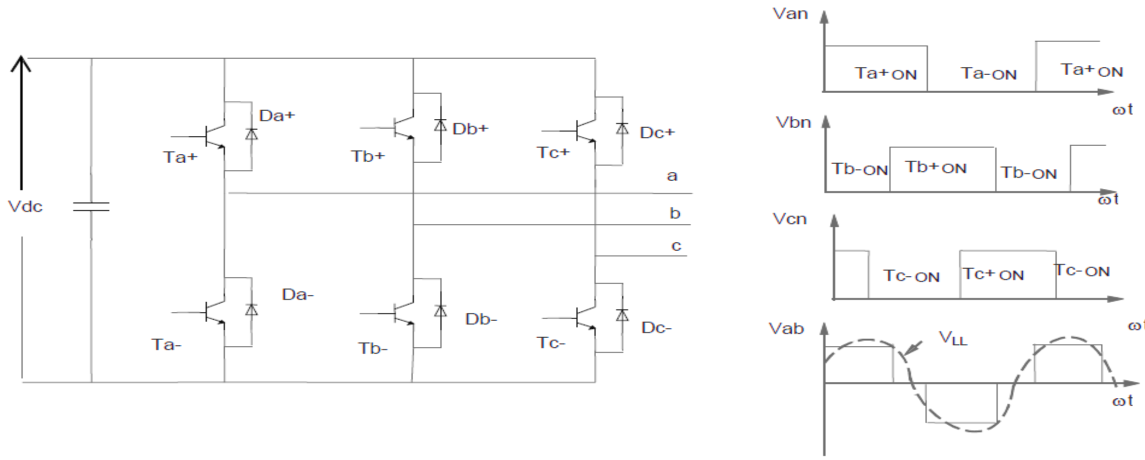

Figure 5: Three phase Inverter and its switching arrangement

This is referred to as two-level since the phase output voltage waveform consists of two output levels; +Vd and 0 Volts The basic function of the VSI is to convert the DC voltage supplied by the energy storage device into an AC voltage. In the DVR power circuit step up voltage injection transformer is used. Thus a VSI with a low voltage rating is sufficient [7]. In three phase inverter each leg is switched according to the PWM technique used. In the case of fundamental switching is used then the switches are ON for a period of 180o with a duty ratio of 50%. The purpose of the capacitor is to absorb harmonic ripple and hence, it has a relatively small energy storage requirement, particularly when operating in balanced conditions. The size of this capacitor has to be increased, if needed, to provide voltage support in unbalanced conditions. Also, since the capacitor is shared between the three phases, sag on only one phase may cause a distortion in the injected current waveforms on the other phases.

2.2. Impedance Network

Figure 4 shows the Impedance network. In this network, L1 and L2 are series arms inductances, C1 and C2 are diagonal capacitances. This is a two port network that consists of split inductors L1 and L2 and capacitors C1 and C2 connected in X-shape.

This network is coupled between the main inverter circuit and the source. The Impedance Source Network is a combination of two inductors and two capacitors. This combined circuits; 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 than the traditional inverters. A brief discussion is given below in terms of physical sizes and requirements.

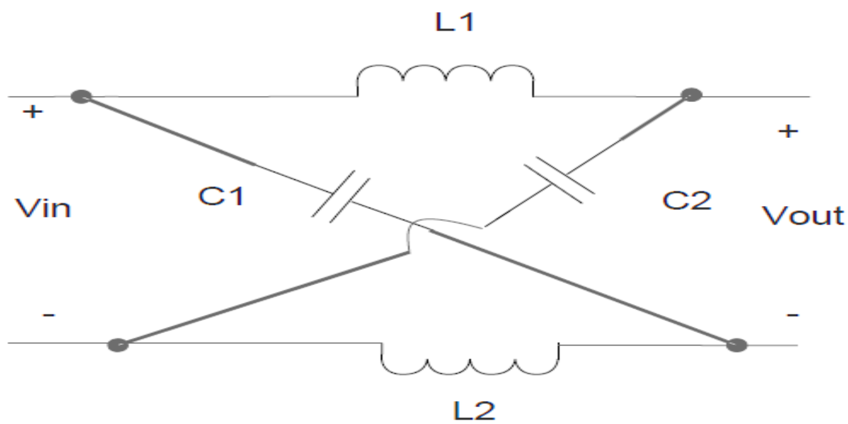

Figure 6: Impedance Network

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. Therefore, a traditional voltage source inverter's capacitor requirements and physical size is the worst-case requirement for the Impedance Source network. Considering additional filtering and energy storage provided by the inductors, the Impedance source network should require less capacitance and smaller size compare with the traditional voltage source inverter. 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, a Current Source Inverter's inductor requirements and physical size is the worst case requirement for the impedance source network. Considering additional filtering and energy storage by the capacitors, the Impedance Network should require less inductance and smaller size compared with the traditional Current Source Inverter.

3. MATHEMATICAL MODELING OF Z SOURCE INVERTER

Assume the inductors (L1 and L2) and capacitors (C1 and C2) have the same inductance and capacitance values respectively to make the Z source network symmetrical.

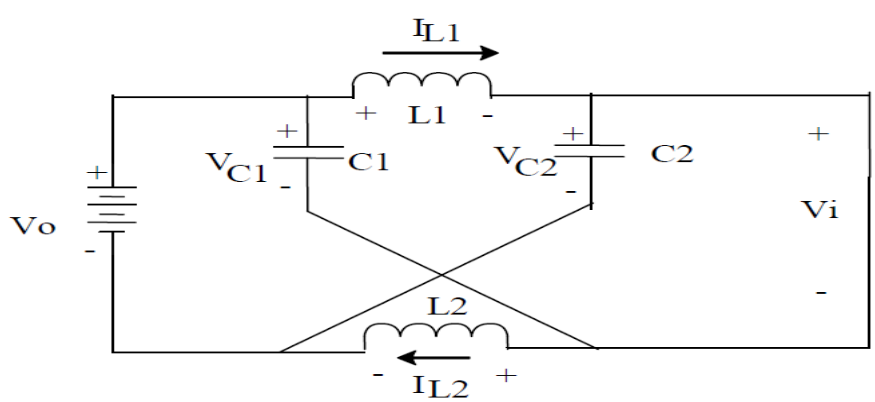

Figure 7: Equivalent circuit of Z Source Inverter

From the above equivalent circuit shown in Figure 4 following equations from (1) to (4) can be derived

$$L_1 = L_2 = L \tag{1}$$

$$C_1 = C_2 = C \tag{2}$$

$$V_{L1} = V_{L2} = V_L \tag{3}$$

$$V_{C1} = V_{C2} = V_C \tag{4}$$

Where V_L is the inductor voltage and V_C is the capacitor voltage.

Consider the Z source inverter is operating in shoot through mode for an interval of T0 during a switching cycle T. In this state both switches of any one phase leg, any two phase legs are conducting. It is inserted in every switching cycle by PWM control. This shoot through state is only a fraction of the switching cycle. Figure 5 shows the equivalent circuit of ZSI under the shoot through mode.

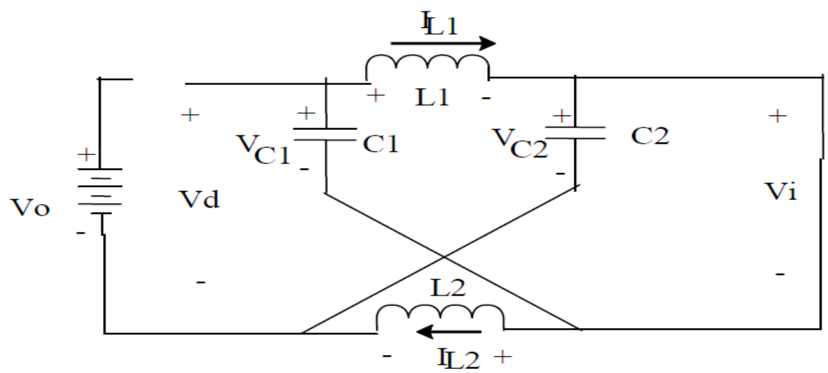

Figure 8: Equivalent circuit of ZSI in shoot through mode

4. RESULTS AND ANALYSIS

From the Figure 6, clearly, the output voltage can be bucked or boosted by controlling the duty ratio, D. Duty ratio control. In addition, the output voltage can be in-phase or out-of-phase with the input voltage depending on operating regions of the duty cycle. This is a unique feature of the Z-source converter. Simulation result of the MATLAB Simulation model three level and three-phase inverter is shown.

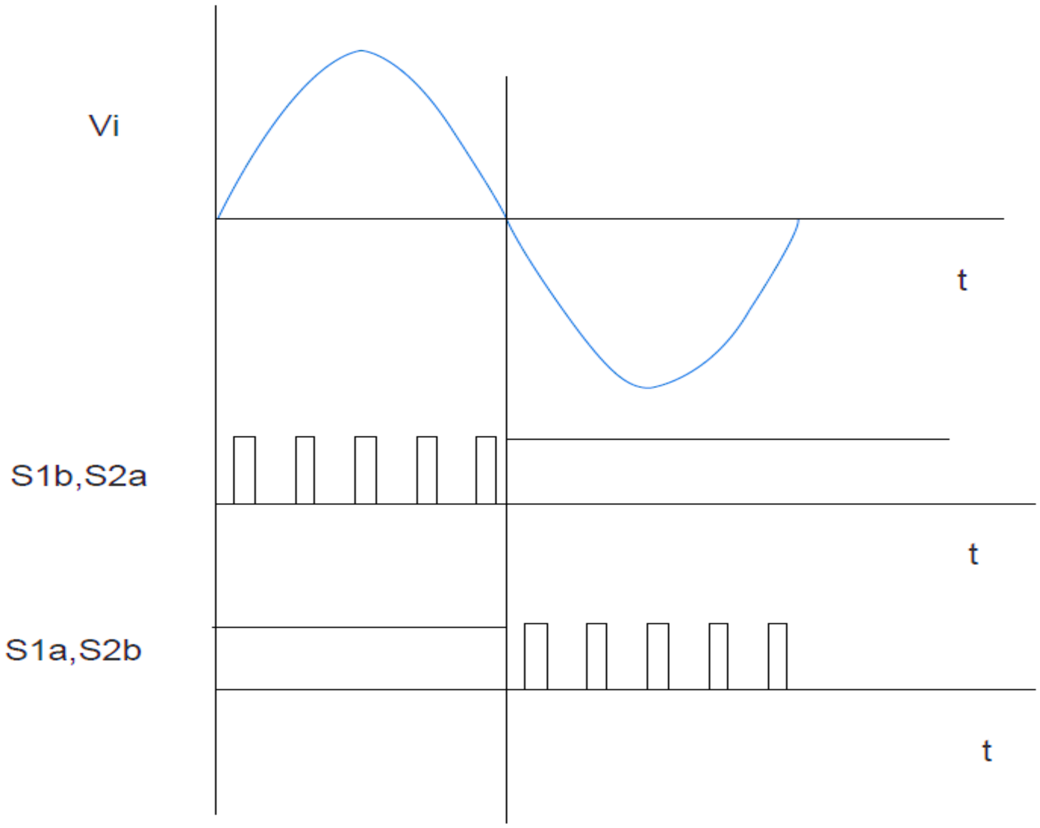

Figure 9: Switching of single phase AC-AC converters

First a case of symmetrical sag is simulated .A 30% voltage sag is imitated at t=1.5 ms and it is kept until t=2.0ms as shown in the Figure and the corresponding input current is shown in the Figure 7.

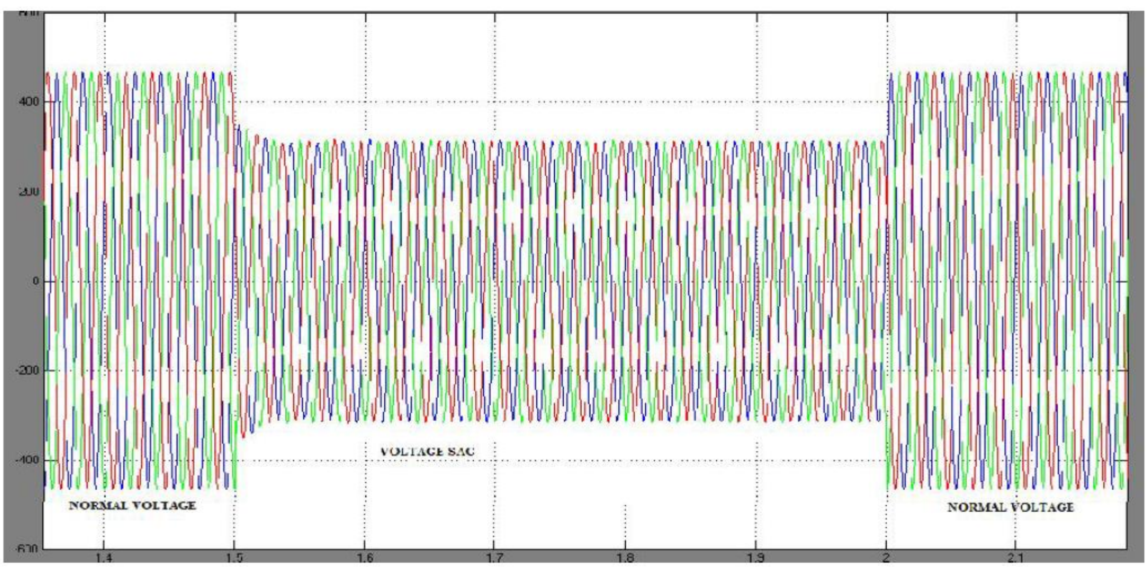

Figure 10: Supply Voltage during sag in VSI based DVR

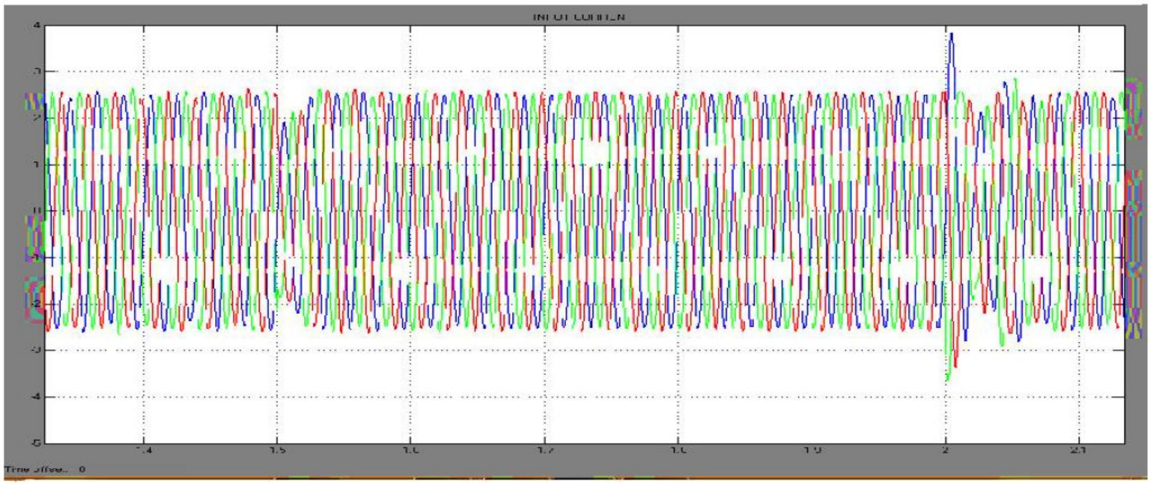

Figure 11: Supply current during sag in VSI based DVR

The Figure 8 show the voltage injected by the DVR and the Figure 9 and 10 show the load voltage with compensation and corresponding load current. As a result of DVR, the load voltage is kept constant throughout the simulation including the voltage sag period. Observe that during normal operation, the DVR is doing nothing. It quickly injects necessary voltage components to smooth the load voltage upon voltage sag.

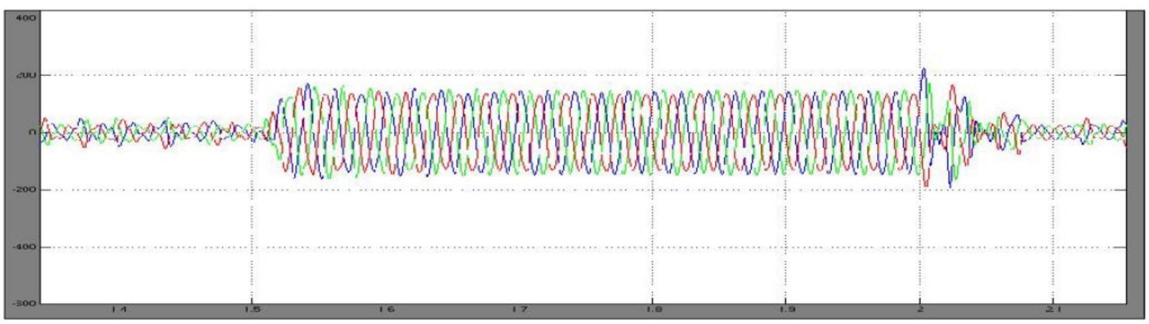

Figure 12: Voltage Injected by VSI DVR during sag

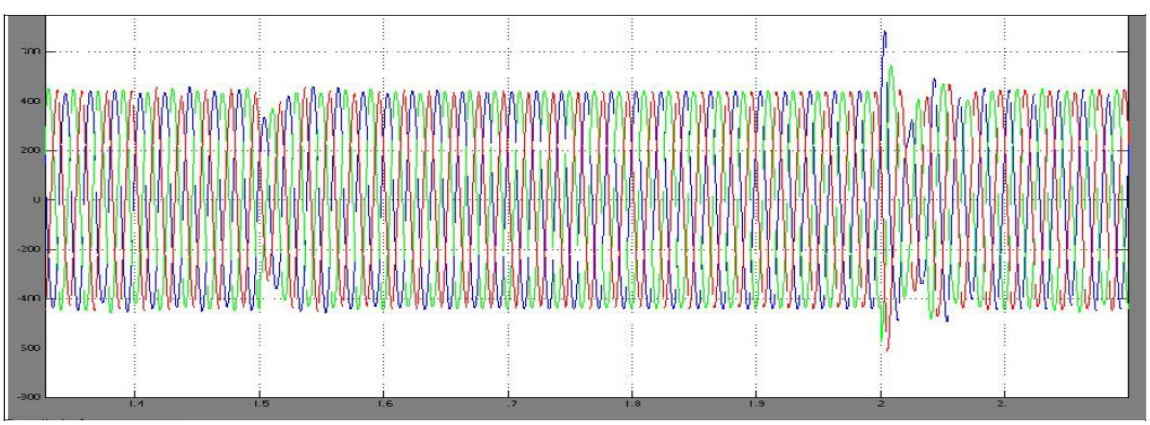

Figure 13: Compensated Load Voltage in VSI based DVR

The application of Z-source inverter is proposed in this paper, in order to optimize DVR operation. The compensation capability of a dynamic voltage restorer primarily depends on the maximum voltage injection ability and the amount of stored energy available within the restorer. Z source inverter is introduced to enhance the voltage compensation capability of DVR and to ensure the constant dc link voltage. The proposed system is simulated under voltage sag and swell. The simulation results show that Z source inverter overcomes the drawbacks of voltage and current source inverter.

5. CONSLUSION

Dynamic voltage restorers (DVR) are used to protect sensitive loads from the effects of voltage sags and voltage swells on the distribution feeder. The DVR is a cost – effective device which is placed in series with a sensitive load, must be able to respond quickly if end users of sensitive equipment are to experience voltage sags/swells.

REFERENCES

[1] R. Hariharan, M. Chakkarapani, G. Saravana Ilango and C. Nagamani, “A Method to Detect Photovoltaic Array Faults and Partial Shading in PV Systems”, IEEE Journal of Photovoltaics, IEEE 2021.

[2] Taeyong Kang, Sewan Choi, Ahmed S. Morsy, Prasad N. Enjeti, “Series Voltage Regulator for a Distribution Transformer to Compensate Voltage Sag/Swell”, IEEE 2021.

[3] A. Rauf and V. Khadkikar, “An enhanced voltage sag compensation scheme for dynamic voltage restorer,” Industrial Electronics, IEEE Transactions on, vol. 62, pp. 2683–2692, May 2021.

[4] S. Jothibasu and M. K. Mishra, “An improved direct AC–AC converter for voltage sag mitigation,” IEEE Trans. Ind. Electron., vol. 62, no. 1, pp. 21– 29, Jan. 2020.

[5] J. Kaniewski, P. Szczesniak, M. Jarnut, and G. Benysek, “Hybrid Voltage Sag/Swell Compensators: A Review of Hybrid AC/AC converters,” IEEE. Industrial Electronics. Magazine, vol. 9, pp. 37–48, 2020.

[6] Radi, M.A., Darwish, M.; Alqarni, M. "Voltage regulation considerations for the design of hybrid distribution transformers," Power Engineering Conference (UPEC), 49th International Universities, On page(s): 1–6, 2014.

[7] J. Kaniewski, Z. Fedyczak, and G. Benysek, “AC voltage sag/swell compensator based on three-phase hybrid transformer with buck-boost matrix-reactance chopper,” IEEE Trans. Ind. Electron., vol. 61, no. 8, pp. 3835–3846, Aug. 2014