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Performance Evaluation of Dynamic Voltage Restorer Based on Transformer-based Z Source Inverter

Deshpande Chinmay V, Deshpande Chaitanya V, Deokar Sanjay A
Department of Electrical Engineering, Zeal Education Society's Zeal College of Engineering and Research, India

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ABSTRACT

In this paper, latest technology is introduced in substitution to conventional voltage and current type inverter with Transformer based impedance (Z) source inverter in voltage sag assessment and mitigation and compared with voltage source inverter based dynamic voltage restorer. Transformer based impedance source inverters (Trans-Z source inverters) are newly proposed inverters that can be used to overcome downside of voltage source inverter, current source inverter and impedance source (Z-source) inverter. T-Z source inverter consists of transformer with high frequency and low leakage inductance along with low reactive component compared with conventional Z source inverter. In case of T-Z source inverter, voltage stress throughout Z-source capacitor is reduced along with inrush current limitation at startup. This paper presents modeling of T-Z source inverter based dynamic voltage restorer using MATLAB/SIMULINK software along with its THD analysis which is compared with VSI based dynamic voltage restorer. Here abc to dq0 control algorithm is employed. The control technique which is employed for simulation shows excellent results for voltage sag and swell compensation.

Corresponding Author:

Deshpande Chinmay V.,
Department of Electrical Engineering,
ZES ZCOER, Narhe, Pune, Maharashtra, India
Email: chinmaydeshpande123@gmail.com

1. INTRODUCTION

Constant voltage is prime requirement of any customer. Most of the lodes connected to system are sensitive to voltage variation. [1] It is risky to operate the equipment below certain voltage limit. In order to supply continuous power to sensitive loads which are connected to system, number of series connected devices can be used [2]. The primary role of these devices is to supply continuous power in order to prevent it from financial losses. The device that can be used to supply constant voltage to the sensitive loads connected to system irrespective of faults and load switching and restores the voltage quickly in seconds is Dynamic Voltage Restorer [3].

Generally DVR is designed in association with voltage source inverter, current source inverter or Z source inverter. The Z source inverter is single stage power converter which provides both buck and boost facility [3]. In order to enhance reliability of system, both the power switches from same leg can be switch on simultaneously without causing problem of short-circuits which is not possible in case of conventional voltage and current source inverter. For this purpose, two capacitors and two inductors connected in unique X shape constitutes impedance part of Z source inverter [4]. But current drawn from source is discontinuous in case of conventional Z source inverter. Also voltage across Z source capacitor is more than input voltage, which results in use of high capacitor voltage capacitors which are more expensive [5].

To solve demerits in concerned with conventional Z source inverter, newly developed transformer based impedance source inverter is used along with dynamic voltage restorer which provides higher voltage gain and compact voltage stress. The proposed system along with T-Z source inverter gives less THD and higher efficiency, high power quality, along with fewer reduced voltage stress and less number of components requirement [6].

2. TRANSFORMER BASED IMPEDANCE SOURCE INVERTER

Figure 1 below indicates the design of voltage fed trans-Z source inverter. This newly developed inverter overcomes the demerits which are associated with conventional Z source inverter.

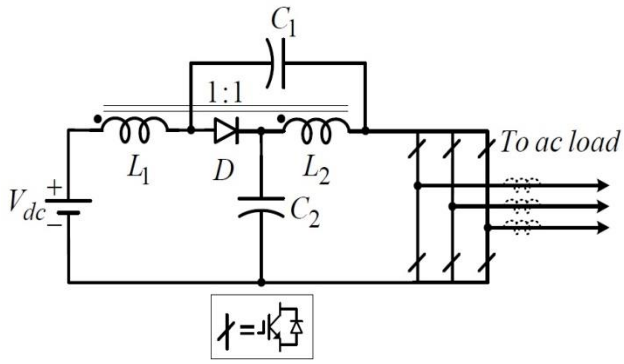


Figure 1. Transformer based impedance source inverter

In case of conventional Z source inverter, two capacitors and two inductors connected in unique X shape constitutes impedance part of Z source inverter. But in case of transformer based Z source inverter, it consists of very low leakage inductance transformer [7]. T-Z source inverter can handle shoot through states when both switches in the same phase leg are turned on. Due to the presence of low reactive component in case of proposed inverter, its efficiency is higher compared with conventional ZSI [8]. It uses only one capacitor, diode and transformer with turn's ratio n: 1 T-Z source inverter can also act in both situations like shoot through and non-shoot through mode. The main aspect of transformer based impedance source inverter [9]:

a. The X shape network present in trans-z source inverter is same as that of ZSI.
b. In TZSI, there are two transformers that can be used and by changing value of transformer's turn's ratio, one can get high boosting factor.
c. As no extra diodes are used in TZSI compared with high boost factor ZSI, its cost is less and size is reduced. Overall loss is also minimum.

2.1. Shoot through Condition

When both the switches of same phase leg get turn ON at a time, the condition is called as shoot through condition. [10] During shoot-through condition, diode D is reversed biased (Diode D is OFF) hence DC link gets separated from AC line. By controlling the interval of shoot through state, the desired voltage can be maintained at its output [11]. The shoot-through zero state contributes to the unique buck–boost feature of the inverter as shown in figure 2. The voltage across L_1 and L_2 are as follows,

$$v_{L1} = V_{dc} + V_{c1}$$

$$v_{L2} = \left(\frac{n_2}{n_1}\right) v_{L1}$$

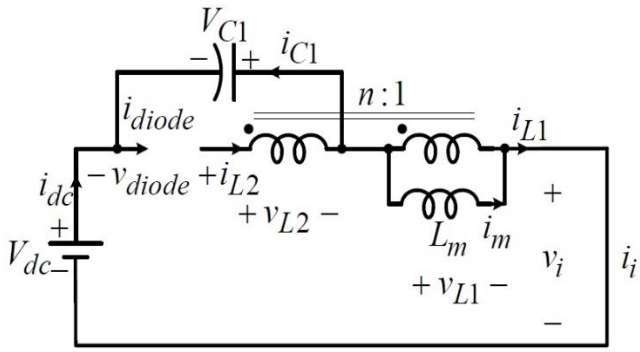


Figure 2. TZSI: Shoot through condition

2.2. Non-Shoot through Condition

Figure 3 describes non-shoot through condition. In case of non-shoot through condition, Inverter Bridge shows either any one of the traditional active states. During active states, voltage is impressed across load which conducts the diode [12]. The current source is open circuited i.e. zero value. During any one out of different non shoot-through conditions, equation obtained is as follows,

$$v_{L2} = -V_{c1}$$

$$v_{L1} = \left(\frac{n_1}{n_2}\right) v_{L2} = -V_{c1}\left(\frac{n_1}{n_2}\right)$$

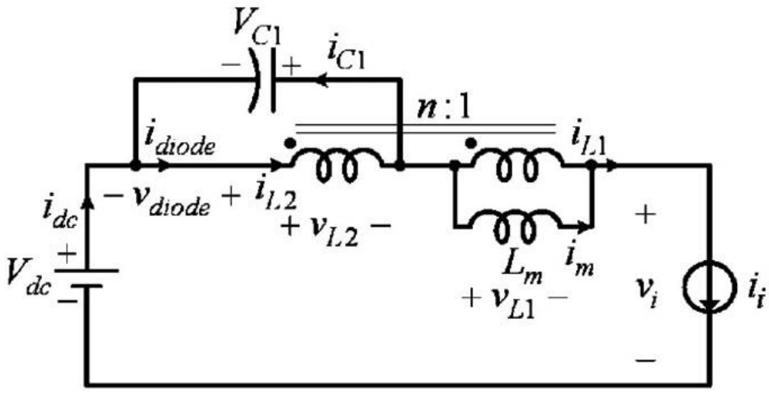


Figure 3. TZSI: Non-shoot through condition

3. IMPLEMENTATION OF NEW INVERTER TOPOLOGY: CASE STUDY

To analyze function of trans-Z source inverter in DVR for voltage sag assessment, circuit is simulated using MATLAB SIMULINK as shown in Figure 4 [13]. A line of 13 kV is step up to 115 kV for transmission purpose using two winding transformer and then it is again step down by using distribution transformer having rating of 115 kV /11 kV. While simulating, it is considered that, the load is suddenly imposed on system at feeder B for the duration of 0.04 to 0.1sec. The transition time of circuit breaker is 0.04 to 0.1 i.e. during that period only load gets acted upon line due to which voltage sag is experienced by load feeder "B". The voltage sag for the duration from 0.04 to 0.1 sec. is corrected by voltage injected from DVR.

Control scheme of DVR consist of abc to dq0 transformation. Line voltage is converted to dq0 form which is compared with set reference dq0 value. It generates the error signal which is again converted to abc form. This generated error signal is used for generation of PWM to TZSI. After TZSI, injection transformer is used which injects required amount of voltage and improves line voltage [14].

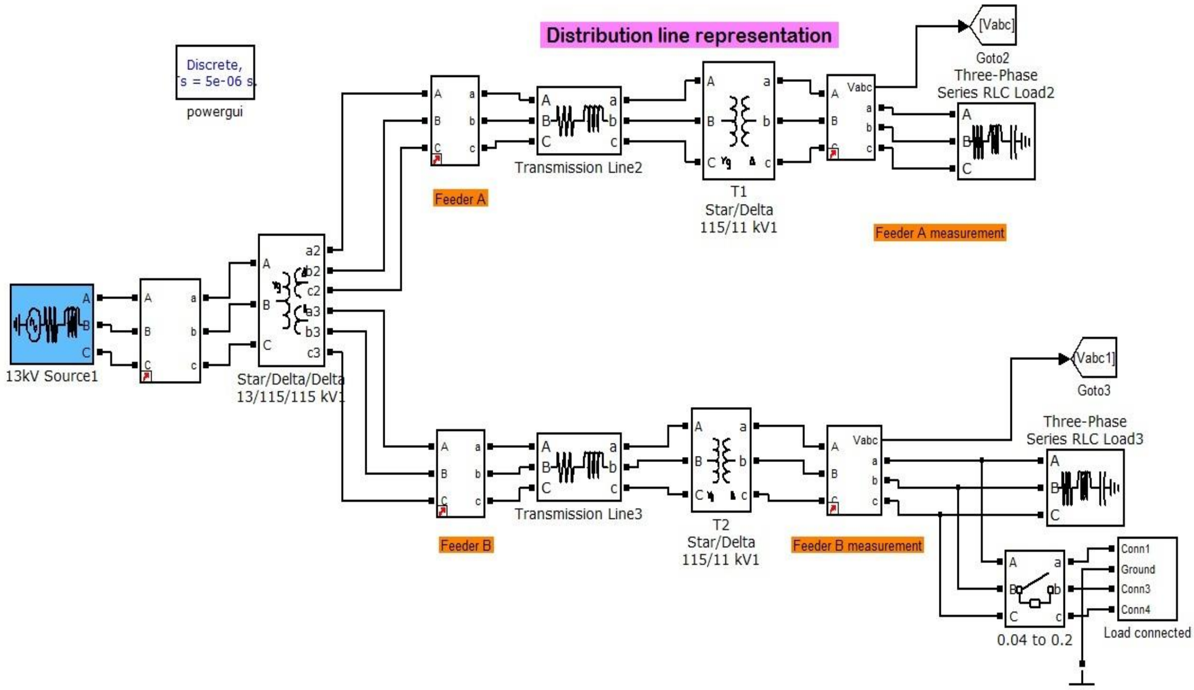
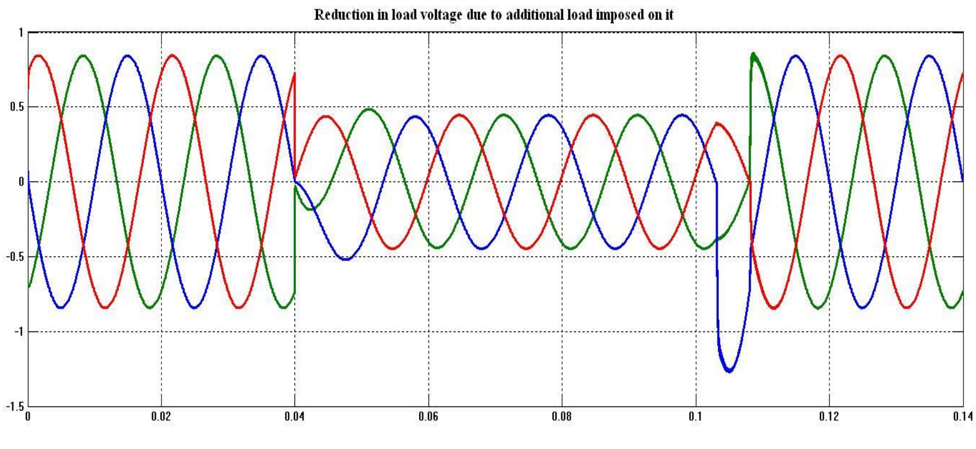


Figure 4. TZSI: Block diagram representation of distributed line model

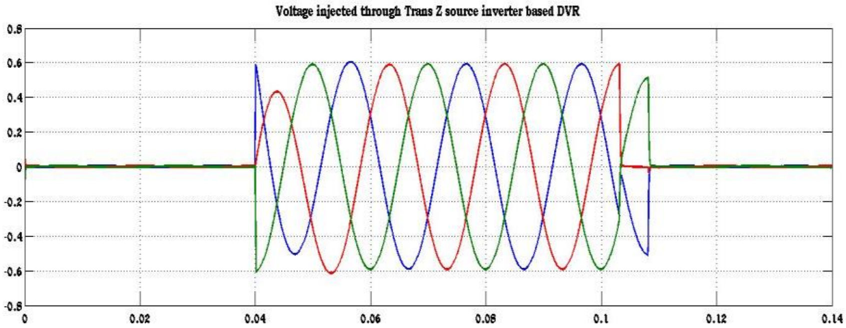
4. SIMULATION RESULTS

Following Figure 5 (a) shows Voltage sag occurs at feeder B due to sudden change in loading condition. Due to load imposed on system, suddenly voltage drops which results in voltage sag condition. Figure 5 (b) shows required amount of voltage which need to be injected through DVR to the system in order to maintain supply side voltage. After injecting voltage into the system, corrected supply side voltage maintains as shown in Figure 5 (c). By comparing proposed system with conventional VSI based DVR, it has been observed that even in case of shoot through condition, TZSI operates efficiently without causing short circuit. THD analysis shows that TZSI is better option in substitution to VSI topology.

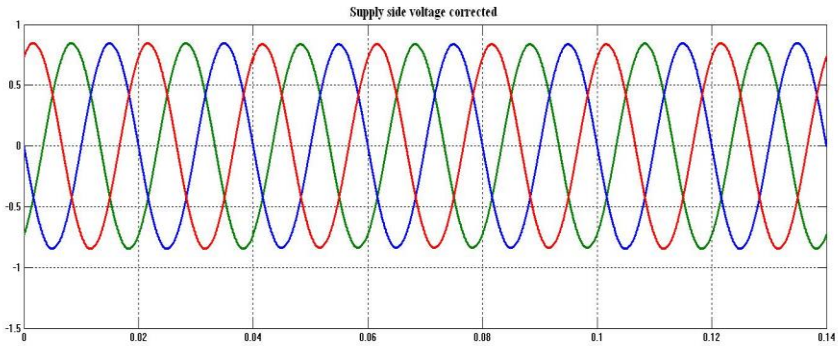


(a)

Figure 5. Voltage waveforms of operation of DVR, (a) Occurrence of voltage sag at feeder B due to sudden change in load, (b) Injected voltage at feeder B through Trans-Z source inverter based DVR, (c) Corrected voltage at feeder B



(b)



(c)

Figure 5. Voltage waveforms of operation of DVR, (a) Occurrence of voltage sag at feeder B due to sudden change in load, (b) Injected voltage at feeder B through Trans-Z source inverter based DVR, (c) Corrected voltage at feeder B

Whenever load on the system increases, there is reduction in voltage value. As voltage drops, current during that period increases as shown in Figure 6.

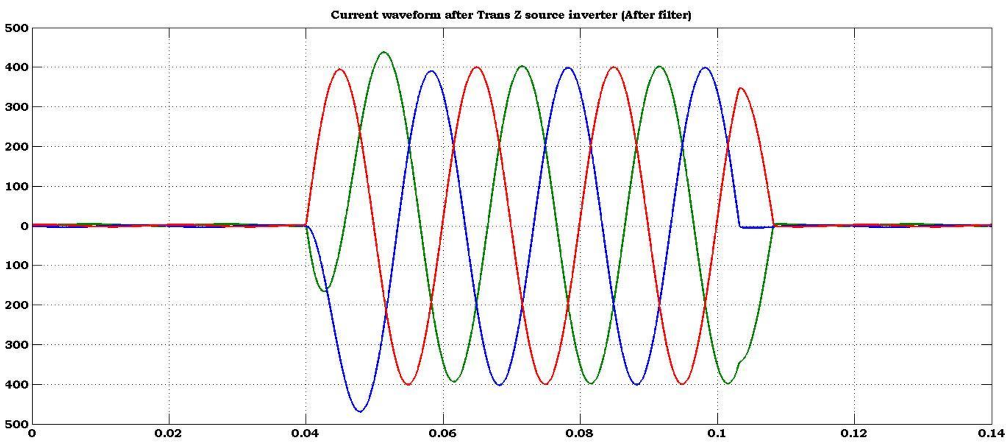
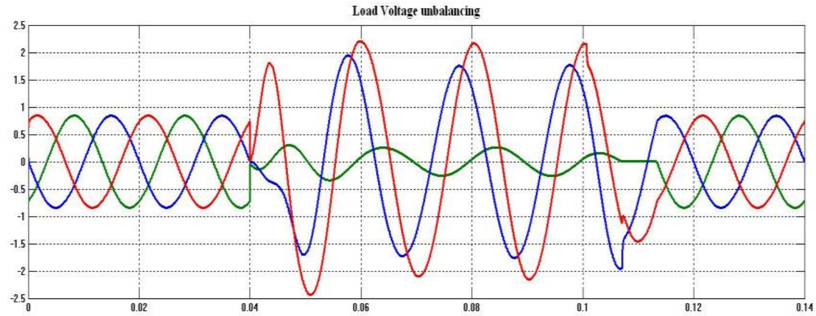
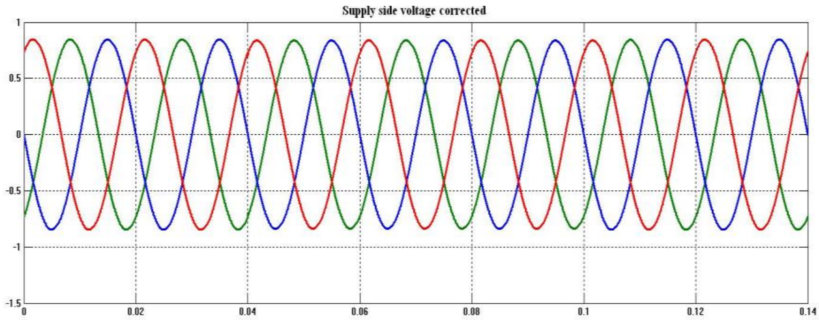


Figure 6. Current waveform during voltage sag period

The trans-Z source inverter based DVR is also capable to inject voltage for balance as well as unbalanced situation. Various unbalanced conditions are analyzed which can be shown in Figure 7 and Figure 8 respectively.

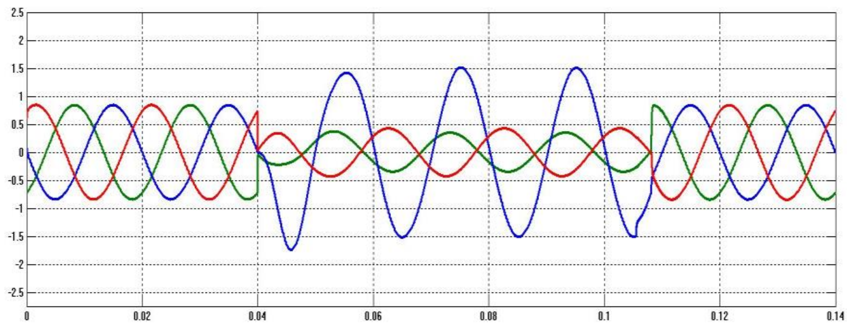


(a)

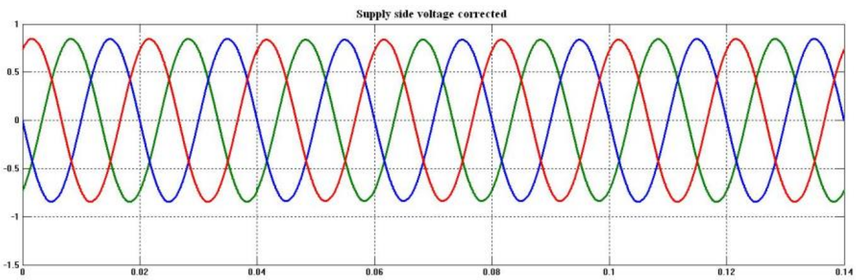


(b)

Figure 7. Voltage waveform during unbalanced voltage sag condition (unbalance in one phase),
(a) Drop in voltage value, (b) Correction in voltage at feeder B by injection through TZSI based DVR



(a)



(b)

Figure 8. Voltage waveform during unbalanced voltage sag condition (unbalance in two phases),
(a) Drop in voltage value, (b) Correction in voltage at feeder B by injection through TZSI based DVR

5. THD ANALYSIS

Following Table 1 show FFT analysis of DVR based on VSI and TZSI inverter topologies. From the values of THD, one can say that by implementing TZSI over VSI, it gives fewer amounts of harmonics.

Table 1. Voltage and current THD analysis for VSI and TZSI based DVR

Type of Inverter	Voltage THD (%)	Current THD (%)
Voltage source inverter	15.09%	2.70%
Trans-Z source inverter	0.02%	2.60%
Type of Inverter	Voltage THD (%)	Current THD (%)

It has been observed that reduction in voltage THD and current THD for Trans-Z source inverter is of 99.86% and 3.70% respectively compared with VSI topology.

6. CONCLUSION

This paper presents transformer based impedance source inverter along with dynamic voltage restorer for voltage sag assessment. The proposed system provides buck, boost and inversion operation at single stage. It is compared with conventional VSI based DVR. From THD analysis, it has been observed that there is significant reduction in voltage and current THD which are within specified limit as per IEEE standard (% Voltage THD = 0.02% and % Current THD=2.60%). Trans-Z source inverter provides higher boosting voltage ability and improves the reliability by reducing the output waveform distortion, increases efficiency and reduces number of components requirement compared with conventional Z source inverter due to which system becomes cost effective. A MATLAB / SIMULINK result shows that response of system has also improved whenever it is replaced from VSI to trans-Z source inverter.

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BIOGRAPHIES OF AUTHORS

Mr. Chinmay V. Deshpande received his BE degree in Electrical Engineering from Savitribai Phule University (formerly Pune University) - India in 2013, and is ME in Electrical Power Systems from Savitribai Phule University (formerly Pune University) – India in the year of 2015. Currently he is working in Department of Electrical Engineering at Zeal Education societies, Zeal college of Engineering and Research as Assistant Professor. His field of interest includes Power Systems and Power Quality, FACTS, Machine design.

Mr. Chaitanya V. Deshpande received his BE degree in Electrical Engineering from Savitribai Phule University (formerly Pune University) - India in 2013, and is ME in Electrical Power Systems from Savitribai Phule University (formerly Pune University) – India in the year of 2015. Currently he is working in Department of Electrical Engineering at Zeal Education societies, Zeal college of Engineering and Research as Assistant Professor. His field of interest includes Power Systems, FACTS.

Dr. Sanjay A. Deokar received his BE degree in Electrical Engineering from Walchand College of Engineering, Sangali, Shivaji University. He has completed ME in Electrical Power systems from PVG’s College of Engineering and Technology, Pune, Savitribai Phule University (formerly Pune University) – India in 2006. He has received Ph.D from SRTM University at SGGS COET; Nanded. He is certified energy auditor. He has total teaching experience of 24 years. Currently he is working as campus director Zeal Education societies, Zeal college of Engineering and Research. His field of interest includes Power Systems and Power Quality.