# Comparative Analysis of Conventional, FWZSI and ZSMLI Based UPS Systems

**Suresh.V, Senthil Kumar. R**

***Abstract:*** ***The UPS systems always have the drawbacks such as higher switching stress, higher THD value and lower efficiency when normal inverters used. Four wire z-source inverter (FWZSI) and z-source multilevel inverter (ZSMLI) are proposed for UPS application to overcome these problems. A comparison is carried out between the proposed FWZSI and ZSMLI with the conventional power converters for UPS systems. The comparison is made based on voltage boost, dc link voltage, ripples in capacitor voltage and inductor current, voltage stress across power switches, power quality and power conversion efficiency . Also the shoot through pulse insertion in the four wire Z-source inverter and z-source multilevel inverter are compared and analyzed in detail. The performance of proposed and conventional power converters are compared for different values of input and output conditions. The results for each scheme are verified with the laboratory experimental set up [1], [2].***

***Keywords: FWZSI, ZSMLI, UPS, Voltage stress, THD.***

## I. INTRODUCTION

UPS Provides quality sinusoidal signal during voltage sag and power quality problems in AC mains (EB). During these periods the traditional power converters in the UPS systems are not efficient to provide quality Output. Traditional PWM inverter in UPS having dead time creates waveform distortion and hence power quality problems with introduction of harmonics and torque ripples [3]. During unbalanced conditions, the input side and output load side create lot of troubles in power quality. Traditionally electricity board neutral wire is used as the fourth wire of UPS system. In case of any power failure in the AC mains, the fourth wire is isolated. For this situation four wire inverter (FWI) and four wire Z-source (FWZSI) inverter are introduced. Four wire inverter (FWI) over comes the power quality issues during unbalanced load conditions.However this is inefficient during voltage sag conditions [4].The proposed Z – Source four wire system shown in Figure 1 provides quality output during voltage sag and unbalanced conditions in AC mains and load side. Z- Source inverter (ZSI) operates in boost mode during both voltage sag and power failure and also it acts as a four wire inverter during normal operation to further improve the performance of UPS system [5].The Z source multilevel inverter is shown in Figure 2.To predict the suitable power converter for UPS system, comparison is made between the proposed ZSFWI and ZSMLI with the conventional three-stage power converters for UPS systems. The comparison is carried out based on voltage boost, dc link voltage, ripples in capacitor voltage and inductor current, voltage stress across power switches, power quality and power conversion efficiency and also the shoot through pulse insertion in the Z-Source four wire inverter [6, 7, 8, 9].

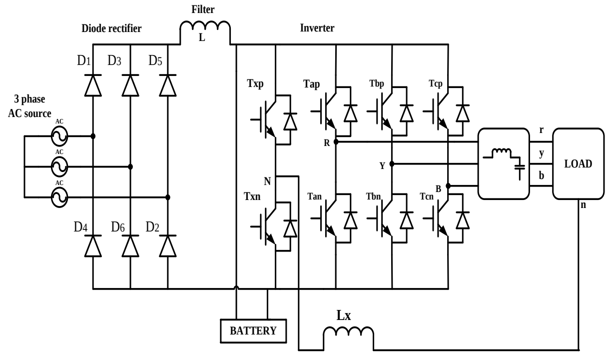


**Figure 1:Three Phase Four Wire Inverter**

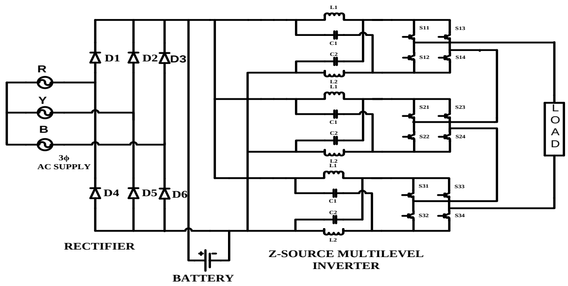


**Figure 2:Z-Source Multilevel Inverter based UPS System.**

## II. SHOOT THROUGH INSERTION

Both the FWZSI and ZSMLI always operate in buck-boost mode. According to the input voltage, the shoot through distribution and insertion of PWM pulses in FWZSI and ZSMLI are varying as shown in Figures 3. Shoot through duty ratio, shoot through time period and modulation index are determined in accordance with the data available in the look up table [10].From Figure 3 for same value of input voltage, the shoot through period requirement of ZSMLI is 10% is lesser than ZSI. This higher value of shoot through period in ZSI leads to increased switching stress. Similarly the high switching frequency duty cycle of buck – boost chopper also increases the switching stress and increases the THD in output voltage[10]-[13].Figures 5 to 7 show the simulated terminal

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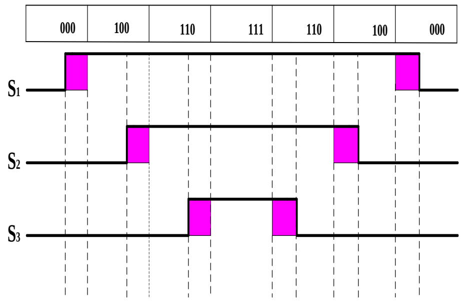
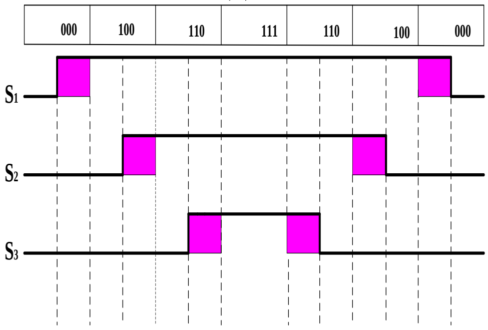
voltage waveforms of conventional PWM inverter, ZSI and ZSMLI for the input voltage of 200 V. It could be seen that for the same input voltage the ZSMLI output voltage is almost sinusoidal but FWZSI and conventional power converter outputs are stepped waveforms. Hence, to filter the harmonics, later two systems require larger size filters [14,15]. Experiments were conducted to verify the validity of the conventional power converter, FWZSI and ZSMLI. In ZSI and ZSMLI the modulation index M is equal to 0.7 and D0 varies from 0.1 to 0.3. The conventional SVPWM based VSI and boost chopper are fabricated for an output power of 3 kW. Figure 8 to 10 shows the experimental waveforms of conventional and proposed power converters line and phase voltages. From the Figures 5 to 7 it is clear that the simulation results very well coincide with experimental results [16].




(a)

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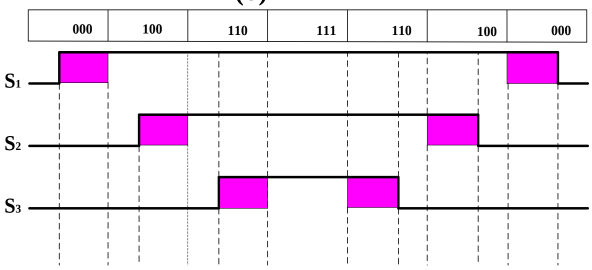
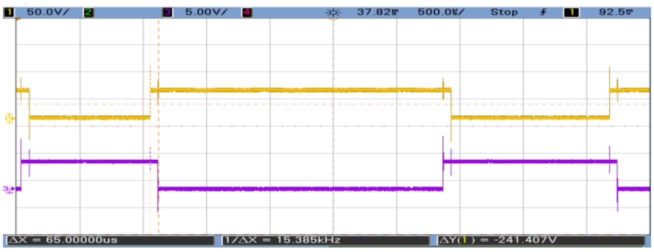



(c)

**Fig. 3:Distribution of Shoot Through Pulses in MSVPWM of ZSI**



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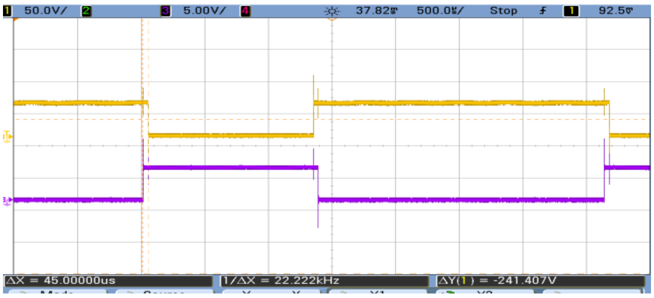


(b)

**Fig. 4 :Experimental Pulse Pattern for FWZSI for Shoot Through Duty Ratio**

**(a) $D_0$ = 0.24 and ( b) $D_0$ = 0.2**

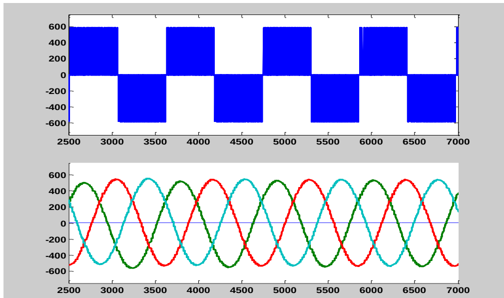


**Fig. 5:Simulation Results of Conventional PWM Inverter Line Voltages**

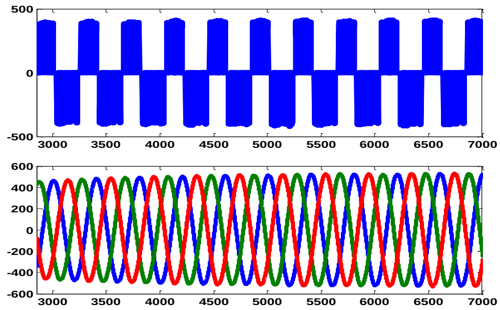


**Fig. 6:Simulation Results of Four Wire Z-Source Inverter Line Voltage**

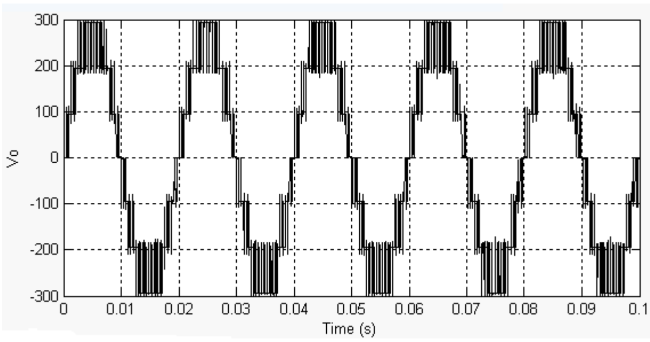



**Fig 7:Simulation Results of Z-Source Multilevel Inverter Line Voltage without Filter**

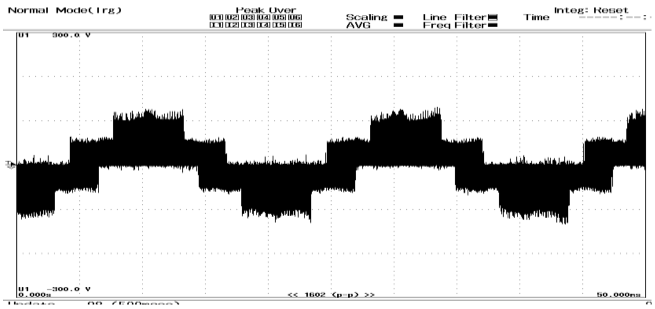


**Fig 8:Experimental Results of Conventional PWM Inverter (a) Phase Voltage**

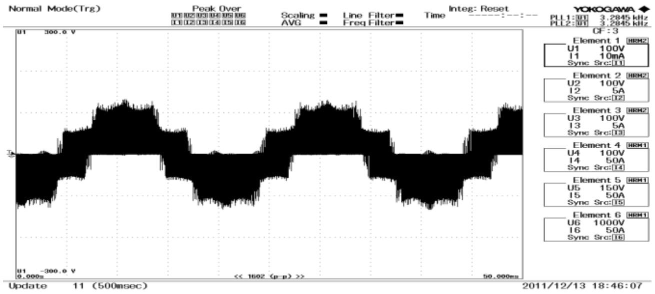


**Fig. 9Experimental Results of Four Wire Z-Source Inverter for Phase Voltage**

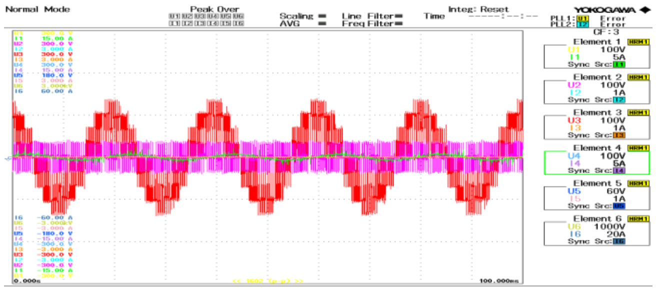
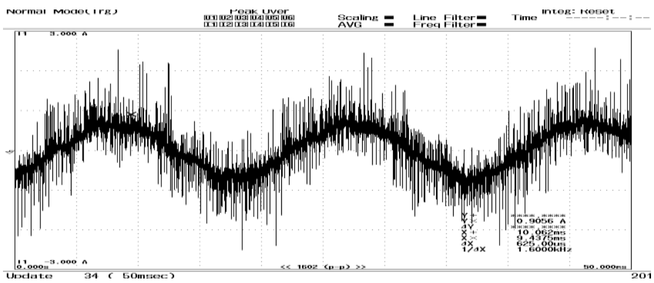


**Fig. 10:Experimental Results of Z-Source Multilevel Inverter Phase Voltage**

## III. SWITCHING STRESS

The voltage boost capability of FWZSI and ZSMLI can be improved by increasing the shoot through period. Lower value of modulation index and higher value of shoot through period increases the switching stress in the power switches. To exactly predict the switching voltage stress, the dc link voltage is measured. To predict the magnitude of switching current stress the ZS-inductor current is measured for various values of shoot through period and modulation index. The variations in inductor current ripples and ripples in DC link voltages are due to the variation of shoot through period. The magnitude of inductor current is twice the load current for the given value of shoot through period and modulation index. The switching stress on the power switches and the THD in the output side of the FWZSI and ZSMLI also depend on the amount of ripples in the Z-source elements. The magnitude of ripples is high at higher shoot through periods. From Figure 11 it is clear that the ripples in the inductor current are 1.2 amps lower in the ZSMLI whereas it is 2.1A and 2.9A higher in FWZSI and conventional system respectively. This higher value of ripples introduces more harmonics in the output voltage. Also this higher value of ripples increases the switching current stresses. Figure 13 shows the voltage stress across the power switches of FWZSI, ZSMLI and conventional system for different values of shoot through duty ratio of m=0.7. The Dc link voltage for different shoot through duty cycle for modulation index of 0.7 is shown in Table 1. Figure 14 shows the switching current stress of the conventional, FWZSI and ZSMLI for various values of shoot through period. From Figure 14 it is evident that the voltage stress in PWM inverter is around 108 Volt greater than the FWZSI and 190 Volt greater than the ZSMLI. The switching current stress in PWM inverter is 0.5 Amp. greater than the FWZSI and 0.9Amp. greater than ZSMLI. Figure 16 shows the variation of voltage stress with the variation of modulation index. The voltage stress is reduced with increase in modulation index. At a modulation index of 0.7 the conventional system provides switching voltage stress 100 V greater than that of ZSI[17]. Figure 15 shows the variation of voltage stress with the variation of modulation index. The voltage stress is reduced with increase in modulation index. At a modulation index of 0.7 the conventional system provides switching voltage stress 100 V greater than that of ZSI.



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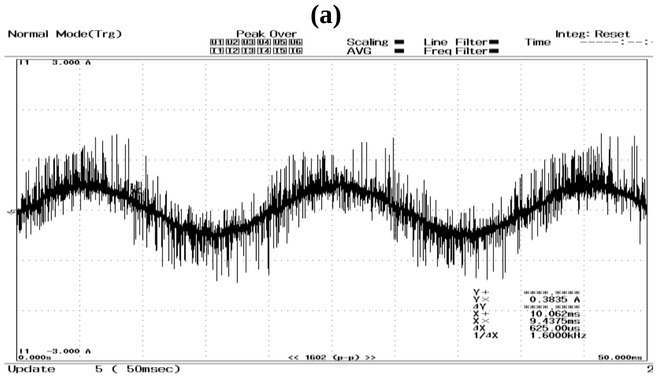

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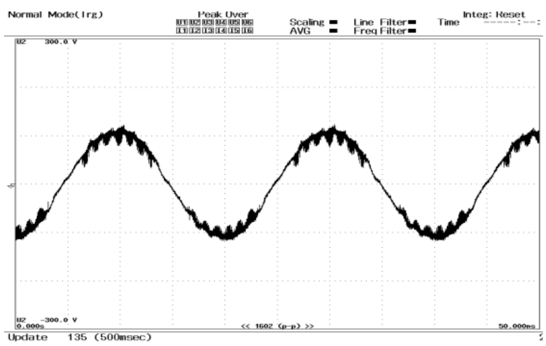

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**Fig. 11:Experimental Inductor Current Waveforms of Conventional (a) PWM Inverter (b) FWZSI and (c) ZSMLI**


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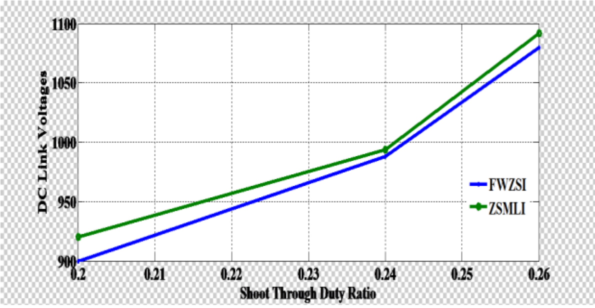



**Fig. 12:Variation of DC Link Voltage with Shoot Through Duty Ratio**

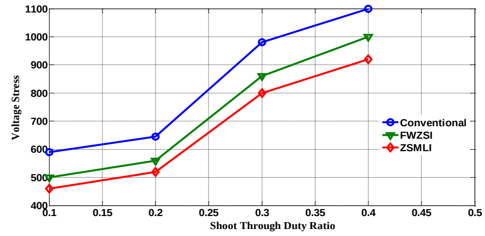



**Fig. 13:Graph between Voltage Stress and Shoot Through Duty Ratio**

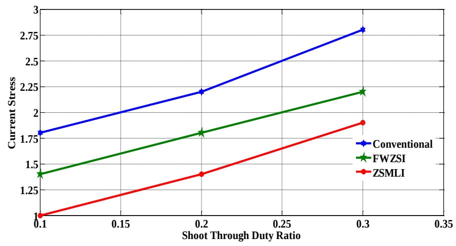



**Fig. 14:Graph between Current Stress and Shoot through Duty Ratio**

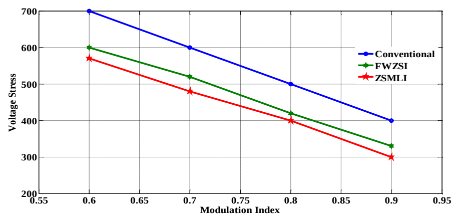


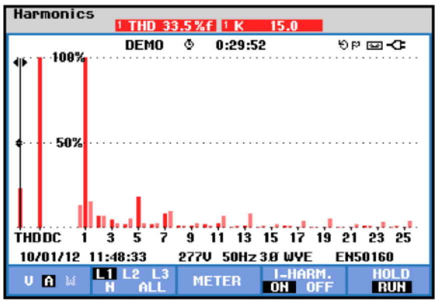

**Fig. 15:Graph between Voltage Stress and Shoot Through Duty Ratio**

**Table 1:DC Link Voltage variation in FWZSI based UPS System ZSMLIbased UPS System**

| S.NO | Input voltage (Volts) | DC Link Voltage (Volts) | Shoot Through duty ratio $D_0$ | Modu lation Index M |
|---|---|---|---|---|
| 1 | 200 | 920 | 0.2 | 0.7 |
| 2 | 210 | 994 | 0.24 | 0.7 |
| 3 | 220 | 1092 | 0.26 | 0.7 |

## IV. POWER QUALITY

The power quality in the UPS system is the most desirable characteristic. The input side power quality is affected by the power converters and their switching frequency in UPS systems. The output side power quality depends on the shape of the voltage waveforms across the load terminals [18]. To predict the input and output side power quality, the proposed and conventional power converters based UPS systems are loaded from 0.1kW to 2kW and the corresponding input current THD and output voltage THD are measured and The input and output side power quality entirely depends on the shoot through duty ratio and modulation index of the FWZSI and ZSMLI for a given value of load power. Table 2 shows the variation of input and output THD of conventional and proposed . Figure 16 shows the input current harmonics spectra of proposed power converters for a load of 1kW. Figure 17 shows the variation of input THD for various loading conditions. The voltage THD of the ZSMLI is around 12.7% lower than FWZSI and 8.5% lower than PWM inverter [15,19].

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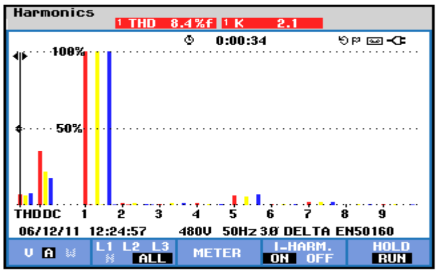


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**Figure 16:Experimental Input THD Spectra of(a) FWZSI and (b)ZSMLI**

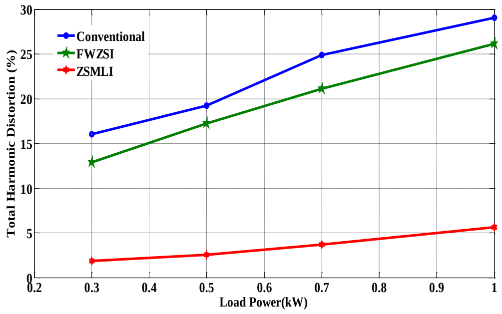


**Fig. 17:Variation of Input THD (%) with Respect to Load Power**

**Table 2:Performance Comparison Between Conventional and Proposed Power Converters**

| S.No | Parameters | Conventional three stage power converter based UPS System | Proposed FWZSI based UPS System | Proposed ZSMLI based UPS System |
|---|---|---|---|---|


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| | | | | |
|---|---|---|---|---|
| 1. | Voltage stress | 120V | 87V | 98V |
| 2. | Current stress | 3.1 | 2.3 | 2.7 |
| 3. | Input current THD(%) | 40.1 | 10.2 | 20.5 |
| 4. | Output voltage THD(%) | 28.3 | 12.7 | 8.5 |
| 5. | Power quality | Distorted voltage due to dead time | Stepped sine wave voltage | Sinusoidal voltage |
| 6. | Efficiency | 83 | 91 | 95 |

## V. PERFORMANCE OF ZSMLI, FWZSI AND CONVENTIONAL INVERTER WITH RECTIFIER LOAD

Figures 18 to 20 show the input voltage and current waveforms of ZSMLI, FWZSI and conventional inverter based UPS system with rectifier load. Most of the UPS are used in rectifier load applications and hence this investigation is carried out for different loading conditions of rectifier with non-linear loads. This research also focused on the performance of conventional and proposed power converters for non-linear unbalanced loading conditions.The power quality of the proposed and conventional power converters are affected during rectifier load conditions. The ZSMLI based UPS system provides almost sinusoidal current waveform. But the current waveform in the conventional system is heavily distorted; this will increase the input THD. The Z-source network in FWZSI and ZSMLI limits this input harmonics injection. Hence the proposed two systems provide almost sinusoidal waves.

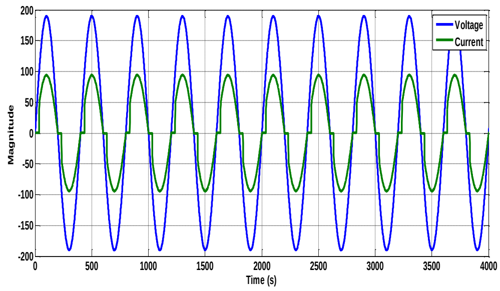


**Figure 18:Simulated Voltage and Current Waveforms of ZSMLI with Rectifier Load**

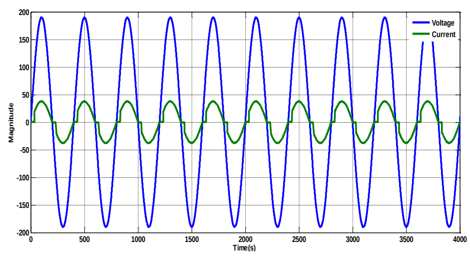


**Figure 19:Simulated Voltage and Current Waveforms of FWZSI with Rectifier Load**

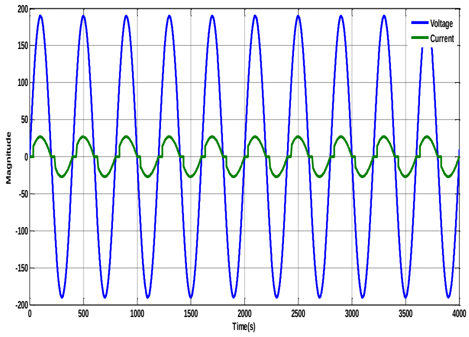


**Figure 20:Simulated Voltage and Current Waveforms of Conventional Inverter with Rectifier Load**

## VI. EXPERIMENTAL SETUP

The experimental block diagram of the proposed FWZSI and ZSMLI are shown in Figures 21 and 22 respectively. The experimental photograph of FWI, FWZSI and ZSMLI are shown in Figures 23 and 24 respectively. The TMS320F2407 digital signal processor is used to generate the PWM pulses for FWZSI and ZSMLI. Power IGBT is used as power switch in experimental setup. IR2110 IC is used for driving and amplifying the PWM signal.

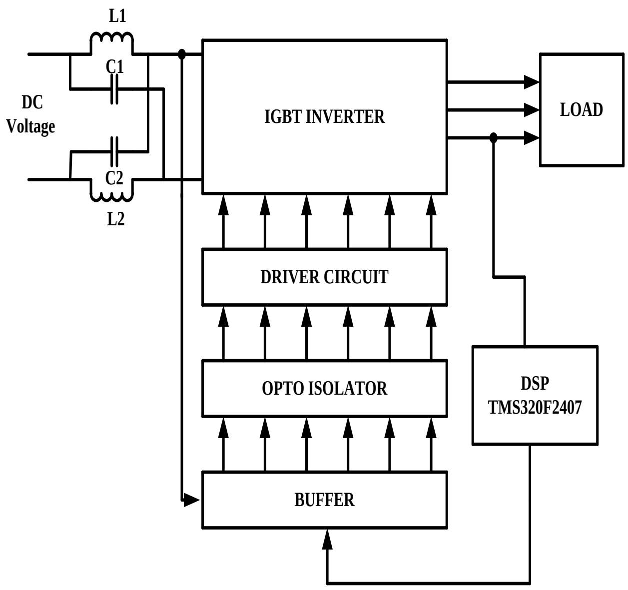


**Figure 21:Hardware Block Diagram of Three Phase Four Wire Z-Source Inverter**


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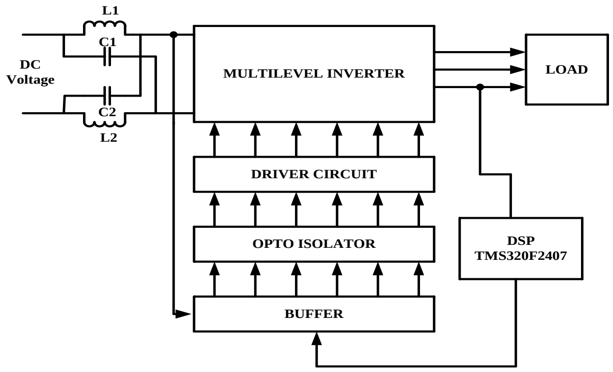


**Figure 22:Hardware Block Diagram of Three-Phase Z-Source Multilevel Inverter**

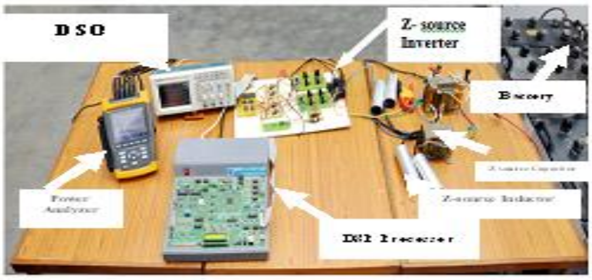


**Figure 23:Laboratory Experimental Setup of FWZSI based UPS**

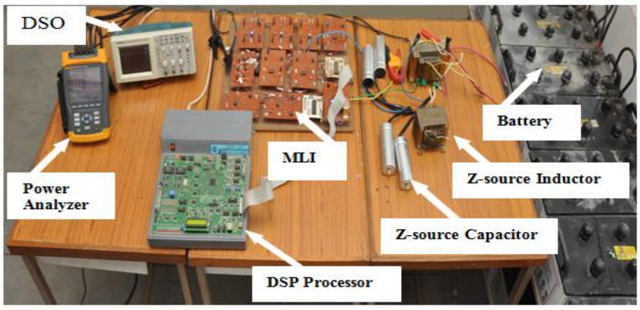


**Figure 24:Laboratory Experimental Setup of ZSMLIbased UPS**

## VII. CONCLUSION

The conventional, ZSFWI and ZSMLI based UPS systems have been analyzed for different values of input voltages. The shoot through placement, switching stress, power quality and efficiency of power converters are compared. The simulation results and experimental results of conventional power converters and proposed FWZSI and ZSMLI based UPS systems are analyzed. The voltage THD in ZSMLI is 8.5% less than the FWZSI and 12.7% less than conventional PWM inverter. Because of staircase waveform, ZSMLI and FWZSI provide better sinusoidal voltage and also require lesser value of filter components compared to conventional PWM inverters. The input current THD of ZSMLI is 10.2%less than FWZSI and 20.5% less than the conventional PWM inverter. The efficiency of the ZSMLI is improved by 4.5% to 6.2% higher than the FWZSI and PWM inverter.

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