International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 8 (2018) pp. 6306-6314

Novel Z-Source High Frequency High Power Factor AC-DC Converter

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Abstract

[3] Today the biggest challenge for DC-DC converter designers is to achieve simultaneously important features as improved transient response , reliability , reduction in cost and that too with the high power density of the converter.[1] To achieve these maximum goals, a novel isolated high frequency (HF) push-pull, DC-DC converter with z-source has been proposed. The proposed topology is aimed to obtain isolated DC voltage from a[1] DC voltage input which is an intermediate stage of AC-DC converter with reduced losses. This topology uses HF link, push-pull buck converter using only two controllable switches with variable wide range output voltage control at desired load current. The novel feature of the proposed converter is , it uses z-source without filter capacitor at the input side, which is able to take care of shoot through of the two consequently turning on and off of the switches and to maintain the source current within safe limits when the duty ratio is 50% for both the switches of converter. Another novel feature of topology is input filter capacitor of a rectifier is shifted to the secondary side of HF transformer which results in obtaining high input power factor on AC side.[1] It would find application in battery charging, charging of high rating super capacitors., heating of bearings, electrolysis, LED lightings. High power density and high power factor on AC side with the simplicity of control are the prominent features of this topology. Simulation results for proposed topology are validated with the hardware results.

Keywords: AC-DC converter, ferrite core transformer, high power density, z-source, high power factor, high frequency push-pull converter.

INTRODUCTION

Nowadays with the awareness of the merits of energy efficiency in the power converters which nearly all products require has dramatically increased the demand for switching regulators. [5]Unlike conventional dissipative series or shunt regulators in which the power regulating switch operates in continuous conduction mode thereby dissipating large amounts of power at high load currents especially when the input-output voltage difference is large. [6]In switched mode power conversion, however the controlling device is almost an ideal switch which is either closed or open. By controlling the duty ratio of the switching pulses the output voltage can also be controlled in a very efficient way. Moreover, since the power semiconductor switch operates always at saturated or cut-off mode except for a brief transition between these two states,[10] the switching regulator can achieve good regulation despite large variations in input voltage and load changes and the efficiency is maintained throughout. [2]Power electronic converters are generally utilized as a part of numerous applications including sustainable power source age, modern hardware/engine drives, electric vehicle/train, air-make, family apparatuses, electronic weights, PC control supplies, control supplies for media transmission gear, and so forth. In the most recent decades, the extent of UPS has been expanding on the planet because of expanding number of basic loads, for example medical equipments, incentive care units require the nonstop supply of great sinusoidal voltage. However UPS is extensive and cumbersome because of the utilization of main frequency In low input voltage system , the conduction loss of switches turns into the primary thought To conquer the hindrances, a novel designed high frequency dc-dc push-pull converter with z-source is proposed.[3]Planners of dc-dc control converters are under tenacious strain to expand control thickness, effectiveness, dependability, enhance transient reaction, and decrease cost, ideally accomplishing every one of these objectives at the same time. In all actuality, certain objectives are more vital than others. For instance, aviation applications frequently have confinements on general framework mass, and a few burdens require quick powerful reaction. The utilization of switching frequencies is a promising way to deal with give considerable picks up in power density and data transfer capacity.[1] In the recent years, high-recurrence control innovation in both the divisions that is purchasers and ventures have grown more in all power control utilization frameworks In any case, particularly high recurrence full inverters utilized for mechanical and shopper machines causes switching loss and conduction loss of influence gadgets. The size and in addition high power thickness is an everlasting subject of energy hardware. High switching frequency is a successful method to enhance power density. [2]With a specific end goal to boost switching frequency, the switching loss ought to be diminished at first. Additionally, because of the restricted vitality stockpiling capacity of batteries, the productivity prerequisite for AC/DC converter in UPS frameworks will be high. In this way, the investigation on the push-pull converter has turned out to be increasingly basic. [1]Power electronics has produced new skylines with respect to power conversion and control. There are a few outline examples of switching controllers. The fundamental reason for the switching mode operation is to decrease the measure of the isolating transformers and to expand the effectiveness.

This paper proposes the novel topology in which voltage of the ac mains is first rectified and applied to z-source without capacitor filter to obtain high input power factor. Then voltage output of z-source at fundamental frequency is applied to high-frequency transformer to obtain high frequency low ac voltage with z-source push-pull converter. Fig.1 represents the block diagram of high power factor z-source push-pull converter. With the help of rectifier, filter and with proper selection of

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design of high frequency transformer desired output DC voltage is obtained from the ac mains through z-source push-pull inverter. The control might be presented at any stage, while the genuine stage relies upon the load prerequisites and the general cost structure. Fig 2 speaks to circuit diagram of proposed gadget. The target of this task is to reenact and outline a low voltage, high current ac-dc converter with high input power factor. The circuit speaks to for transformation of voltage from 230 V ac voltage to low dc voltage. The design is accomplished utilizing a high frequency dc-dc push pull converter with z-source. Z-source is utilized to acquire high power factor. With the help of pulse width modulation technique and ferrite core transformer a reduction in converter size is achieved. This task will investigate the likelihood of low cost power electronic interface (ac-dc converter). With the help of this high frequency push-pull ac-dc converter 24V,15 A is obtained from 230 V ac mains. The current capability of converter can also be increased as per the load requirement

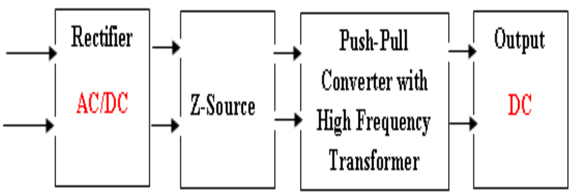

Figure 1. Block diagram of high power factor, high frequency ac/dc z-source push-pull converter

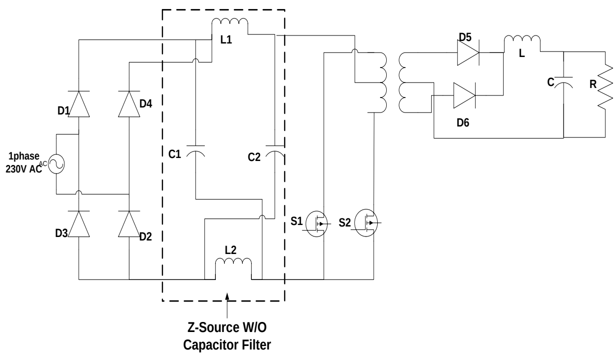

Figure 2. Circuit diagram ac/dc z-source push-pull converter

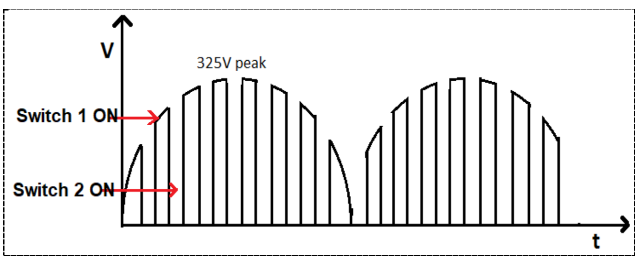

Figure 3(a) Expected output of input rectifier with z-source

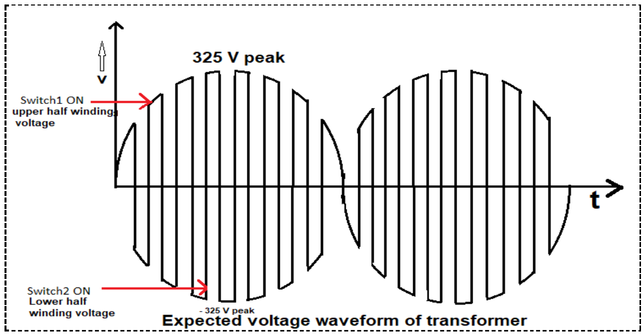

Figure 3(b) Expected Voltage envelop waveform of transformer with z-source without capacitor filter

Fig 3(a) represents the methodology used in the proposed AC/DC converter which shows pattern for expected output of z-source w/o filter capacitor. In the absence of filter output of z-source is half wave rectified waveform (pulsating DC) instead of pure DC voltage. Therefore a primary voltage of transformer is in the form of the loop as shown in Fig 3(b). when switch1 is ON current flows through upper half portion of the transformer winding which gives 325 V peak voltage and when switch2 is ON current direction is reversed and it flows through the lower half of the transformer winding which results in negative peak voltage of 325 volts . Thus the transformer voltage is obtained in the form of envelop having positive and negative peak voltage of 325 volts as shown in fig 4. Thus this unique methodology is proposed in AC/DC converter to obtain unity power factor.

A push-pull converter is an intermediate stage of AC/DC converter. [2]Since transformation ratio is fixed to obtain variable output dc voltages high switching frequency with variable duty ratio is used. In the proposed topology 50 kHz switching frequency with variable duty ratio 7% to 50 % is successfully obtained with microcontroller IC dsPIC33EP256MC202. [2]The benefits of utilizing novel push-pull converter with z-source are its simplicity, high input power factor and high power application, which prompts expanded use in mechanical DC power applications.

This paper is organized as follows: First section includes an introduction to AC-DC push-pull converter with z-source with block diagram schematic and methedology of its working and literature review. Second section deals with the modelling and simulation of proposed scheme. Third section presents complete hardware set up, control circuit discription and experimental results for proposed Novel z-source high frequency high input power factor AC-DC converter. Fourth section presents comparison of simulation and hardware results. And finally concluded with the novel results.

PROPOSED SCHEME

[1]AC supply is power origin of electric dc load. Today it's a need of transformation and innovation of novel techniques that could change over ac to dc with high power factor to take care of the demand of these dc loads. DC current which is obtained from 230V, 50 Hz input supply has many applications such as

for battery charging, electrolysis, led lighting etc. To meet the set target of high power factor, high dc current and high power density electronics devices such as rectifier, z-source, push-pull converter with high frequency ferrite core transformer and control circuit using microcontroller IC dsPIC33EP256MC202is used. In the proposed device to carry large amount of DC current output rectifier circuit is made with power diode using IRF 460..

[1]High switching frequency is the requirement of high power density device (Febriyandi Imam, (2014) Nowadays it is the need of the hour to achieve ac-dc power converters with high power density, high efficiency, reliability, enhance transient response, and most importantly to maintain high input power factor with reduced cost of device. Ideally accomplishing each of these objectives at the same time is a big challenge.

High power density device is designed with high switching frequency. With the application of high switching frequency, switching losses and core losses in magnetic components are increased. Ideally accomplishing each of these objectives at the same time is a big challenge.

Expected waveforms of proposed methodology are validated with the simulation results and then simulation results are validated with hardware results

Modeling of Proposed Project Architecture

Novel technique used in the proposed device is full wave rectifier dc voltage without filter capacitor is applied to z-source which is connected between rectifier and push-pull converter. With the help of high switching frequency pulsating dc voltage of z-source is converted to high frequency ac voltage with the help of push-pull converter. Finally high frequency transformer and rectifier with MOSFET (IRF460) used as power diode in the circuit transform ac voltage to the desired dc voltage. To obtain pure dc output voltage filter capacitor is connected across the output rectifier circuit. Simplicity and ability of push-pull convertor to vary to high power application has increased its demand in industries for DC power application.

Simulation Model

Figure 4 represents Matlab simulation model of proposed high power factor z-source Push-Pull converter.

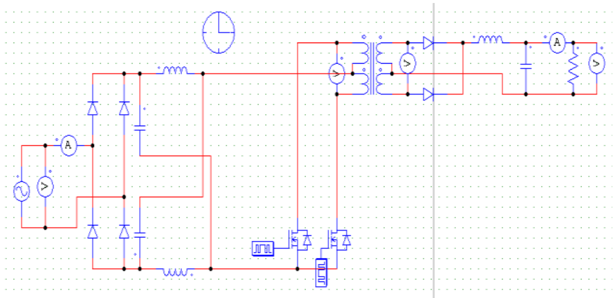

Figure 4. Simulation model of z-source Push-Pull converter

SIMULATION RESULTS OF Z-SOURCE PUSH-PULL CONVERTER

Fig.5 represents the primary (325 V) and secondary voltage (24 V) of high frequency ferrite core transformer. Fig 6 represents transformer peak to peak primary voltage of 632 V, which is as expected waveform of methodology as shown in fig 3. And peak to peak 48 V secondary voltage. Since input filter capacitor is removed resultant voltage waveform is in the form of envelop. Fig 7 represents zoom view of primary and secondary voltage of transformer respectively. Fig 8a and 8b represents Source current and source voltage (230 V) of z-source push-pull converter resulting in a high power factor near to unity. Fig.8 represents DC Current (24 A) waveform and DC voltage (24 V) waveform across the load. Fig 9 represents DC voltage and current waveform across the load and Fig 10 represent transient response of this novel topology which shows that transient response of the system is very fast and it is almost 0.1 sec.

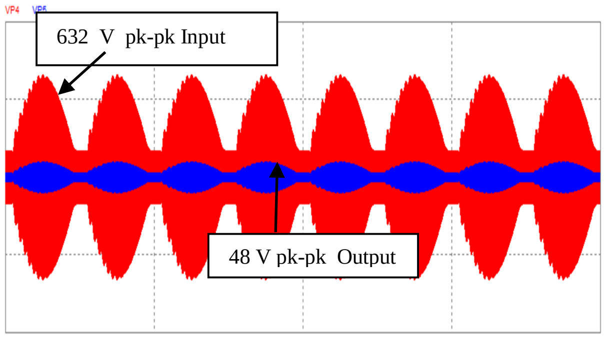

Figure 5. Input and output voltage waveform of HF transformer of z-source push-pull converter

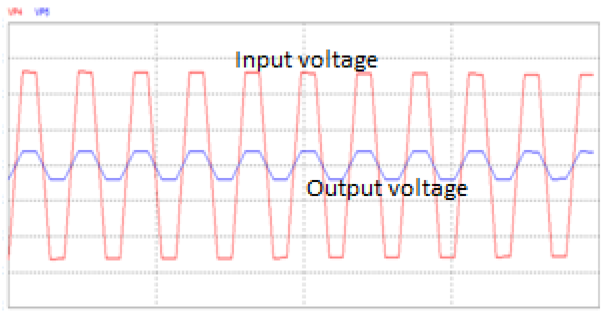

Figure 6. Zoom view of input and output voltage of High Frequency Transformer

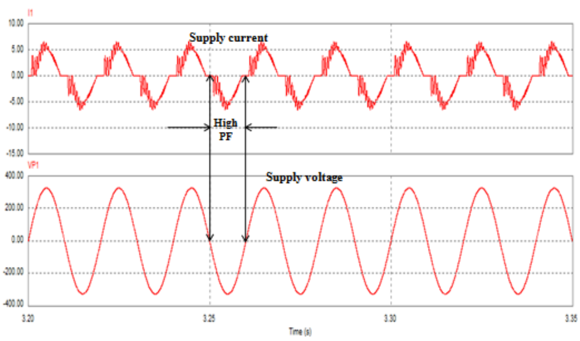

Figure 7. Source current and source voltage of z-source push-pull Converter resulting in near to unity power factor

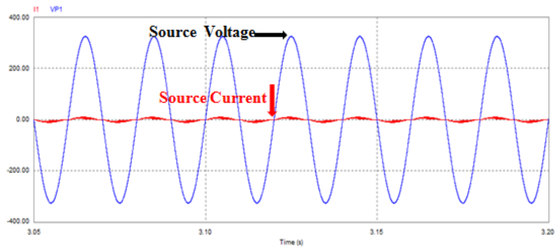

Figure 8. Source current and source voltage (230 V) with z-source push-pull Converter resulting in a high power factor near to unity.

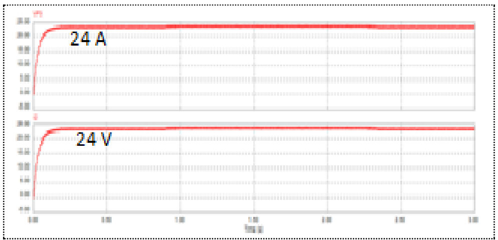

Figure 9. DC voltage and current waveform across the load

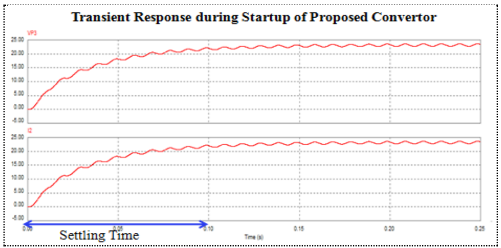

Figure 10. Transient Response during Startup of Proposed z-source AC-DC push-pull convertor

Thus from the simulation results High input power factor , low output dc voltage and high dc current is achieved successfully. That means, the topology and suggested methodology successfully worked in simulation.

HARDWARE SETUP AND RESULTS

Fig 14 represents complete hardware setup and experimental set up of Novel z-source high frequency high input power factor AC-DC push-pull converter (Kamil, Mohammad (2007).

Hardware setup is mainly devided in 4 parts. 1. Control circuit using microcontroller IC dsPIC33EP256MC202 to generate 50 kHz switching frequency pulses. 2. input rectifier circuit with z-source. 3. Push-pull converter with high frequency ferrite core transformer and 4. Output rectifier with power diode using MOSFET IRF460.

Control Circuit:

To obtain 50 khz switching frequency pulses microcontroller IC dsPIC33EP256MC202 is used in PWM I/O pin pair in Push-Pull Output mode since proposed converter is push-pull converter. Fig 11(a) and fig. 11(b) represents printed circuit board and hardware set up of IC dsPIC33EP256MC202 control circuit for 50 kHz switching frequency respectively. Fig 12 represents 50 kHz pulses from IC dsPIC33EP256MC202. PWM variation pot of IC provides the facility of getting variable duty ratio which results in variable output voltage.

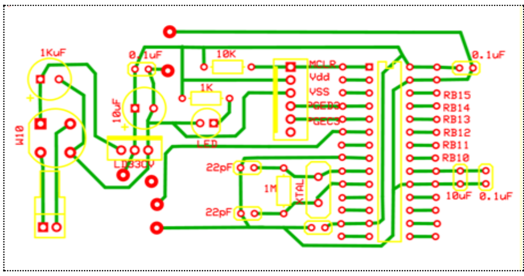

Figure 11(a) Printed Circuit Board for microcontroller dsPIC33EP256MC202

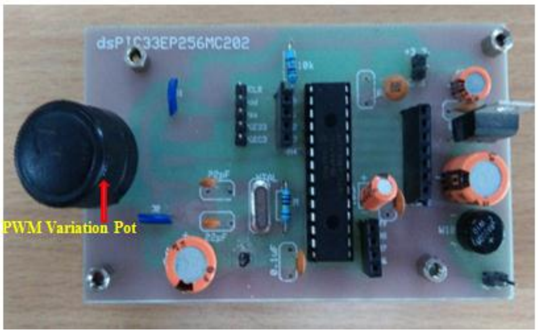

Figure 11(b) Hardware setup of microcontroller IC dsPIC33EP256MC202

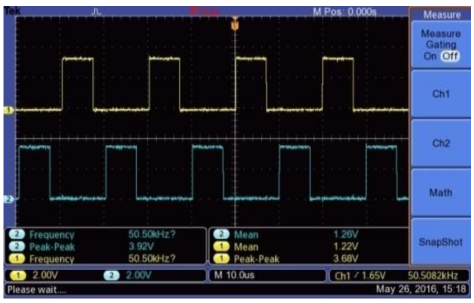

Figure 12. 50 kHz , 3.9 V pulses from control circuit.

MOSFET (IRF460) as Power Diode

In the proposed device MOSFET (IRF460) is proposed as power diode to carry large amount of current on load side. Short circuiting gate terminal to source terminals. The MOSFET is

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converted to power diode Fig13 represents connection diagram and hardware of power diode using MOSFET IRF460

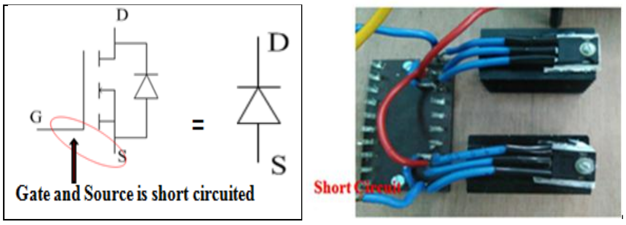

Figure 13. Connection Diagram of MOSFET (IRF460) as HF Power Diode

Complete Hardware Set Up:

Fig 14 represents complete hardware setup of Novel z-source high frequency high input power factor push-pull AC-DC converter

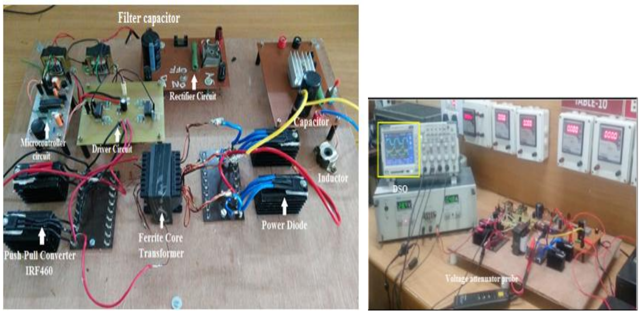

Figure 14. Complete Hardware and experimental set up of z-source push-pull high frequency high input power factor AC-DC converter

HARDWARE RESULTS

Control Circuit

Fig 15,Fig 16 represents variable duty ratio switching pulses from driver circuit at 50 kHz frequency.With variable duty ratio variable output voltage is obtained as shown in Fig 17 and Fig 18.

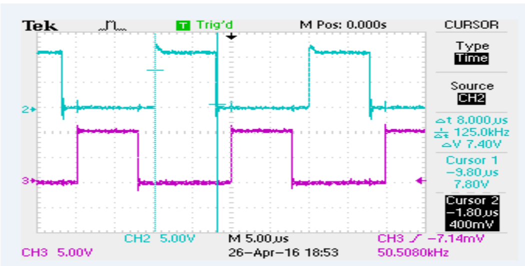

Figure 15. PWM Gate Pulses for 40.40 % duty ratio, Δt=8.0 μs At switching frequency of 50.508 kHz from driver circuit

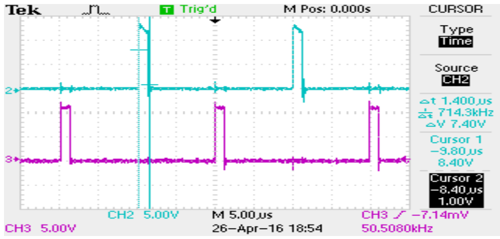

Figure 16. PWM Gate Pulses for 7.07 % duty ratio, Δt=1. 4 μs At switching frequency of 50.508 kHz from driver circuit

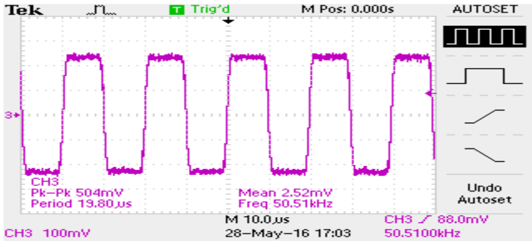

Figure 17. Transformer secondary voltage 5.04 V at 50.51 kHz switching frequency

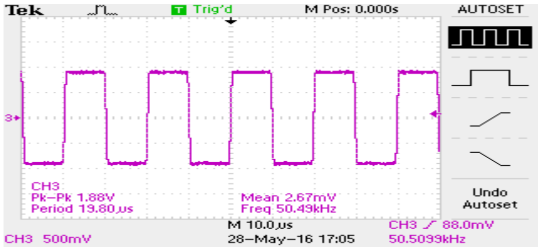

Figure 18. Transformer secondary voltage 18.8 V at 50.509 kHz switching frequency

Hardware Result: Push-Pull Converter:

Push-pull converter includes center tap transformer. When switch 1 conducts current flows in the upper half winding of center tap transformer and when switch 2 is ON current flows in the lower half of the transformer as it is shown in Fig19.

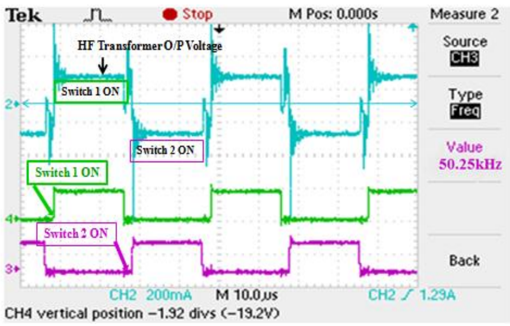

Figure 19. Output of Convertor for 45% Duty Ratio with Load at 50.25 kHz

Fig 20, 21 and 22 represents transformer current at terminal 1,terminal 2 and continuous switch current through terminal 3

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(centertap terminal) respectively. Fig 23 represents turning off time of switcheds which is found to be 4.4 µsec, which results in trapazoidal shaped output of converter instead of square waveform.as shown in zoom view in Fig 7

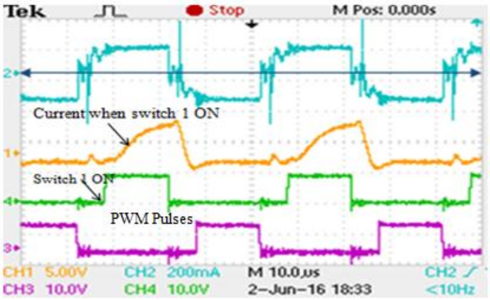


Figure 20. Transformer secondary current at terminal 1 when switch 1 is ON for 45% duty ratio, 50.25 kHz frequency.

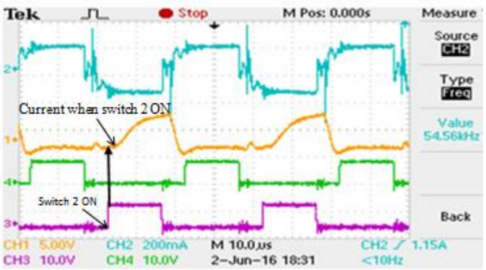


Figure 21. Transformer Secondary at terminal 2 when switch 2 is on for 45 % DR at 54.56 kHz switching frequency

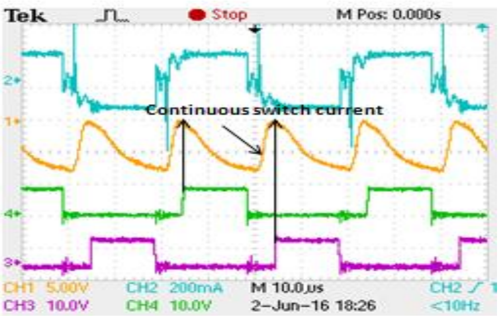


Figure 22. Continuous switch Current at terminal 3 (center tap terminal) of the transformer for 45% duty ratio at 50 kHz frequency

Figure 23. The turning off time of switch Δt=4.4 µs of push-pull switches

Fig 24 represents HF transformer input voltage envelop of 632 V pk-pk and output voltage envelop of 48 V pk-pk. Thus after rectification 24 V DC output voltage is obtained. Fig 25 represents HF transformer primary and secondary center tap terminal voltage envelope of the waveform which shows that frequency of input voltage is half the frequency of the center tap voltage on the secondary side of transformer. Fig 26 represents output DC voltage 22 V and 13 A DC current across load.(Maurya. R. 2012). Fig 27 and 28 represents source current and source voltage of the converter with z-source which shows that voltage and current are in phase resulting in high input power factor.Thus achiveing novel feature of high input power factor almost unity. Fig 29 represents source voltage and current without z-source which shows that input current is spiky.

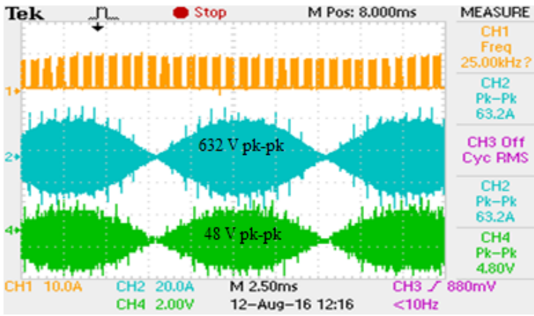


Figure 24. HF transformer input voltage 632 pk- pk and output voltage 48.0 volt with z-source

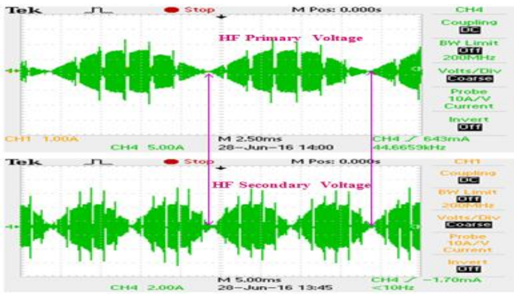


Figure 25. HF Transformer Primary and secondary voltage at 45 kHz switching frequency

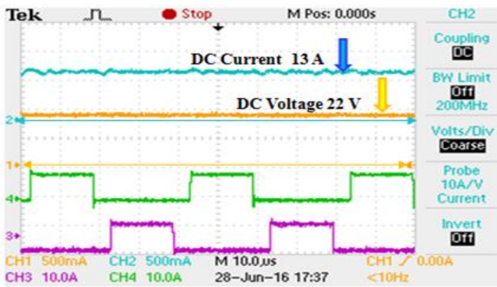


Figure 26. DC voltage and DC currentof proposed converter with z-source across load at 50 kHz switching frequency

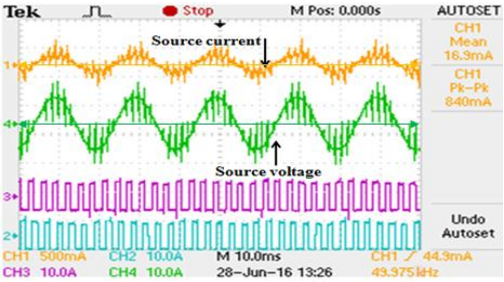


Figure 27. Source current and source voltage of the converter with z-sourceat 49.975 kHz switching frequency resulting in high input power factor

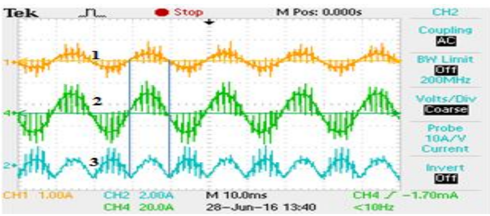


Figure 28. 1- Source current, 2- Source voltage 3- HF output rectifier current for switching frequency of 50 kHz. All are in phase

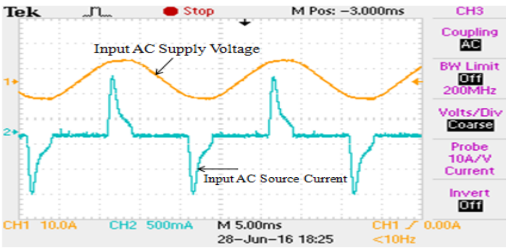
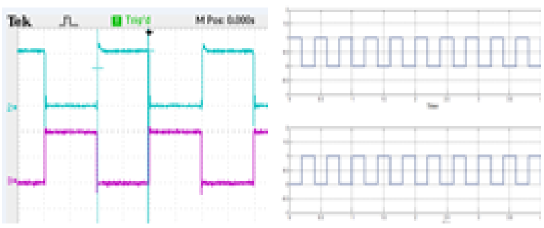


Figure 29. Source voltage and source current of conventional HF Push-Pull DC-DC converter at 50 kHz switching frequency w/o z-source

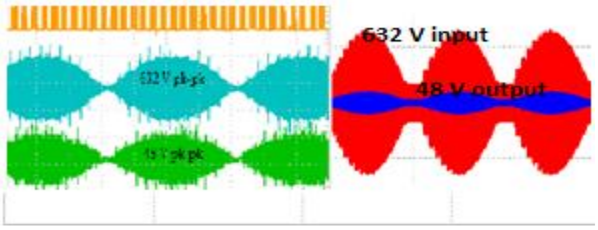
COMPARISON OF SIMULATION AND HARDWARE RESULTS

Fig 30,31,32 and 33 represents comparison of simulation results and the hardware results for proposed novel z-source high frequency high power factor AC-DC push-pull converter. It shows that analysis of the topology is validated with simulation and the hardware results.



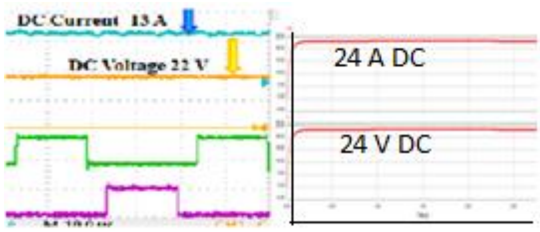
(a) (b)

Figure 30. PWM Gate Pulses for 50% duty ratio for 50 kHz switching frequency (a)- Hardware waveform (b)- Simulation result



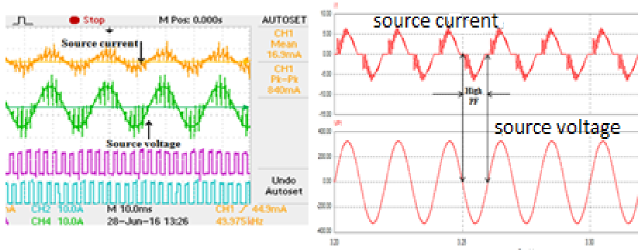
(a) (b)

Figure 31. Comparative results of peak to peak input and output voltage envelop of converter with z-source (a) Hardware results (b) Simulation result



(a) (b)

Figure 32. comparative results of DC voltage and DC current of converter with z-source across load at 50 kHz switching frequency(a) hardware result (b) simulation result



(a) (b)

Figure 33. comparative results of Source current and source voltage of the converter with z-source at 49.975 kHz switching frequency resulting in high input power factor (a) hardware result (b) simulation result

CONCLUSION

The newly developed proposed 50 kHz, HF push–pull DC-DC convertor with z-source has added novel feature of high input power factor on AC supply side, with wide range output voltage control at desired load current. Addition of z-source on input side is able to take care of shoot through of the two consequently turning on and off of the switches and to maintain the source current within safe limits when the duty ratio is 50% for both switches. With the another novel feature of shifting of capacitor from input side to output side of rectifier circuit, high power factor near to unity is achieved on source side. Another novel feature with z-source is that it has an inherent limitation to inrush current at startup. The transient response of the current at startup has considerably reduced as compared with the current response of converter without z-source. All these novel features has been proved from hardware results.

This novel converter has important applications in

- Charging of Super Capacitors ,
- For simultaneous Battery charging,
- For Electric Vehicles ,
- LED Lightings,
- Electrolysis and Electroplating

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