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ANALYSIS OF ZVT DC-DC BUCK-BOOST CONVERTER

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Abstract— The ZVT DC-DC buck-boost converter are commonly used to deliver higher load voltage from given low voltage source and vice versa. The conventional boost converter has disadvantages are requires a higher duty ratio even for realizing the moderate voltage gain, unable to reach expected levels of voltage gain at extreme duty ratios on account of excessive losses, and the efficiency on full load is low due to higher switching losses. To eliminate some of these limitations, higher-order boost pulse width modulated (PWM) converters are utilized. This converter gives a voltage gain close to twice the conventional boost converter. It is a single switch topology, which undergoes zero voltage transition during the switch OFF to ON-state transition. Furthermore, the zero-voltage transition is realized here through an LCS-cell consists of a L_r - C_r resonating circuit together with one additional switch. The ZVT DC-DC buck-boost converter are used in many applications such as self-regulating power supplies, battery power system, adaptive control, power amplification etc. The buck-boost converter is simulated in Matlab/Simulink on a laboratory scale-down 24 to 100V, 50W prototype converter.

Keywords— Buck-Boost converter, Zero Voltage Transition, LCS-cell.

I. INTRODUCTION

DC-DC boost converters are most commonly used to deliver higher load voltages from given low voltage source. The conventional boost converter has disadvantages are requires a higher duty ratio even for realizing the moderate voltage gain at extreme duty ratios on account of excessive losses, and the efficiency on full load is low due to higher switching losses. To eliminate some of these limitations, higher-order boost pulse width modulated (PWM) converters are utilized. These converters give the higher voltage gain but at higher switching frequencies, the full-load efficiency is still a limitation.

For improvement in efficiency of these converters, soft switching schemes are implemented. The two schemes which are Zero voltage switching (ZVS) during turn-on and Zero current switching (ZCS) during turn-off. These schemes are selected on the basis of device used i.e, IGBT or MOSFET. Even though efficiency is improved using these techniques, they still suffer from some limitations. The ZCS turn-off suffers from limitations such as rise in losses during conduction, converter circuit diode subjected to higher voltage stress and conduction losses increase due to presence of the main switch in series with the resonant inductor. Some of these limitations are eliminated using the soft transition methods such as zero-voltage/zero-current transition (ZVT/ZCT) techniques [4]. To realize better efficiency at the full load condition. The additional network produces both the voltage amplification and the soft switching for the MOSFET [2].

The aim of this paper is efficiency improvement of the fifth order boost converter, belonging to higher order family, by utilizing the ZVT technique to obtain soft-switching. Here the soft switching is realized by integrating the ZVT cell into the fifth-order boost converter [5].

II. PROPOSED CONVERTER TOPOLOGY

In order to improve the efficiency while achieving higher gains the reduction in transition losses is essential. In view of this the transition cells for realizing soft-switching must use the minimum number of devices. The zero-voltage transition (ZVT) cells reported in literature uses L_r - C_r resonating circuit along with auxiliary switch and diode. Although this structure can realize switch soft-transition, but the two devices are needed.

A zero-voltage transition cell consisting a L_r - C_r resonating circuit along with one auxiliary switch is for fifth order boost converter. In comparison to conventional ZVT cell, one diode is less in this scheme. In comparison to other fifth-order boost converters reported in literature this topology gave better voltage boosting feature. Including soft-transition, networks will improve the efficiency of the converter. The ZVT and



ZCT soft-transition networks are explained and OFF to ON soft-transition is investigated and hence ZVT network introduced appropriately.

The ZVT network consists of two resonating inductors, a capacitor in addition to a diode, and auxiliary switch. For the buck mode introducing one diode connected anti parallel to diode D_1 . For the buck and boost operation these two diodes are controlled by two switches. Duty ratios of two switches are change, it can operate in either buck or boost mode. The circuit diagram of the ZVT DC-DC buck-boost converter is shown in Fig.1. The proposed converter exhibits four operating modes in boost mode and two operating mode in buck mode. Equivalent circuits of boost mode operation are shown in Fig. 2 to Fig. 5 and buck mode operation are shown in Fig. 6 and Fig. 7.

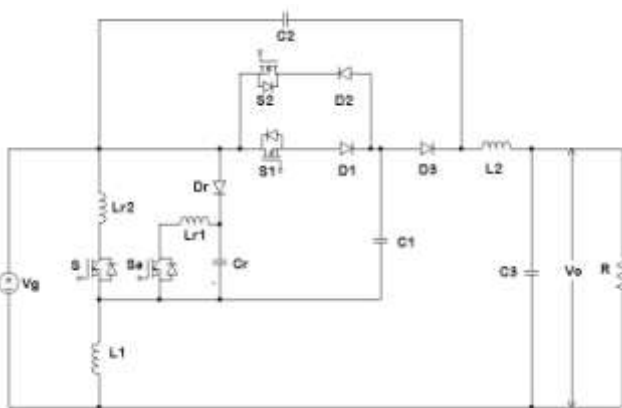


Fig. 1. Circuit diagram of ZVT DC-DC Buck-Boost Converter.

A. Boost Mode

Mode-1 operation: This mode is initiated by turning-ON of the auxiliary switch S_a . The voltage across the resonating inductor is almost constant. The resonating inductor has current linearly increases and the resonating capacitor is charged to supply voltage. At the end of this mode, this current becomes zero and the diode D_1 goes to OFF-state at zero current switching (ZCS). The voltage starts building up next mode of operation.

Mode-2 operation: In this mode the auxiliary switch (S_a) is in ON-state and hence the inductor L_r is resonating with the capacitor C_r . The voltage across the main switch starts decreasing at the end of this mode this become zero. At that moment the voltage across the main diode D_1 also reaches to full voltage. In this mode the voltage across the main diode D_2 starts decreasing and finally reaches to zero by the time when the voltage across the main switch reaches to zero. At the end of this mode both the main switch and diode D_2 are ready for zero-voltage transition.

Mode-3 operation: During this mode D_2 , S_a are in ON state and the anti-parallel diode of the main switch start conducting the negative current. During this mode the auxiliary switch and resonating inductor is carrying a constant current. This mode is going end when the main switch gate signal is released and the switch is ready for zero-voltage turn-ON transition.

Mode-4 operation: During this mode anti-parallel diode of main switch carry the negative current and main switch gate signal is released. Although main switch gate signal is present the negative current still flows through its anti-parallel diode until the auxiliary switch turns-OFF. At the end of this mode the auxiliary switch must be turned-OFF.

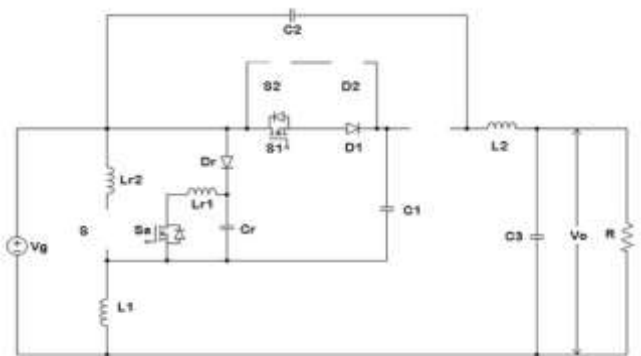


Fig. 2. Mode-1 equivalent circuit.

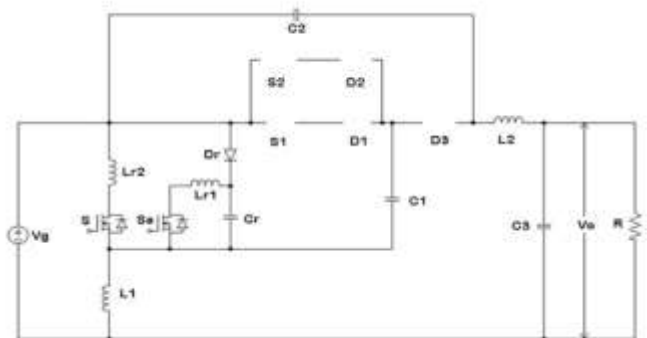


Fig. 3. Mode-2 equivalent circuit.

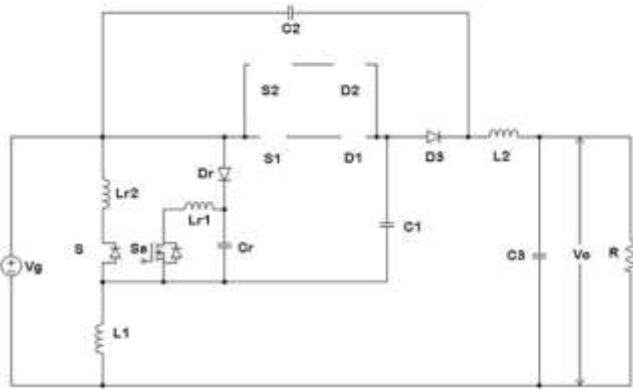


Fig. 4. Mode-3 equivalent circuit.

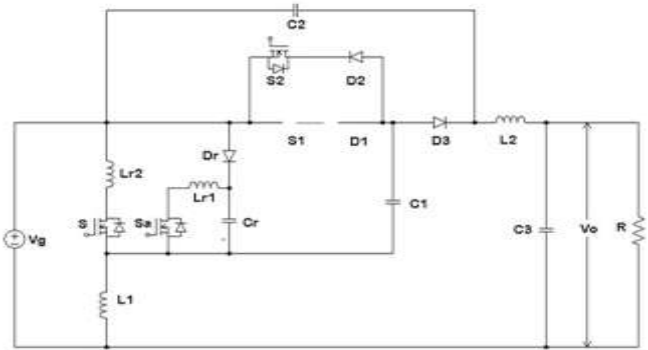


Fig. 7. Mode-2 equivalent circuit.

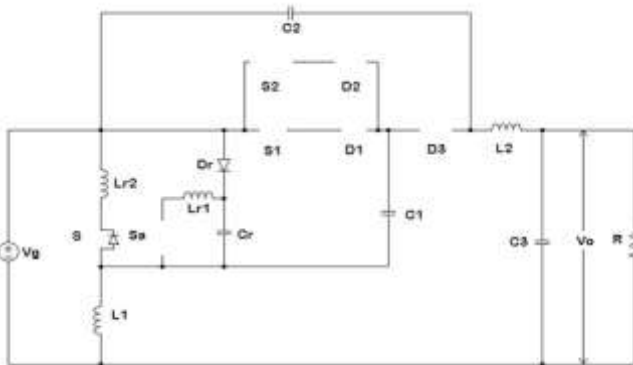


Fig. 5. Mode-4 equivalent circuit.

B. Buck Mode

Mode-1 operation: Initially the main switch S is ON and other switches are OFF state. The inductors L₁ and L_{r2} are stored the energy.

Mode-2 operation: In this mode S, S_a and S₁ switches are ON state. If the diode D₂ and D₃ are conducting in forward biased. The output voltage is less that of input voltage.

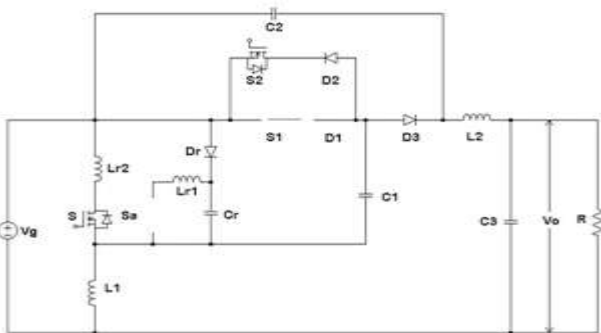


Fig. 6. Mode-1 equivalent circuit.

Table -1 Converter Parameters

Parameter	Values
V _g	24V
V _o	48V
P _o	25W
R	100Ω
D	0.5
D _{aux}	0.15
D ₁	0.9
D ₂	0.01
F	20KHz

III. DESIGN OF ZVT BUCK-BOOST CONVERTER

The power stage components of the ZVT buck-boost converter are designed as per the input parameters given in table 1.

$$L_1 = [(V_g - V_{c3} - V_o)D] / (f_s \Delta i_1) \tag{1}$$

$$L_2 = [(V_g D)] / (f_s \Delta i_2) \tag{2}$$

$$C_1 = [(2-D)V_g] / [(1-D)R_f \Delta V_{c1}] \tag{3}$$

$$C_2 = [(2-D)V_g] / [R_f \Delta V_{c2}] \tag{4}$$

$$C_3 = [(1-D)V_o D] / [8L_2(2-D)f_s \Delta V_{c3}] \tag{5}$$

IV. GATE SEQUENCE OF ZVT BUCK-BOOST CONVERTER

The four switches are gated with different switching pulse. Switching strategy is as shown in Fig. 8. The duty ratio are shown in table 1 and switching frequency of 20 kHz.

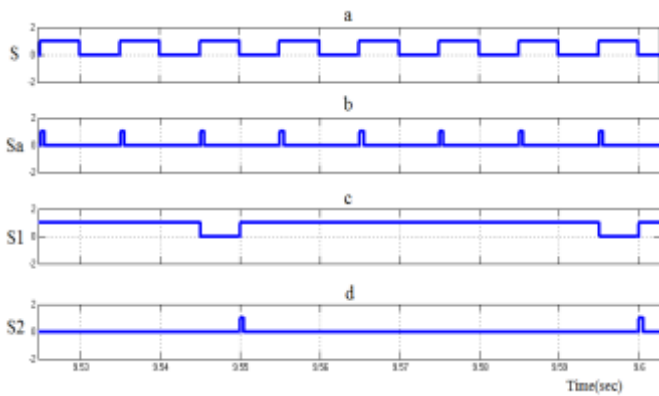


Fig. 8. (a) Gate pulse of S (b) Gate pulse of S_a (c) Gate pulse of S_1 (d) Gate pulse of S_2 .

V. SIMULATION PARAMETERS

A 50Watt prototype ZVT buck-boost converter system has been designed to verify the effectiveness of the zero voltage turn-ON transition performance. The converter is supplied from a 24V and the desired load voltage is 48V in boost mode and 14V in buck mode. The parameters of the designed converter to meet the specification are shown in table 2.

Table -2 Component Values

Components	Values
L1	150 μ H
L2	50 μ H
Lr1	1.5 μ H
Lr2	4.5 μ H
Cr	50nF
C1	47 μ F
C2	47 μ F
C3	100 μ F
R	100 Ω
fs	20KHz

VI. SIMULATION MODEL AND RESULTS

The circuits are drawn in Matlab/Simulink software. The simulink model of ZVT buck-boost converter is shown in Fig. 9.

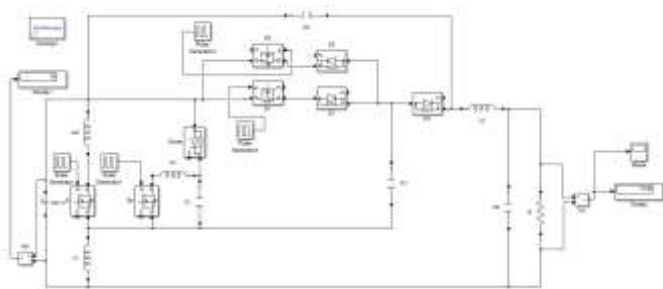


Fig. 9. Simulink Model of ZVT DC-DC Buck-Boost Converter

The model is simulated to obtain plots of boosted output voltage, voltage across switches, voltage across capacitor and current through inductor are shown in following figures.

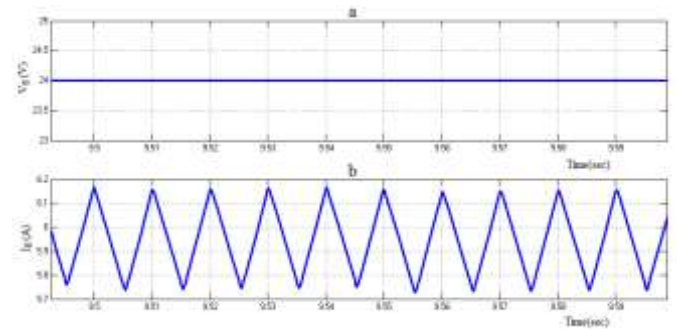


Fig. 10. (a) Input voltage V_g (b) Input current I_g .

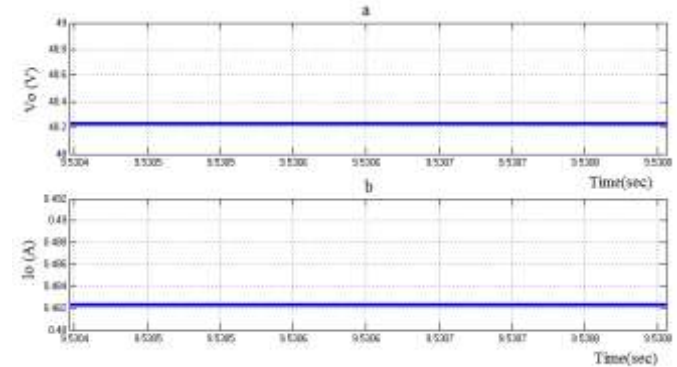


Fig. 11. (a) Output voltage V_o (b) Output current I_o .

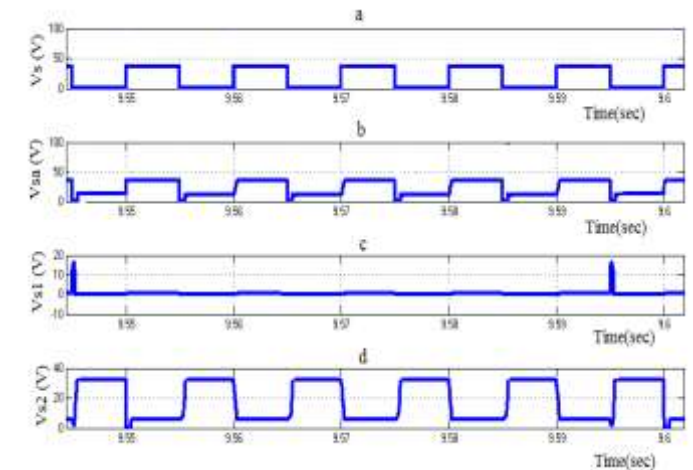


Fig. 12. (a) Voltage Stress across switch S (b) Voltage Stress across switch S_a (c) Voltage Stress across switch S_1 (d) Voltage Stress across switch S_2 .

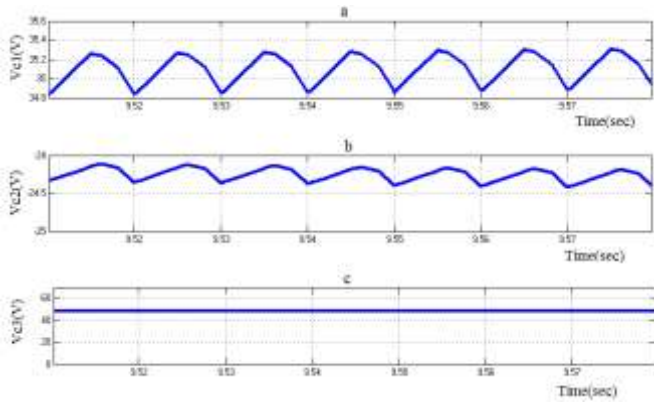


Fig. 13. (a) Voltage across C_1 (b) Voltage across C_2 (c) Voltage across C_3 .

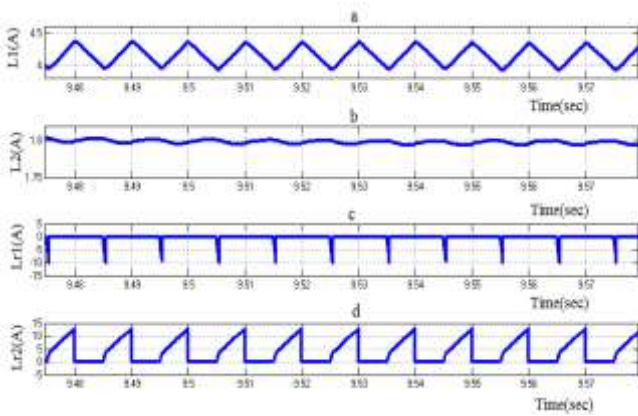


Fig. 14. (a) Inductor current L_1 (b) Inductor current L_2 (c) Inductor current L_{r1} (d) Inductor current L_{r2} .

The model is simulated to obtain plots of buck output voltage, voltage across switches, voltage across capacitor and current through inductor are shown in following figures.

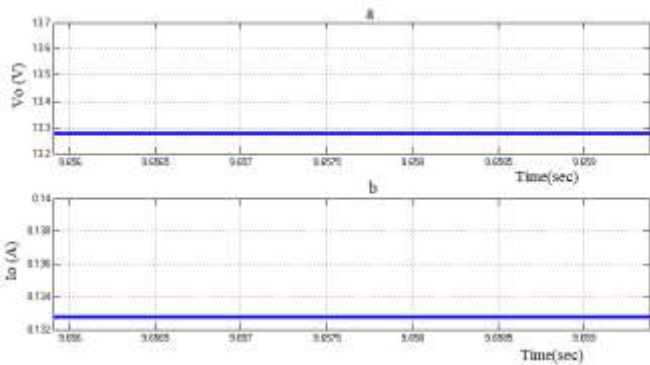


Fig. 15. (a) Output voltage V_o (b) Output current I_o .

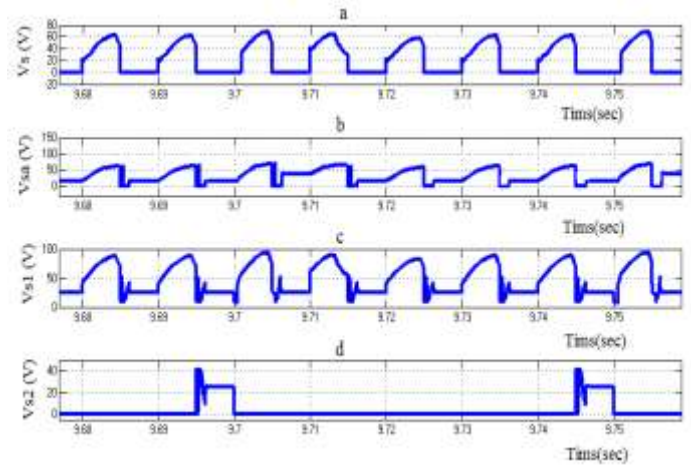


Fig. 16. (a) Voltage Stress across switch S (b) Voltage Stress across switch S_a (c) Voltage Stress across switch S_1 (d) Voltage Stress across switch S_2 .

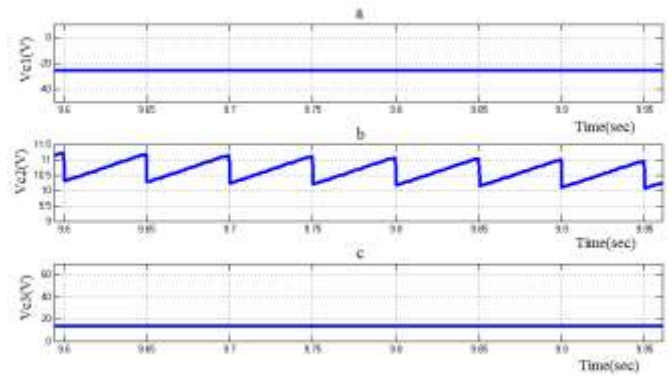


Fig. 17. (a) Voltage across C_1 (b) Voltage across C_2 (c) Voltage across C_3 .

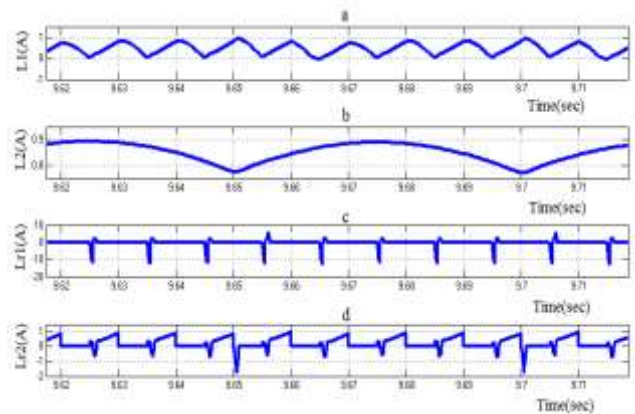


Fig. 18. (a) Inductor current L_1 (b) Inductor current L_2 (c) Inductor current L_{r1} (d) Inductor current L_{r2} .



Simulation of the proposed circuit gave output voltages 48V in boost mode and 14V in buck mode for an input voltage of 24V. From the simulation results we can see that the proposed converter can be used for both buck and boost operation.

VII. EXPERIMENTAL SETUP AND RESULTS

Experimental set up of the ZVT fifth order boost converter is shown in Fig. 19. To obtain the switching pulse micro controller PIC16F877A is used. The program for control pulse is written in microC. The program is verified and the frequency is checked by simulating the program using proteus software. The output of the micro controller is given to a driver IC TLP250. These pulses are fed to the gate of switches in the power circuit.

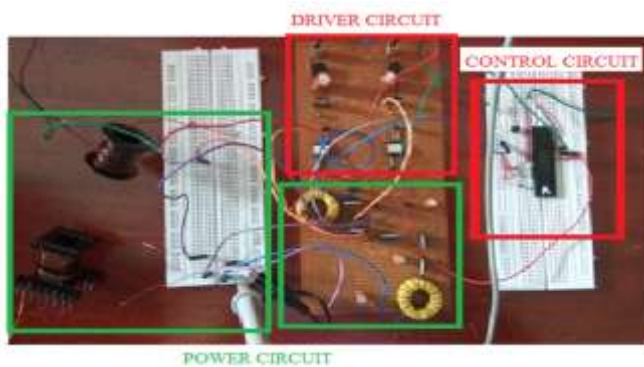


Fig. 19. Experimental setup of ZVT fifth order boost Converter

The input DC voltage to the converter and the output is taken across the resistors. The output voltage shown in Fig. 20.



Fig. 20. Output V_0

VIII. CONCLUSION

The ZVT DC-DC buck-boost converter is simulated using MATLAB/Simulink software. The ZVT DC-DC buck-boost converter has been found to be yielding improved efficiency as compared to ZVT fifth order boost converter. The advantage of the converter is that it can be operated in buck and boost

mode. The duty ratio of the switches S1 and S2 are interchange to operate in buck or boost mode. The hardware model is show in above and the voltage gain is obtained as 2. The analysis result were validated through simulation and experimental measurements. Measured result were in close agreement analytical prediction.

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