BIDIRECTIONAL DC-DC CONVERTER WITH SOFT-SWITCHING TECHNIQUE FOR BATTERY CHARGING

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Abstract: *In this paper soft switching technique is employed for a bidirectional non-isolated DC-DC converter. For turn on Zero-Voltage Switching (ZVS) technique is applied for turn off and Zero-Current Switching (ZCS) technique is implemented. Input voltage (VL) acts as source in step-up mode. High output gain is attained as a result of current flow from source to load. If VL acts as load that is when the current flow reverses the output voltage gain is low. When hard switching technique is used the switching loss increases and more heat is dissipated. Therefore in this technique, life span of switches is improved by less heat loss and the output voltage can be increased. The converter plans to reduce the switching current and also improves voltage gain when compared to the conventional bidirectional converters. It uses an intermediate switching pattern to carry out seamless mode change.*

Key words: *Zero voltage switching (ZVS), Zero current switching (ZCS), Pulse width modulation (PWM), Continuous conduction mode (CCM), Bidirectional DC-DC converter (BDC).*

1. INTRODUCTION

A DC-DC converter is an electronic circuit which converts direct current from one voltage level to another which is a type of power converter. The converter can be used in aero space applications, battery charging, battery operated Electric vehicle, telecom applications. Such electronic devices mostly contain several sub-circuits that are different from that supplied by the battery or any external supply may be higher or lower than the supply voltage. Moreover, the battery voltage decreases as its stored power is decreased. Switched DC-DC converters offer a method to increase voltage from a partially lowered battery voltage, thereby save the space instead of using a number of batteries. Most DC-DC converters will regulate the output. High efficiency light emitting diode (LED) power sources belong to the type of DC-DC converters, which regulates the current through the LEDs, and the charge pumps will double or triple the input voltage [1]. A bidirectional DC-DC converter is used for dc-dc conversion process. The power converter has two full bridge converters, one act as inverter and other as rectifier. This bidirectional DC-DC converter is suitable for electrical vehicle applications. It has advantages of simple circuit with soft switching implementation (ZVS and ZCS), without additional devices. It has high efficiency and simple control. These advantages make the converter applicable for low, medium and high power applications; mainly for auxiliary power supply in fuel cell vehicles and power generation. It is used in applications where high power density, low cost, low weight and high reliability power converters are required. Micro Controller is used to create pulses for switches. It triggers, operate and control Metal Oxide Semiconductor Field Effect Transistor (MOSFET) devices. Pulse Width Modulation (PWM) technique is used to reduce the harmonics and noises in the circuit [3] - [8].

Most of the existing Bidirectional DC-DC Converters (BDC) has a basic circuit structure, which is fed by a current or voltage on one side. Based on the auxiliary energy storage and conduction period, the bidirectional DC-DC converter can be classified into buck and boost converters. The buck type has energy storage placed on the high voltage with low conduction period and the boost type has it placed on the low voltage side with high conduction period. It is classified into two types:

- Isolated DC-DC Bidirectional Converter
- Non- Isolated DC-DC Bidirectional Converter

The converter has the following advantages [9]:
1) High voltage gains for both boost and buck operations;
2) Reduced voltage stresses of switches;
3) ZVS turn on and ZCS turn off of switches in Continuous Conduction Mode (CCM) operation;
4) Reduced energy volumes of passive components;

2. PROPOSED CONVERTER

The proposed converter consists of a general half-bridge converter as the main circuit and an auxiliary circuit that includes the capacitor C_a, inductor L_a, and four High-Voltage Side (HVS) switches as shown in fig1. It is assumed to regulate the HVS voltage, while allowing bidirectional power flow according to the direction of inductor current. The block diagram consists of BDC whose input is connected to a DC source and output is filtered by inductor-capacitor (LC) filter, which is fed to a battery. The switches used in the BDC are MOSFETS that are triggered using pulses generated by PIC controller and amplified by a power amplifier. The power supply is given separately to this control circuit.

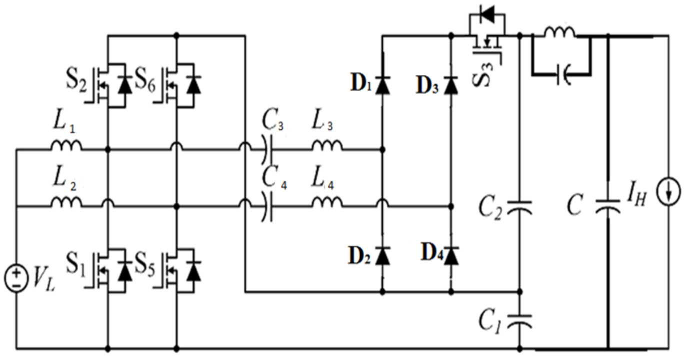

Fig 1: Circuit diagram of proposed converter

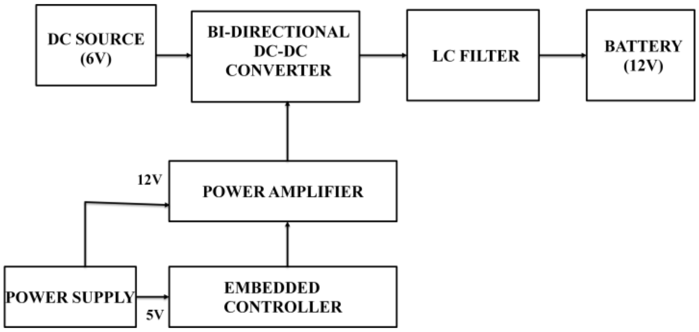

Fig 2: Block diagram of proposed converter

a. Operating Principle

The capacitances C_1, C_2 and C are large enough so that voltages V_{C1}, V_{C2}, and V_C across them are constant during the switching period T_S. In boost mode, Low-Voltage Side (LVS) switches S_1, S_2, S_5 and S_6 are operated with asymmetrical complementary switching with duty cycles of D (duty cycle) and 1−D respectively. Initially when S_1 is turned on, inductor currents i_{Lf} starts to increase and i_{La} starts to decrease respectively. The slopes are determined by the following equations:

$$\frac{di_{L1}}{dt} = \frac{V_L}{L_1} \quad [1]$$

$$\frac{di_{L2}}{dt} = \frac{V_L}{L_2} \quad [2]$$

$$\frac{di_{L3}}{dt} = \frac{V_{C3}-V_{C1}-V_{C2}}{L_3} \quad [3]$$

$$\frac{di_{L4}}{dt} = \frac{V_{C4}-V_{C1}-V_{C2}}{L_4} \quad [4]$$

To analyze the steady state operation of the converter, the following assumptions are made [10]:

1) The output capacitor C is large enough to assume that the output voltage V_o is constant and ripple free.
2) The main inductor Lf is large enough to be treated as a constant-current source I_{Lf}.
3) Main inductor L_f is much greater than resonant inductor L_r.
4) The semiconductor devices and the reactive elements are ideal.

b. Voltage Conversion Ratio

The HVS voltage is given by the following equation:

$$V_H = \frac{2}{1-D_{eff}} \cdot V_L \quad [5]$$

where the effective duty is defined as follows:

$$D_{eff} = D - d_3 \quad [6]$$

where d_3 means duty loss at switch S_3. The output voltage can also be expressed as follows:

$$V_H = \frac{2}{1-D} \cdot V_L - \Delta V \quad [7]$$

where ΔV is the voltage drop caused by the duty loss. The voltage drop ΔV can be obtained as follows:

$$\Delta V = \frac{2V_L * d_3}{(1-D)(1-D+d_3)} \quad [8]$$

Because the average current of C_3, C_4 and C_2 is zero, the average absolute currents of HVS switches can be expressed as follows:

$$\frac{1}{T_S}\int_0^{T_S} |i_{S3}|\, dt = I_H \quad [9]$$

where $I_H = V_H / R_H$.

A. Mode I operation

The diode across switches S_1 and S_5 conducts initially as shown in fig. 3(a). The current flows through both L1, C_3, L_3, D_1 and L_2, C_4, L_4, D_3 to switch S_3 to C_1, C_2 and then to the load.

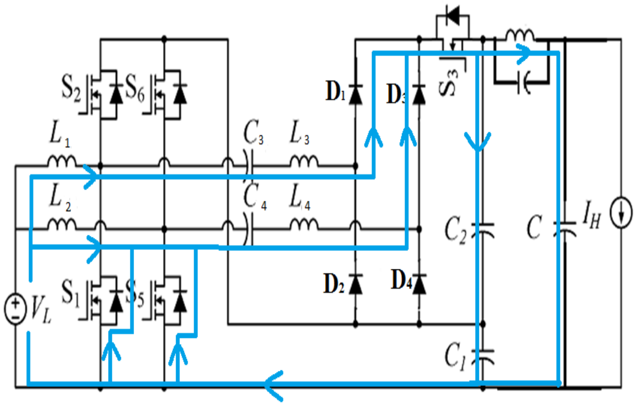

Fig 3(a): Mode I operation

B. Mode II operation

The switches S_1 and S_5 start conducting. The input voltage is fed to the input inductors L_1 and L_2 to store charge as well as to the load.

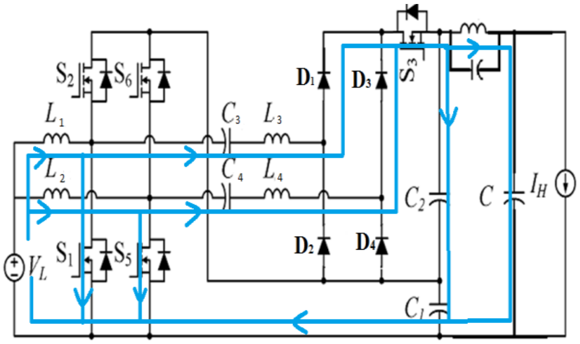

Fig 3(b): Mode II operation

C. Mode III operation

The capacitor C_1 starts discharging where the current flows load and input switches. The current through switches S_1 and S_5 is the sum of input current and current through capacitor C_1 respectively.

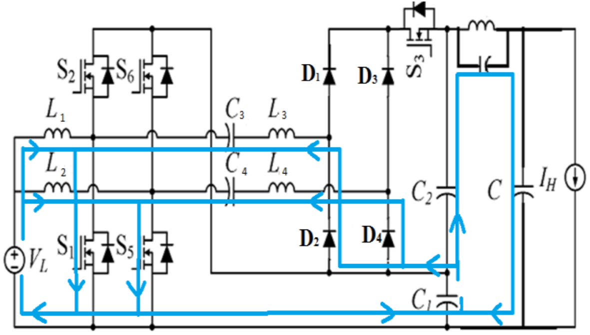

Fig 3(c): Mode III operation

D. Mode IV operation

The diodes across switches S_2 and S_6 allows current to flow from input to capacitor C_1. The HVS diodes D_2 and D_4 conduct.

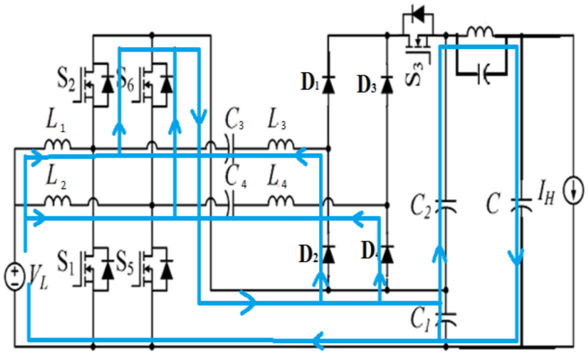

Fig 3(d): Mode IV operation

E. Mode V operation

The switches S_2 and S_6 are turned on which forward biases the diodes D_1 and D_3 respectively. Switch S_3 is turned on so that the current flows to the battery load.

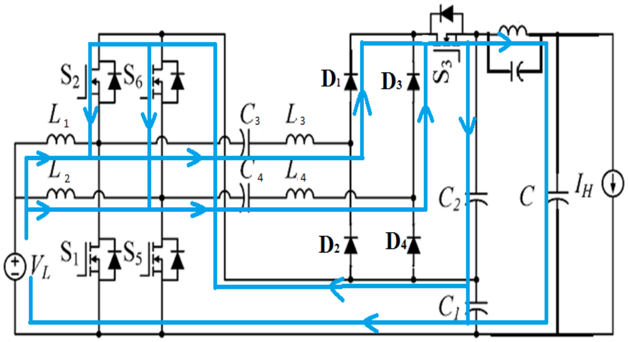

Fig 3(e): Mode V operation

3. SIMULATION RESULTS

The interleaving technique can be applied to reduce the size of passive components and current stresses. A 5.9W prototype of the BDC shown in Fig.1 has been simulated according to the following specification:

$P_o = 5.92$ W, $f_s = 1$ kHz, $V_H = 14.21$ V, $V_L = 6$ V,
$L_f = 50$ µH, $L_a = 50$ µH, $C_a = 10$ µF, $C_1 = C_2 = 10$ µF.

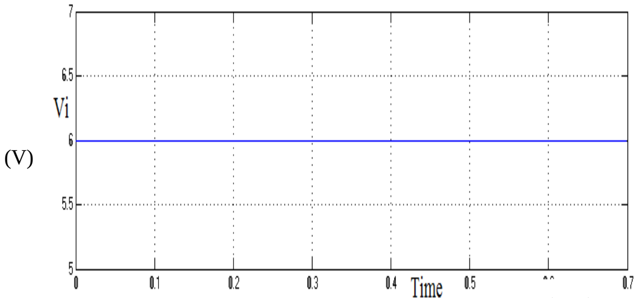

Fig 4: Input voltage waveform

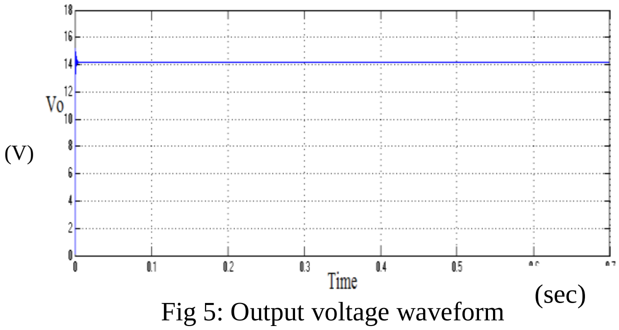

Fig 5: Output voltage waveform

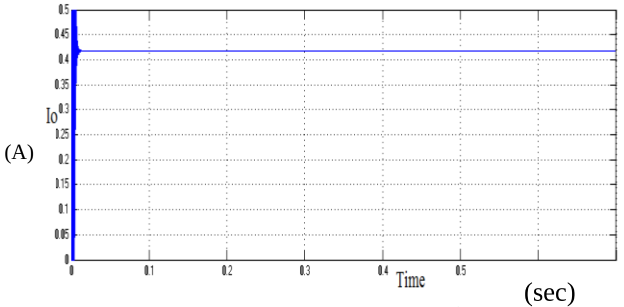

Fig 6: Output current waveform

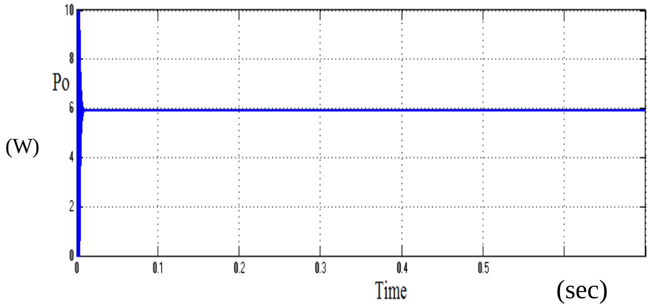

Fig 7: Output power waveform

The pulses given to the gate of each switch is shown in fig.10. The gate pulses to switches S_1 is complement to switch S_2. The gate pulse given upper switches S_2 and S_6 and the gate pulse given lower switches S_1 and S_5 are identical.

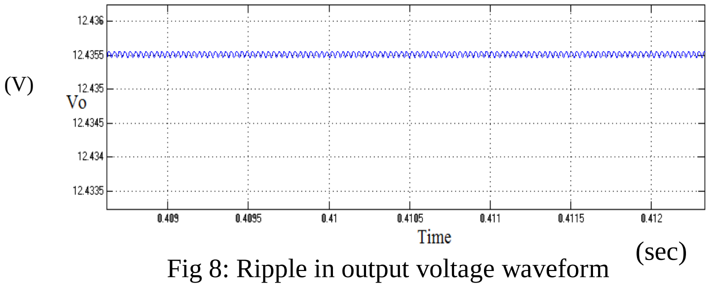

Fig 8: Ripple in output voltage waveform

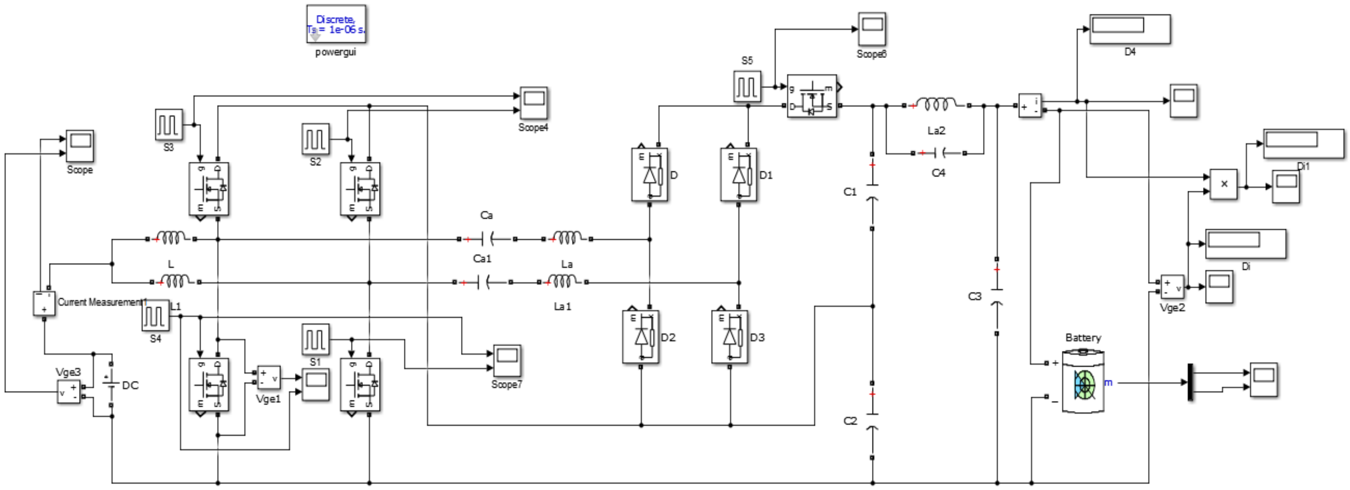

Fig 9: Simulink diagram of proposed circuit

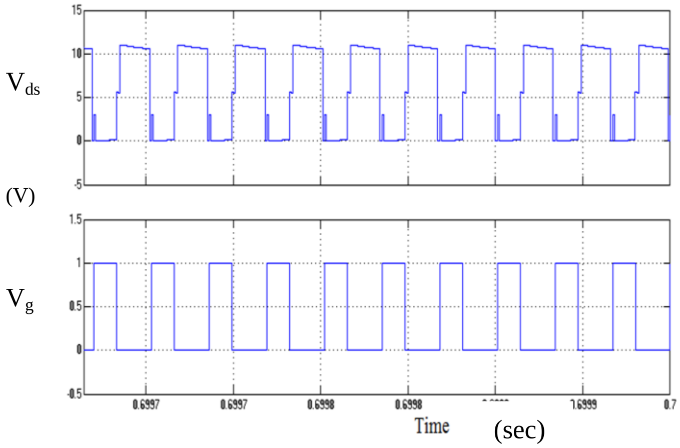

Fig 9: Drain to source voltage and switching pulse of single switch

6V DC input is given to get an output voltage of 14V, power obtained of 6W approximately with a 0.42A output current. The drain to source voltage applied to each MOSFET switch is 10V.

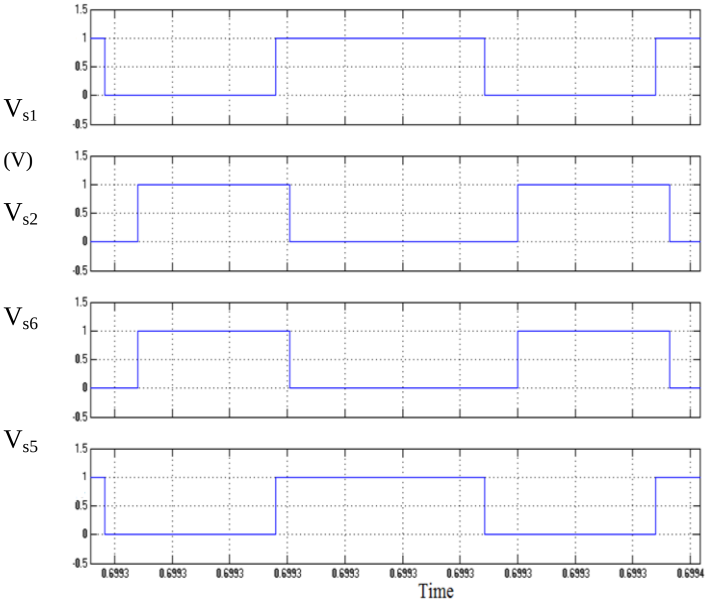

Fig 10: Switching pulses to four switches

4. HARDWARE RESULTS

The simulated prototype has been implemented and the output is verified. The output of the setup is given to a rechargeable battery used in motorcycle.

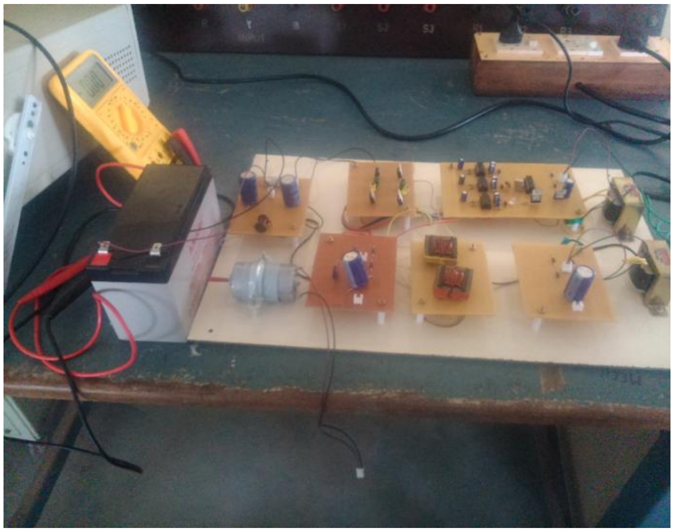

Fig 11: Complete hardware setup

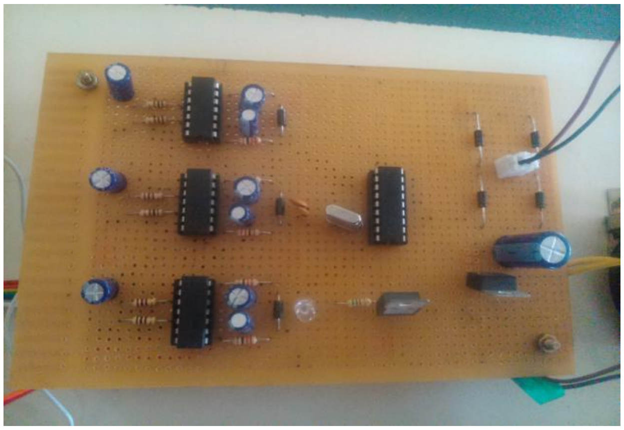

Fig 12: PIC microcontroller circuit

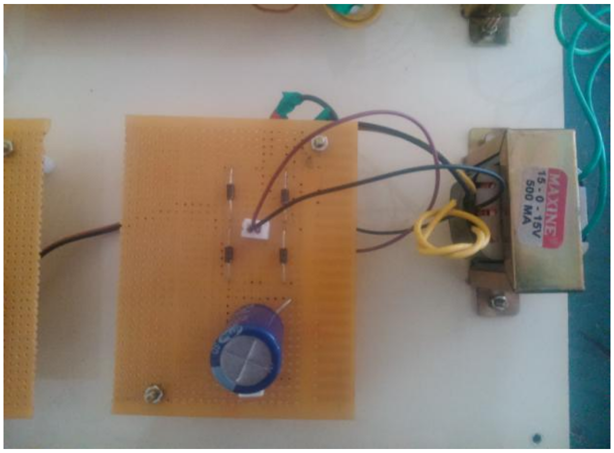

Fig 13: Input power circuit

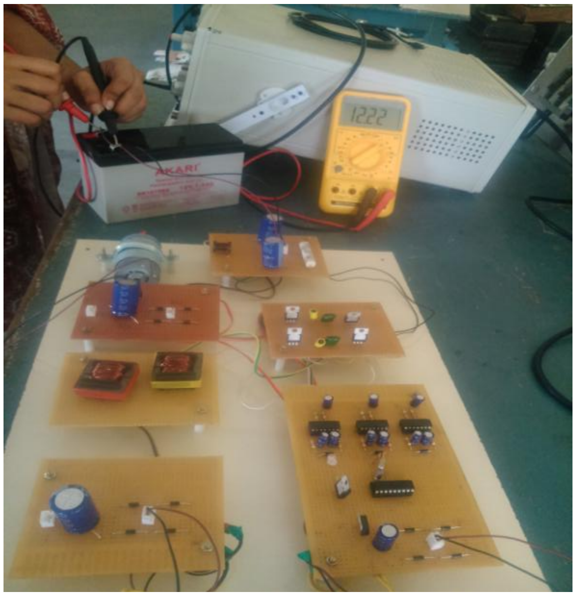

Fig 15: Output 12V in multimeter

Fig 16: Output 12V in CRO

5. CONCLUSION

In this paper, a non-isolated soft switching BDC has been proposed for high-voltage gain and low-power applications. The proposed converter can achieve ZVS turn on of all switches and ZCS turn off some switches in both boost and buck operations. An optimized switching sequence has been presented along with an intermediate switching pattern to carry out seamless mode change. ZVS reduces the switching current and frequency and a high output voltage is obtained. A 5.9W prototype of the proposed converter has been simulated to justify the proposed operation. A 6V DC input voltage is boosted to 14V and fed to the resistor after filtering. The converter used for low power applications can be modified by isolating the LVS and HVS using a transformer for high power applications.

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