ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645
Indian Journal of Science and Technology, *Vol 9(38), DOI: 10.17485/ijst/2016/v9i38/101916, October 2016*

Single Stage Multi Input DC-DC/AC Boost Converter with Sliding Mode Control

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Abstract

Objectives: This paper proposes a single stage conversion of multiple input dc to dc/ac output. This structure reduces multi stage conversion and eliminates the need of transformer. **Methods/Statistical Analysis**: The bidirectional switching port is used to reduce circuit complexity and for simple operation. The bidirectional circuit connects battery to load. The voltage is stepped up to high level using boost converter. The output obtained is pure ac/dc without the need of filter. The voltage can be regulated with the help of a battery which charges and discharges when required. The bidirectional circuit switching control is done by using sliding mode controller. **Findings**: The control of the converter is possible during the change in voltage from 40v to 50v. **Novelty/Improvement:** Implementing sliding mode control in simulation.

Keywords: Distributed Generation (DG), Fuel Cells (FC), Multi Input Converter (MIC), Photo Voltaic (PV), Sliding Mode Control (SMC)

1. Introduction

In recent years, the usage of renewable resources is becoming more necessary due to the increased consumption of fossil fuels. The implementation of multiple renewable resources is in need because we cannot rely on a single source. In current field of research, hybrid systems are highly preferred for their multi input topology. Multiple sources have to be interfaced together to obtain a pure dc or ac output. This paper proposes a high voltage dc or ac output using bidirectional converter with the help of sliding mode control.

A single stage MIC with a centralized structure and boosted voltage inputs aims to reduce switches and using a battery for producing a required voltage[1]. Multi input converters supply power to a single load[2]. This can be done simultaneously by, every source connecting to load or each source supplying load one at a time. Grid connected hybrid systems with wind and PV reduce generation cost. Cost effective maximum power point tracking techniques like perturb and observe are implemented[3].

This paper integrates buck boost converter with multi input to get a pure dc output. Multiple input dc-dc converters simplify circuit and reduce cost effectively[4]. Single input dc-dc converters aims to minimize number of components. This system uses a forward conduction switch and blocks reverse current[5]. Hybrid electrical vehicles require power for traction application. The power flow changes for each mode of operation, the modes are forward motoring and regeneration[6].

Hybrid energy system is used for conversion of dc to ac power. This system is able to do both buck and boost operation with the help of a transformer[7]. Three input dc boost converter with bidirectional port is used. The battery storage is presented with only four switches and each switch is independently controlled by pulse signals[8].

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A new topology with dc link and magnetic coupling is studied. This system interconnects many sources without the need for more switches[9]. Feedback is difficult in the implementation of multi input and multimode operated converters[10]. In a four port dc converter, three ports are operated in regulated voltage while the fourth port is used for balancing power[11]. Converter topology for dual input dual mode operation is compared with three port operation[12].

High step up voltage is achieved by using coupled inductors[13]. Energy management in DG is done using bidirectional converter from sources such as Photovoltaic and Fuel cells[14]. A slow transient response is corrected using multi-level inverter[15]. The converter operates in both stand-alone mode and grid interfaced mode, and provides continuous supply by using fuel cell. This system also employs active filtering[16].

In the hybrid system, both photovoltaic and wind sources are connected to produce an ac output with reduced cost[17]. For high gain applications, duty cycle of bidirectional converter is increased. An impedance network is used to avoid reverse recovery problems[18]. A bidirectional dc converter with z source inverter is fed by hybrid system[19]. Sliding mode control is implemented in dc to ac boost converter[20]. Single stage PV based boost inverter is implemented to compensate voltage problems like sag, swell and interruptions[21]. Multi input converter with various PWM methods and their control strategies are discussed[22-30]. Hybrid applications include solar, wind and fuel cells with dc converter is studied[31–36].

2. Single Stage Multi-Input Operation

There are multiple stages involved in producing an ac or dc output from multiple dc inputs. This system reduces multiple stages of conversion and filtering by implementing bidirectional converter. The multiple stages include voltage boosting, inversion of dc to ac power, and a transformer to step up the voltage. Here the ac voltage can be taken and converted to dc voltage. These steps can be simply bypassed by using a bidirectional circuit, which acts either converter or inverter based on the mode of operation.

3. Block Diagram of Single Stage Multi-Input Converter

The block diagram of two input boost converter with switching circuit interfaced with load is shown in Figure1. A battery is connected to the switching circuit.

The bidirectional circuit is used to provide the power to load from both the sources. The battery discharges

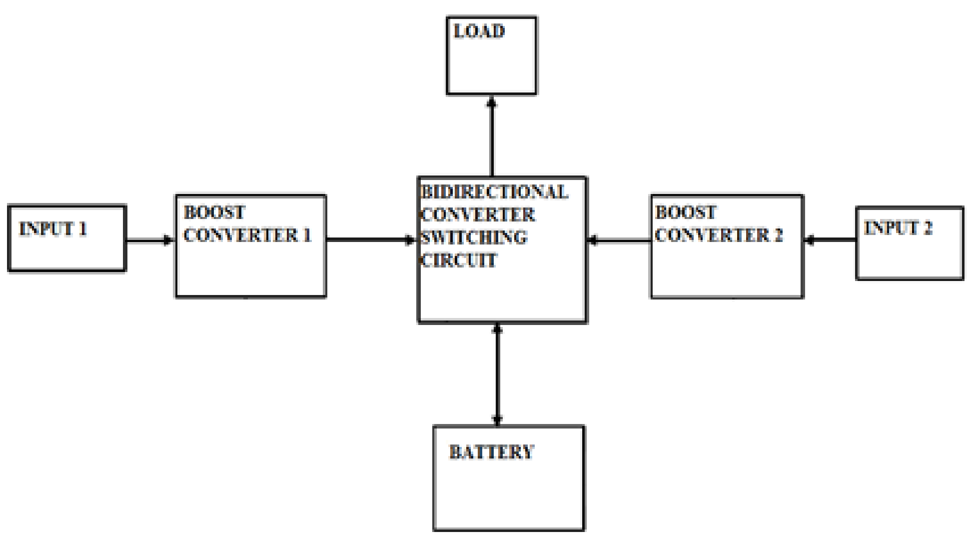

Figure 1. Block diagram of single stage multi input converter.

when the respective switches conduct.

The bidirectional circuit conducts both sides to provide power to load continuously. The main advantage of having a load fed from bidirectional circuit is the centralized control. The switching of central converter determines its mode of operation and usage of battery. This is irrespective of any number of loads.

The centralized control becomes unstable if inputs vary. This can be overcome by implementing sliding mode control. The number of boost converter stages can be increased with the number of inputs. The centralized control remains same whatsoever.

The battery is charged and discharged during the circuit operation for providing the required voltage. It mostly discharges during ac mode of operation.

4. Circuit Diagram

The circuit diagram for boost converter based bidirectional single stage switching circuit is shown in Figure 2. The components and their values are given.

The input is given to boost converter for high voltage. The capacitor acts as voltage balancer. More inputs can be added on the either side of main circuit. The dependable sources are used here based on the fact that the source adjusts according to load and operates accordingly. The bidirectional switching circuit operates in two modes. The overall output is obtained in load resistance R_L. The inductance and resistance are connected in series with the battery for controlling the voltage level.

The voltage inputs V_a and V_b differ in magnitude. Input V_a is 40 volts and V_b is 50 volts. So their respective boost inductor values vary. The lower half power switches in the bidirectional circuit are replaced by capacitors for reducing switching losses.

Circuit diagram single stage multi input boost converter is shown in Figure 2.

5. Modes of Operation

The circuit operates in two modes of operation. The modes are dc output mode and ac output mode. In dc output mode, the one switch conducts. The voltage is obtained across capacitor. In ac output mode, the switching circuit conducts. The battery discharges and the voltage difference between both capacitors provide an ac output.

6. Dc output Mode

The input voltages Va and Vb are boosted and compared with each other. The difference between them appears in the output R_L. V_{11} and V_{12} are the voltage outputs across capacitor C_1 and C_2 respectively.

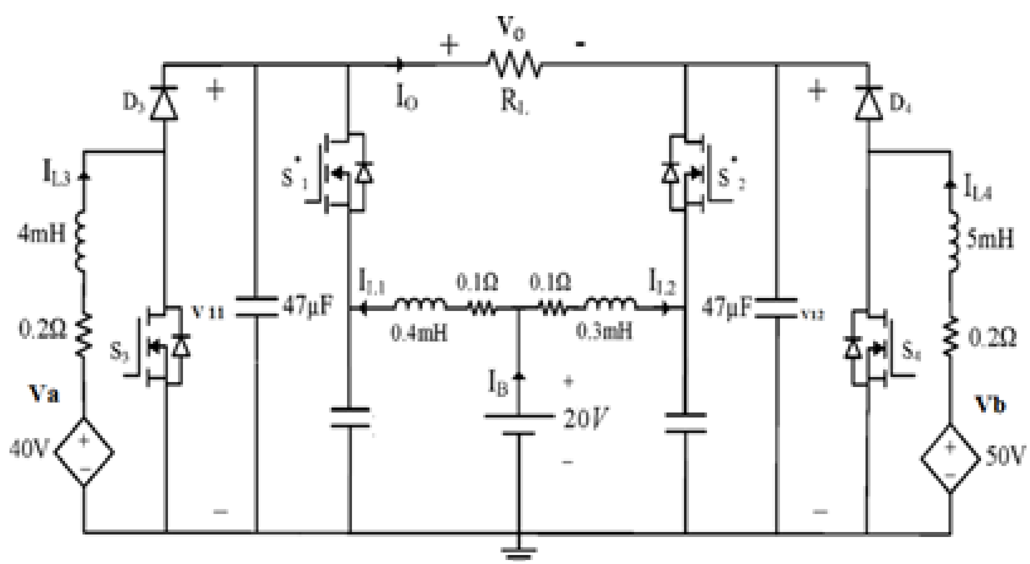

Figure 2. Circuit diagram single stage multi input boost converter.

$$V_{11} = V_a, \qquad V_{12} = V_b, \qquad V_0 = V_a - V_b \tag{1}$$

And the output current and power at R_L are given by,

$$I_0 = \frac{V_a - V_b}{R_L}$$

$$P_0 = V_0 I_0 = \frac{\left(V_a^2 - 2V_a V_b + V_b^2\right)}{R_L} \tag{2}$$

The power of both sources can be simplified as follows,

$$P_{11} = \frac{(V_a^2 - V_a V_b)}{R_L} \tag{3}$$

$$P_{12} = \frac{-\left(V_a V_b - V_b^2\right)}{R_L} \tag{4}$$

As much as the voltage inputs are added the difference between both side voltages is taken as dc output voltage. The switch S_2 conducts the path closes.

7. Ac Output Mode

During AC mode of operation both the switches conduct and dive out a sinusoidal output. The difference between the two voltages is 180°, while their dc component remains similar:

$$V_{11} = V_{dc} + \frac{V_m}{2}\sin\omega t \tag{5}$$

$$V_{12} = V_{dc} - \frac{V_m}{2}\sin\omega t \tag{6}$$

The output voltage is hence obtained as follows:

$$V_0(t) = V_{11}(t) - V_{12}(t) = V_m \sin\omega t \tag{7}$$

The current and power values can be deducted from this:

$$I_0(t) = I_m \sin\omega t, \qquad I_m = \frac{V_m}{R_L} \tag{8}$$

$$P_0(t) = V_0(t) I_0(t) = -\frac{V_m I_m}{2}\cos 2\omega t + \frac{V_m I_m}{2} \tag{9}$$

The corresponding power of both sources is as follows:

$$P_{11} = V_{dc} I_m (\sin\omega t) - \frac{P_0}{2}\cos 2\omega t + \frac{P_0}{2} \tag{10}$$

$$P_{12} = -V_{dc} I_m (\sin\omega t) - \frac{P_0}{2}\sin\omega t - \frac{P_0}{2}\cos\omega t + \frac{P_0}{2} \tag{11}$$

The ac output voltages across capacitor C_1 and C_2 are compared an equivalent waveform is produced which gives the resulting output at load R_L. The average power is half the product of voltage output and current output whereas the 2ω is pulsating component of load power.

8. Simulation Results

The following circuit is simulated in MATLAB Simulink environment and following results are obtained. The circuit operates in two modes, i.e., dc output mode and ac output mode.

8.1 Dc Output Mode

The supply voltages are 40 and 50 volts, these are boosted up by boost converter.

Simulation of single stage converter with sliding mode control for dc output is shown in Figure 3.

In sliding mode control, the difference in ac and dc output mode is dc signal can be varied easily and manipulated for control purpose. The ac power has to be converted to dc and then controlled.

The input voltages are different from one another making the system adaptive, and implementing control would result in robust performance. The input voltages are changed after some time to 50V and 60V for first and second source respectively. The changes in the input are reflected on output for few milliseconds and then the control system maintains the output as expected.

Input voltages for dc-dc mode of operation are shown in Figure 4.

Voltage obtained across capacitors C_1 and C_2 is shown in Figure 5.

The capacitors C_1 and C_2 are important in obtaining voltage across resistor. The difference between these two would generate the output voltage from the number of outputs. The capacitor voltages read 150V and 40V. The

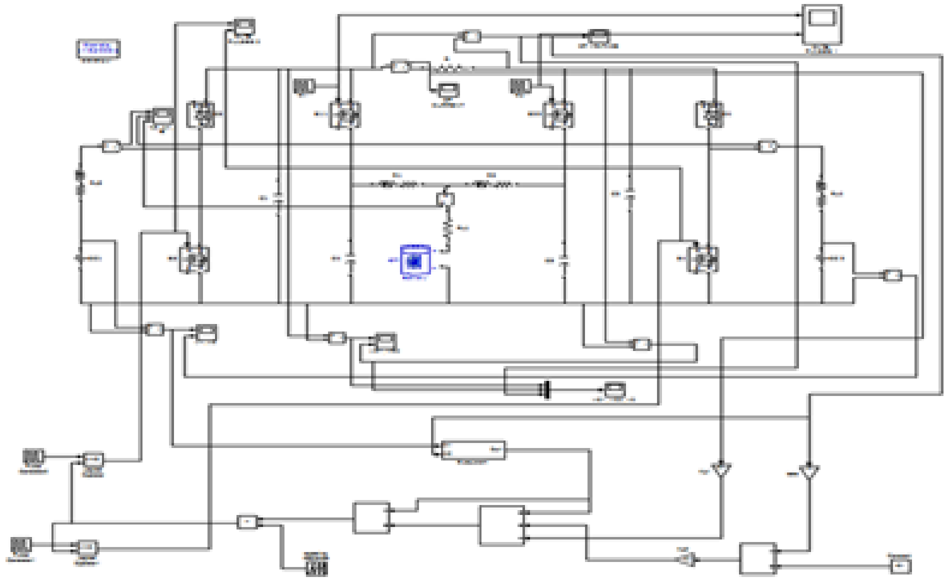

Figure 3. Simulation of single stage converter with sliding mode control for dc output.

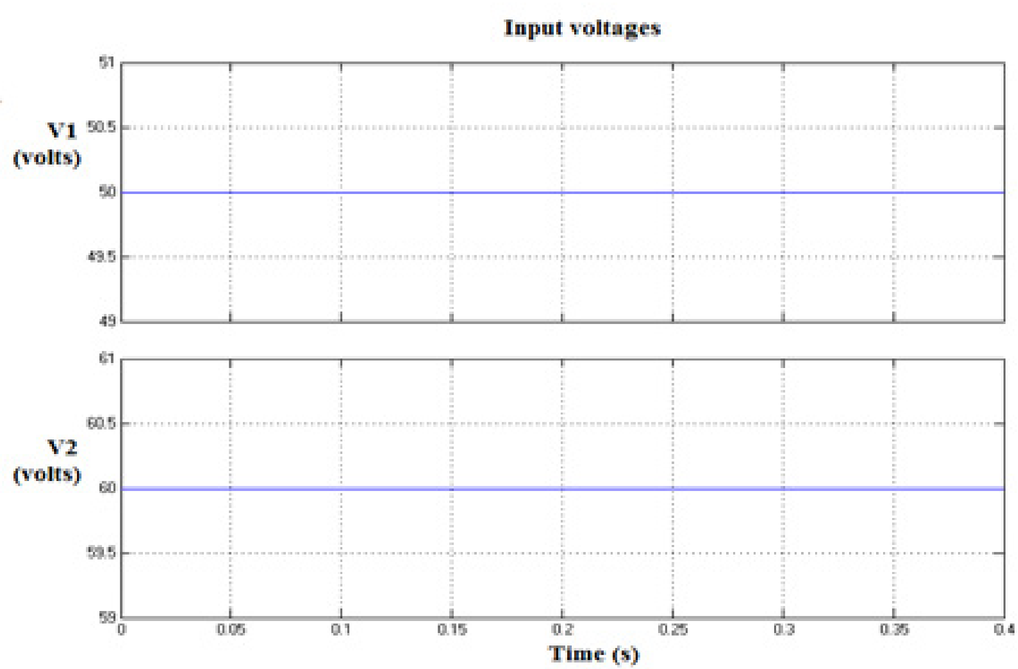

Figure 4. Input voltages for dc-dc mode of operation.

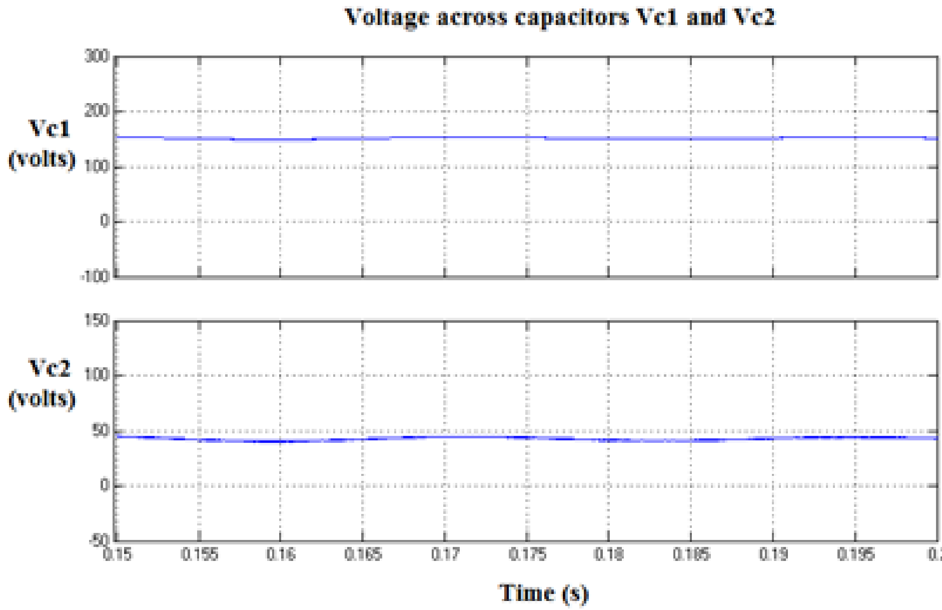

Figure 5. Voltage obtained across capacitors C_1 and C_2.

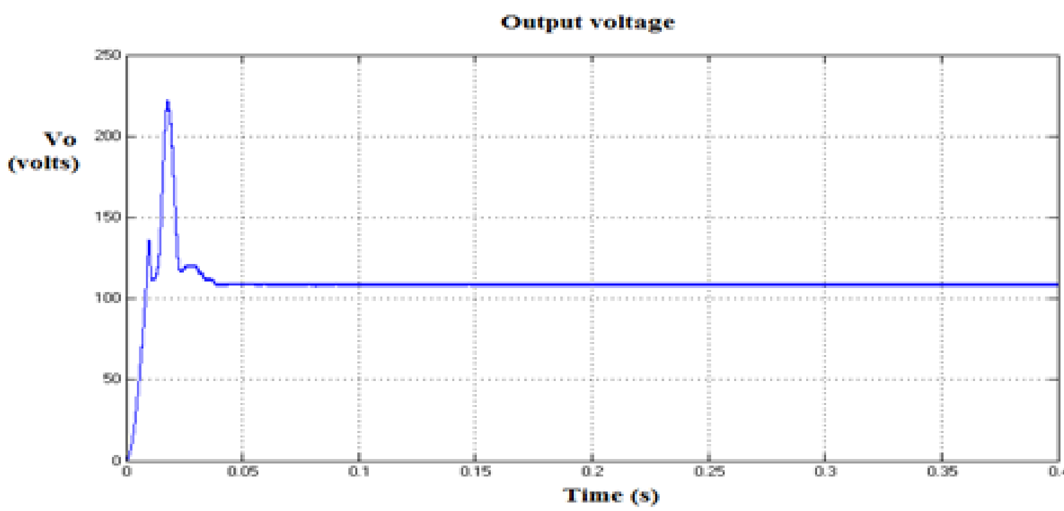

Figure 6. Dc output voltage across resistor.

difference is due to their input values inductance values and capacitance values.

Dc output voltage across resistor is shown in Figure 6.

The dc output is the difference between 150V and 40V and the obtained voltage is 110V. The initial disturbance in rise is due to transients and the system has to adjust to input changes and still be able to produce same output.

8.2 Ac output Mode

The ac voltage is obtained by implementing the bidirectional converter circuit. This inversion operation is carried out and produces peak to peak ac voltage. The sliding mode control is used to give the pulses to the inverter switches, and the inverter converts dc power into ac.

The output voltage is obtained across the resistor in ac mode. The battery supplies the input dc voltage to the circuit. The input voltages 40V and 50V remain the same.

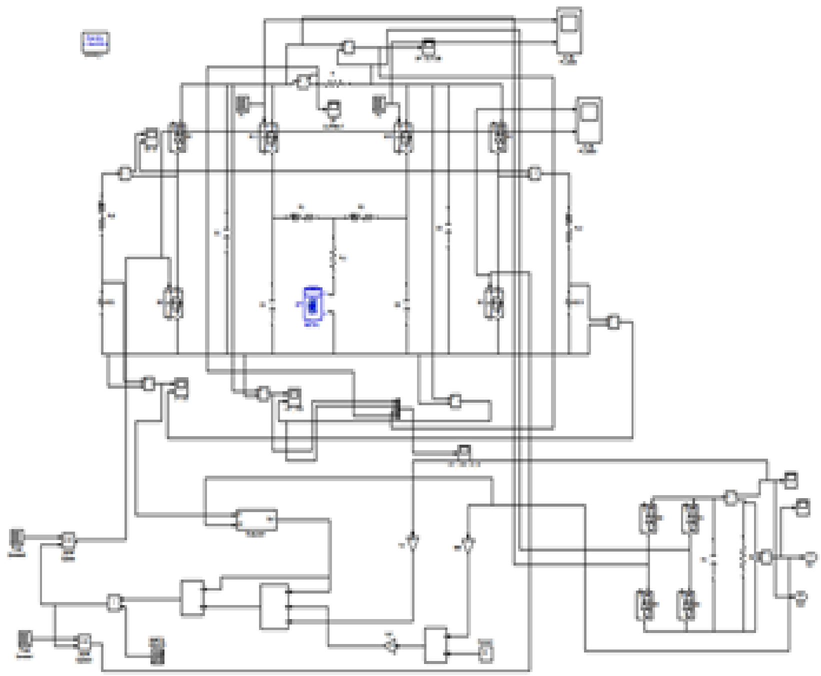

Figure 7. Simulation of single stage multi input converter with sliding mode control for ac output.

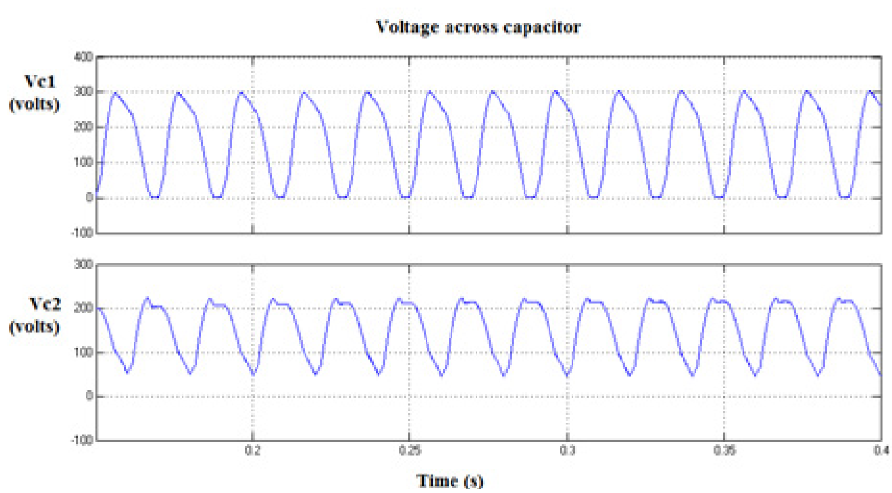

Figure 8. Voltage obtained across capacitors C_1 and C_2.

The varying voltage across the capacitor is due to the fact that the switches conduct vice versa. The switch S_1 conducts for positive half cycle and the switch S_2 conducts for negative half cycle of the output voltage. A pulsating voltage is obtained across capacitors C_1 and C_2.

Simulation of single stage multi input converter with sliding mode control for ac output is shown in Figure 7.

The output voltage value is the difference between the voltages across two capacitors. As shown in the Figure 8, the capacitor 1 has voltage of about 300V and capacitor 2 has the voltage of 100 V. When the waveforms are overlapping, the obtained voltages resemble a pulsating wave.

Voltage obtained across Capacitors C_1 and C_2 is shown in Figure 8.

The output voltage is obtained across R_L. The peak to peak output voltage is 400V. The battery discharges using both the switches, and the discharged voltage is 20V.

Ac output voltages across load resistor are shown in Figure 9.

The replacement of switches by capacitors does not have much impact on output voltage, but the switching losses can be reduced.

The output voltage required is a sine wave 50 Hz frequency. The ac voltage has initial transients and adjusts later because of closed loop configuration.

9. Experimental Results

The system can be realized in hardware simulation by implementing a small scale model with input voltages as 6V and 11V. The capacitor is rated for 22μF, and the two inductors are rated for 2mH and 3mH respectively. The controller used here is PIC controller P167877A which has major functions like generating clock pulse using crystal oscillator.

Prototype of single state multi-input converter is shown in Figure 10.

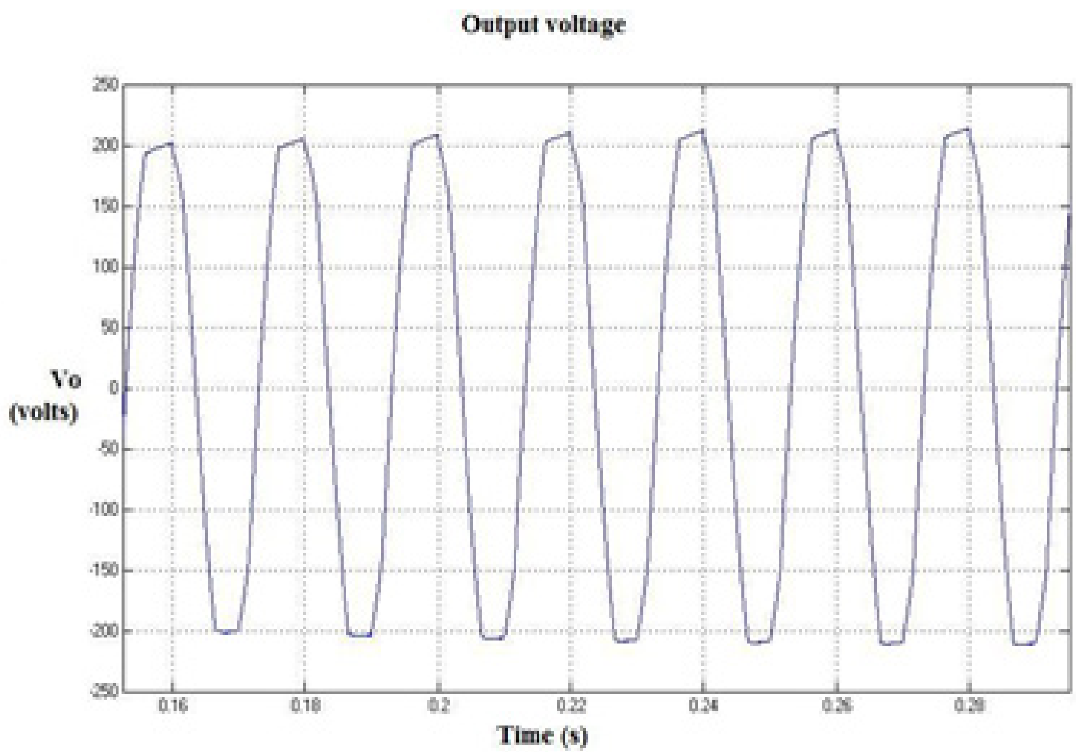

Figure 9. Ac output voltages across resistor.

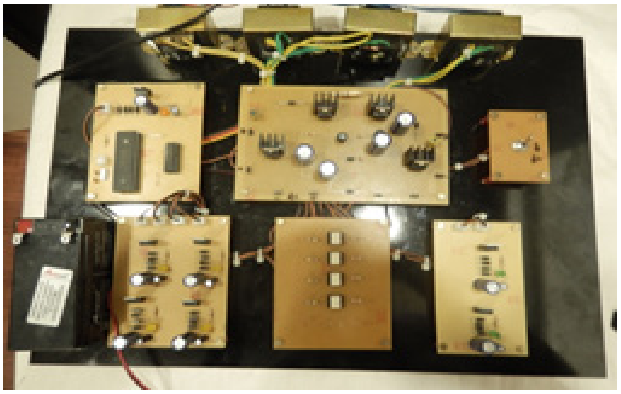

Figure 10. Prototype of single state multi-input converter.

A 230V ac supply is stepped down to 5V, 15V, 12V and 6V by each transformer separately. The 5Vdc supply obtained from regulated power supply is utilized by gate pulse circuits and micro controller. The 15V dc obtained from another regulated power supply is used by opt coupler. The 12V and 6V are inputs voltages are given to the switching circuit.

Dc voltage input 6 volts is shown in Figure 11.

In the given Figure 11 the input is taken as 6V and other input as 12V while the capacitor charging voltage is 13V. They are added up to get the desired dc voltage of 30V.

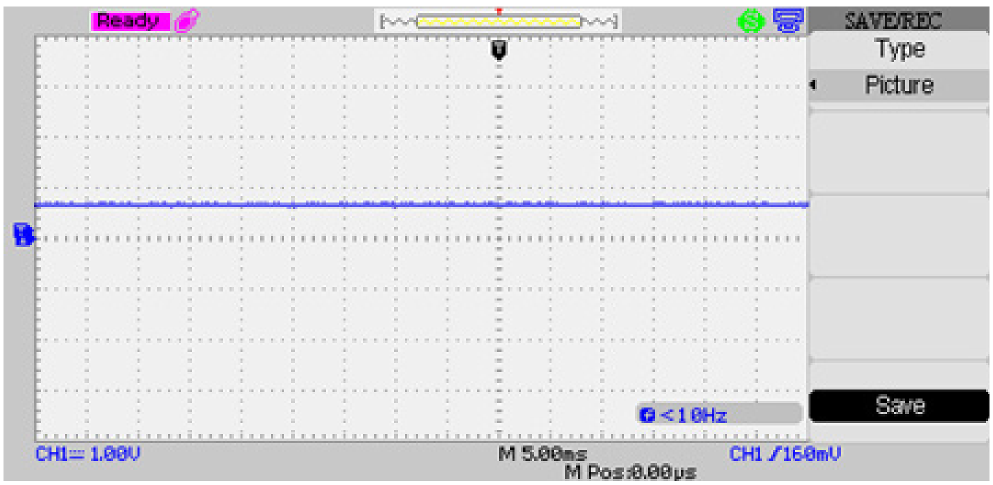

Figure 11. Dc voltage input 6volts.

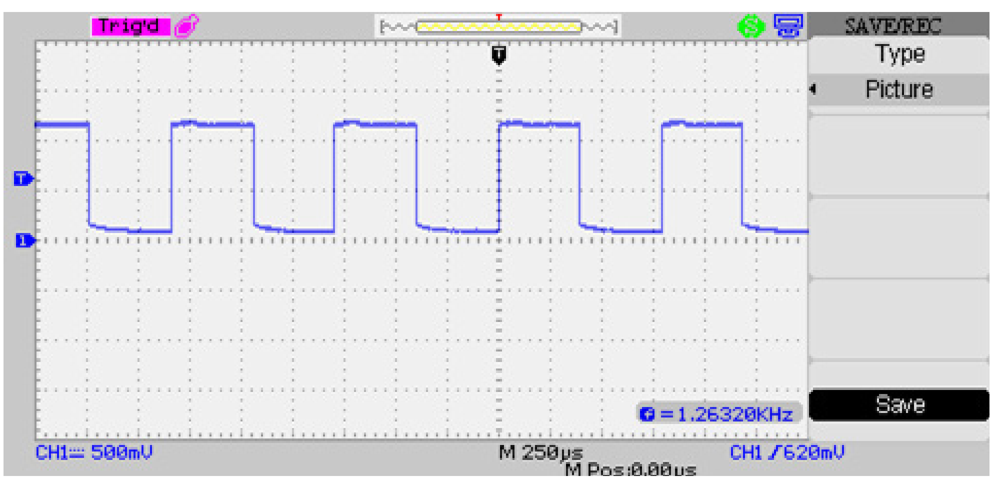

Figure 12. Triggering pulses for the switch S1.

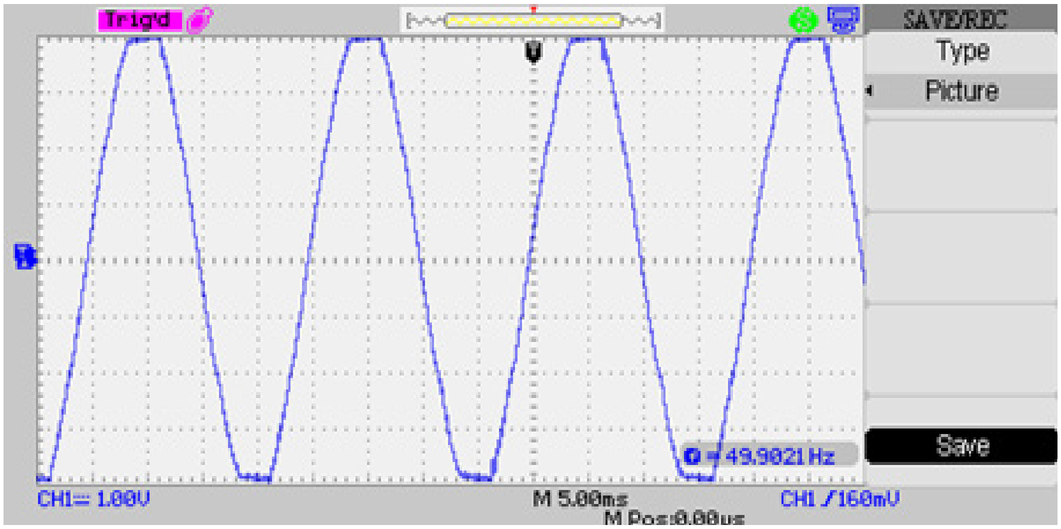

Figure 13. Ac output obtained across R load.

Triggering pulses for the switch S1 is shown in Figure 12.

The pulses are given to switch S1 for the conduction period of 50μs. Both the switches S1 and S2 of the converter conduct at different intervals during ac mode of operation.

Ac output obtained across R load is shown in Figure 13.

The peak to peak voltage across load resistor R_L is 80V. The battery voltage available during ac mode is measured to be 20V.

10. Conclusion

Multi input converter using two voltage sources is simulated with sliding mode control. The converter is able to produce both high voltage dc and ac output. The control is simplified by using centralized bidirectional switching method with sliding mode. The results obtained show capacitor voltage values and inductor current values satisfactorily. The output expected is obtained with the help of a battery which charges and discharges accordingly. The prototype model built for single stage multi input bidirectional converter provides dc and ac output voltage, when operated separately in dc mode and ac mode respectively. The output voltages obtained from prototype model are verified with the output voltages obtained from the simulation circuit.

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