

# Bi-Directional Buck-Boost DC-DC Converter for Stand Alone PV Power Generation Systems

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**Abstract:** The bidirectional buck–boost converter can supply the current in both directions based on the mode of operation decided by the requirement of the application. The additional battery is connected with bidirectional DC-DC converter. This particular battery is utilized during some events when more power is needed to step up the voltage particularly during up lifting. Bidirectional buck–boost converter is used to charge the battery when the load is running smoothly from source. This is called reverse mode of operation. When transients and overload condition occur across a load, Bidirectional buck–boost converter starts working in forward mode to discharge the battery to the load. If the load is AC load, DC-AC converter is connected between Bidirectional buck–boost converter and the load.

**Keywords:** Power Electronics Converter, Renewable Energy Conversion, Energy Storage Interface, Battery Energy Storage System (BESS), DC Power Regulation, Voltage Step-Up and Step-Down Converter, Solar Power Conditioning.

## I. INTRODUCTION

The use of new energy is urgent with the emergence of the extreme weather. Solar energy is inexhaustible and renewable. It is clean, safe and maintenance-free. It plays an important role in the long-term energy strategy. With the increase in demand for generating power using renewable energy sources, energy storage and interfacing the energy storage device with the grid has become a major challenge. Energy storage using batteries is most suitable for the renewable energy sources like solar, wind etc. A bi-directional DC-DC converter provides the required bidirectional power flow for battery charging and discharging.

The solar power is mainly composed of the solar cell array, accumulator battery, the controller and the DC/AC inverter. The solar cell array is used as the conversion of solar energy into electrical energy. The battery is used as storing electrical energy. The battery stores energy in sunny days and discharges energy in bad weather. The controller is to control the charge and discharge, the current protection, voltage protection, etc. The inverter changes the DC power come from the solar cell array into AC power the user can directly use. Bidirectional inverter allows current flow in both direction and therefore permits energy flow from the grid to storage when solar energy is not available. With the rapid depletion of the conventional fossil fuels, energy crisis and environmental pollution become more serious. In recent years much effort has been made to find

renewable clean energies in the countries all over the world, and solar energy is found to be such an ideal and durable one. Since the 1970s solar energy photovoltaic power has received great attention and experienced impressive progress. The solar energy photovoltaic power will play an important role in alleviating the energy crisis, reducing the environmental pollution and improving the greenhouse effect.

## II. LITERATURE REVIEW

The development of efficient power conversion systems for photovoltaic (PV) applications has attracted significant research interest in recent years. Various researchers have investigated the design and implementation of DC–DC converters to improve the efficiency, reliability, and power management capability of solar energy systems. Bi-directional buck–boost converters have emerged as an important solution for integrating energy storage devices such as batteries with standalone photovoltaic systems. These converters enable power to flow in both directions, allowing the system to store excess energy generated by the PV panels in batteries and supply power back to the load when solar energy is insufficient. Previous studies have highlighted that such converters enhance the flexibility and stability of off-grid PV systems by maintaining proper voltage levels and ensuring continuous power supply. Several studies have focused on improving the efficiency and control strategies of DC–DC converters used in renewable energy systems. Researchers have

proposed advanced switching techniques and control algorithms to minimize power losses and improve the voltage regulation of buck–boost converters. The integration of Maximum Power Point Tracking (MPPT) techniques has also been widely discussed in the literature to ensure that the PV system operates at its optimal power generation point under varying environmental conditions such as changes in sunlight intensity and temperature. These approaches help maximize the energy harvested from solar panels and improve the overall performance of the photovoltaic system.

In addition, many researchers have explored the role of energy storage systems in standalone PV applications. Battery storage systems connected through bi-directional converters allow efficient charging and discharging processes while protecting the battery from overcharging and deep discharge conditions. Studies have demonstrated that incorporating intelligent control methods into the converter design can further improve energy management and system reliability. Advanced digital controllers, microcontrollers, and power electronic devices are increasingly being used to enhance the dynamic response and efficiency of these converters. Moreover, the literature suggests that bi-directional buck–boost converters provide better adaptability in hybrid renewable energy systems where multiple energy sources such as solar and wind may be integrated.

Recent research also emphasizes the importance of compact design, high conversion efficiency, and reduced switching losses in modern power electronic converters. New semiconductor devices and improved circuit topologies have been proposed to increase converter performance while reducing system cost and complexity. These advancements contribute to the development of more efficient standalone PV power generation systems capable of meeting the growing demand for clean and sustainable energy. Overall, the existing literature indicates that bi-directional buck–boost DC–DC converters play a crucial role in improving the efficiency, stability, and energy management capabilities of standalone photovoltaic power systems, making them a key component in modern renewable energy technologies.

### III. PROPOSED SYSTEM

The main aim of this work is to design and analyze a photovoltaic system coupled with battery energy storage systems using bidirectional DC-DC converters. To control the output

voltage of the buck-boost converter, the controller is designed to change the converter duty cycle using a microcontroller. The model of the buck-boost converter and the controller is derived, and the simulation model is designed in PSIM software. This framework combines a DC-DC converter and a bidirectional buck-boost converter equipped with an inverter at the output. DC-DC converter feeds the DC bus which supplies power to the inverter and bidirectional converter. The inverter supplies to the AC bus which is connected to AC load.

#### Block Diagram

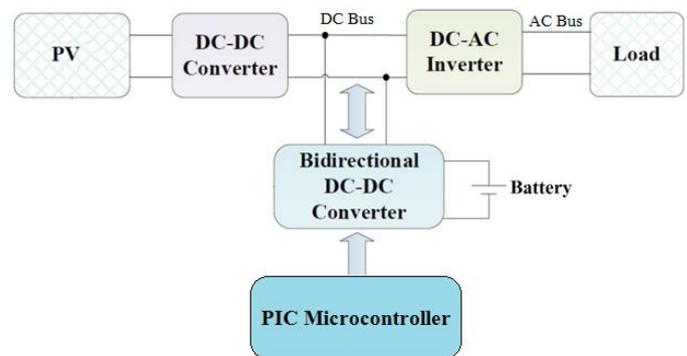


Figure 1: Block diagram

#### Block Diagram Description

This project designs and proposes a Bi-directional Buck-boost converter and a DC-DC converter for powering up an inverter and to charge a battery storage system from a standalone solar PV input source. DC-DC converter basically maintains a constant output voltage for supplying the DC bus to the inverter and a stable voltage to the bi-directional converter. An also provides isolation between the PV source and DC bus. The battery charge and discharge controller employ a bidirectional buck-boost converter that simultaneously exhibits the energy conversion characteristics of buck and boost converters. Thus, the energy conversion efficiency is significantly increased.

Furthermore, this converter in the system framework provides not only battery energy storage functions, but also facilitates auxiliary power supply at the load terminal. By implementing the system characteristics are mentioned previously, the power supply can be managed and controlled. The DC-DC converter is focused on tracking and controlling the output power of the photovoltaic module array. Therefore, the

system's DC link voltage (VH) varies according to solar irradiation and tracking processes.

If VH is directly connected to the load terminal system, the system will become compromised. Therefore, we proposed a control strategy that allowed VH to be controlled at a V setting through the charge and discharge control function of a bidirectional buck-boost DC-DC converter. The control method involves adopting the error between of the DC link voltage VH and its command value to further obtain the battery charge/discharge current command value through the DC link voltage controller. Subsequently, here PIC microcontroller is used which controller senses the charge and discharge current (IL) of the battery to follow its command value to achieve DC link voltage (VH) regulatory functions. Additionally, to prevent excessive IL, the system restricts the maximum charging current.

**Circuit Diagram**

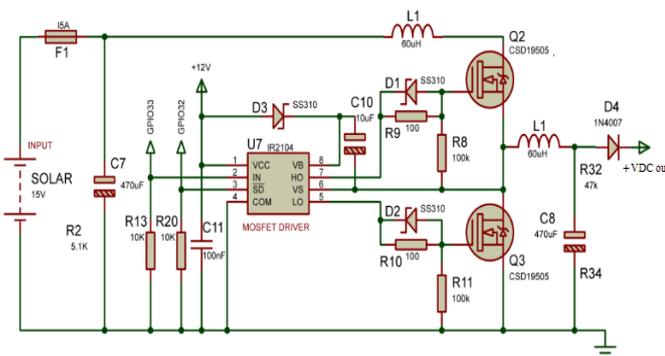


Figure 2: DC-DC Converter Circuit

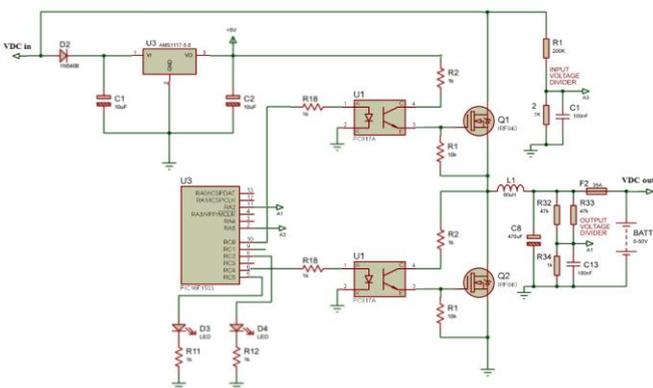


Figure 3: Bi-Directional Converter Circuit

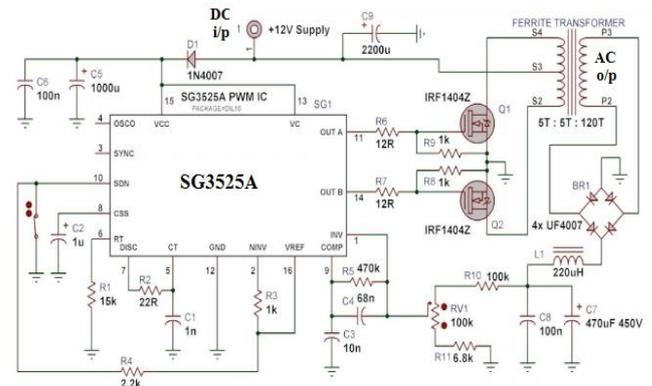


Figure 4: Inverter Circuit

**Description**

**DC-DC Converter**

The DC-DC converter is designed using IR2104 IC which is fed by the PWM switching pulses from microcontroller. Implementation of a PIC16F1503 microcontroller is done to control the operation of a buck converter. The input voltage from the PV solar panel source is fed to the DC-DC converter. It produces a stable DC output regardless of the input voltage from the PV panel. Thus a constant DC output is given to the DC bus. Here 12V solar panel is used which has voltage range from 12-18V. The output of the DC-DC converter is 14V DC.

The IR2104 has a built-in dead time function. IR2104 has logic input pins name IN and SD. IN is the input logic for the PWM signal for switching and SD is an enable pin. SD is simply a pin that overrides everything. When SD is LOW; Q2 and Q3 both turns off regardless if there's a PWM signal present at IN. When SD is HIGH, either Q2 or Q3 will turn on, depending on the IN pin logic state. When IN is HIGH; Q2 is HIGH and Q3 is LOW. When IN is LOW; Q2 is LOW and Q3 is HIGH. Thus the MOSFETs are driven by the pulses from the IR2104 IC and inductor is switched producing desired DC output.

For the switching action, several components must be considered. These include the switch to the load and the switching controller. For switch, MOSFET is chosen. IR2101 is selected to drive the MOSFET. The input signal for the driver come from PWM signal generated by Microchip PIC16F1503 microcontroller. This PWM output is not capable of driving the MOSFET. Driver is used to amplify the PWM output and is

connected to the gate of the MOSFET.

### Bi-Directional Converter

The bidirectional converter is designed using PIC16F1503 microcontroller which provides necessary switching pulses and also controls the mode of operation by sensing the input and output voltage levels. The voltage feedback from the input DC bus and output of the converter which is connected to battery is given to the microcontroller ADC pin A1 and A3. Sensed voltages are compared with the set threshold by the microcontroller and switching mode of the converter is controlled according by varying the PWM pulses. It senses the voltages and increases or decreases its pulse width for maintaining the required voltage. Regulator IC AMS1117 provides regulated 5V to the microcontroller.

When the input voltage is higher than the battery voltage then the bi-directional converter operates in charging mode. When the input voltage is lower than the battery voltage the bi-directional converter operates in discharging mode. Here the output voltage of the bi-directional converter is 14V which is connected to a 12V battery bank.

### Switching Pulses

The microcontroller board is used for generating the PWM in the circuit. There are two PWM signals generated at pins 2 and 3 of the board with a phase difference of 180 degrees. In the microcontroller sketch, first the pins 2 and 3 of the board are configured to digital output using pin Mode () function within the setup () function. In the loop() function which is meant to iterate infinitely, the pins 2 and 3 are set to digital logic or LOW and HIGH respectively followed by a delay of 0.5 second. The digital logic at the pins 2 and 3 is reversed after the delay and again a delay of 0.5 second is provided. This generates two PWM signals having a frequency of 0.5 Hz and 50 % duty cycle having a phase difference of 180 degree with respect to each other.

The PWM signals to drive the MOSFETs are generated from PIC16F1503 microcontroller. PIC16F1503 microcontroller has two CCP (Capture/Compare/PWM) modules. These modules are used to create the PWM signal. Pin RC2 is used to output the PWM signal.

### Inverter

DC voltage from the DC-DC converter and bi-directional converter are tied to the DC bus which supplies the input of inverter. The inverter converts 12V DC to 220V AC. The output can be connected to AC loads. Here a H-Bridge inverter is used which is operated by MOSFET switches. Switching pulses for the MOSFETs Q1 and Q2 are provided by KA3525 IC which supplies two PWM pulses output which 180 degrees are out of phase. A step-up transformer is connected to the output of inverter. During operation of the MOSFETs the DC current that is fed to the inverter is converted into AC current in the primary winding of transformer. 12V AC in the primary winding is converted into 220V AC output at the secondary winding which can be fed to AC load.

In addition, many researchers have explored the role of energy storage systems in standalone PV applications. Battery storage systems connected through bi-directional converters allow efficient charging and discharging processes while protecting the battery from overcharging and deep discharge conditions. Studies have demonstrated that incorporating intelligent control methods into the converter design can further improve energy management and system reliability. Advanced digital controllers, microcontrollers, and power electronic devices are increasingly being used to enhance the dynamic response and efficiency of these converters. Moreover, the literature suggests that bi-directional buck-boost converters provide better adaptability in hybrid renewable energy systems where multiple energy sources such as solar and wind may be integrated.

Recent research also emphasizes the importance of compact design, high conversion efficiency, and reduced switching losses in modern power electronic converters. New semiconductor devices and improved circuit topologies have been proposed to increase converter performance while reducing system cost and complexity. These advancements contribute to the development of more efficient standalone PV power generation systems capable of meeting the growing demand for clean and sustainable energy. Overall, the existing literature indicates that bi-directional buck-boost DC-DC converters play a crucial role in improving the efficiency, stability, and energy management capabilities of standalone photovoltaic power systems, making them a key component in modern renewable energy technologies.

**IV. SCHEMATIC OF THE PROPOSED CONVERTER IN PSIM**

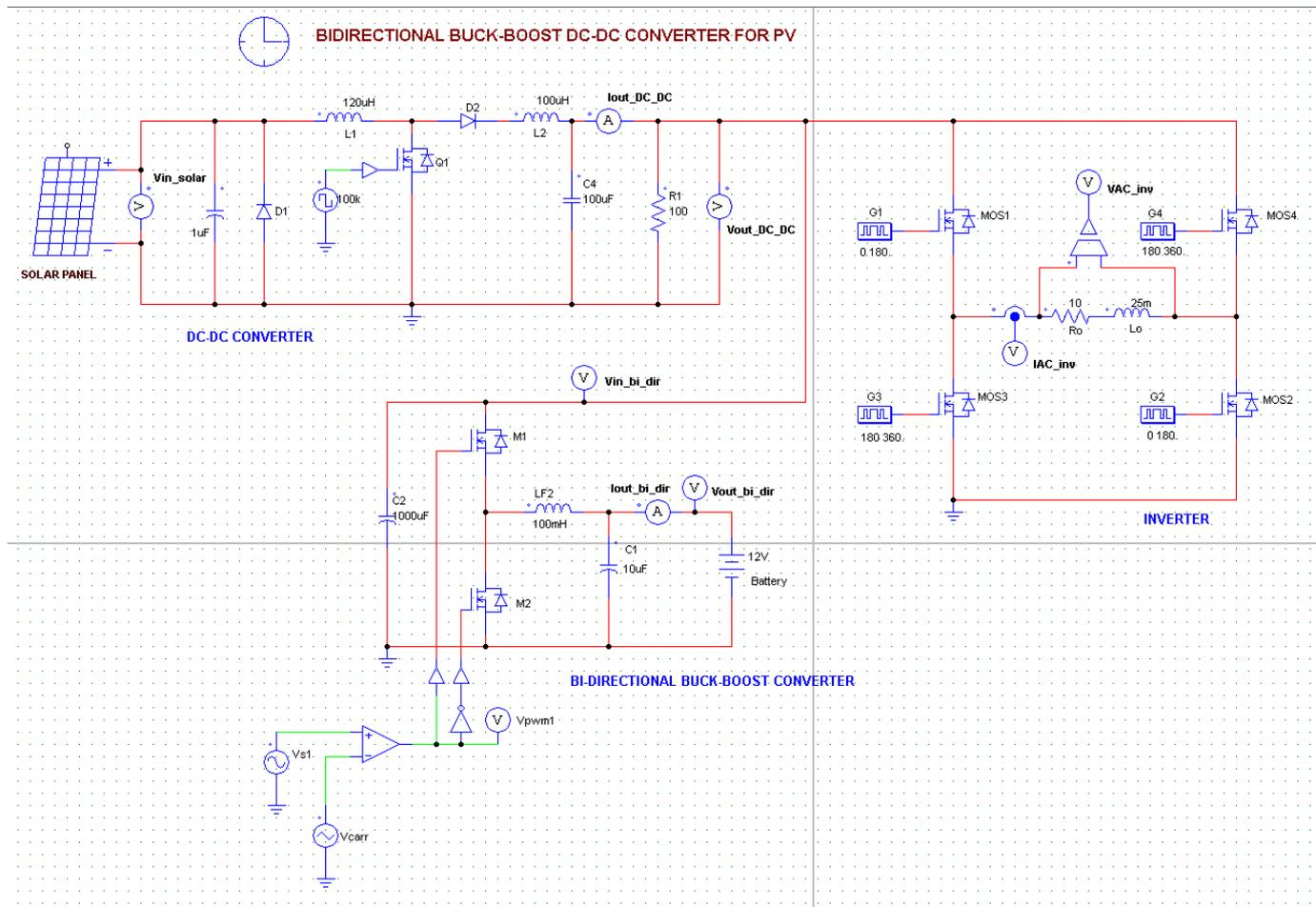


Figure 5: Schematic of the Proposed Converter in PSIM

**Input and Output Waveforms**

Input Voltage of DC-DC Converter

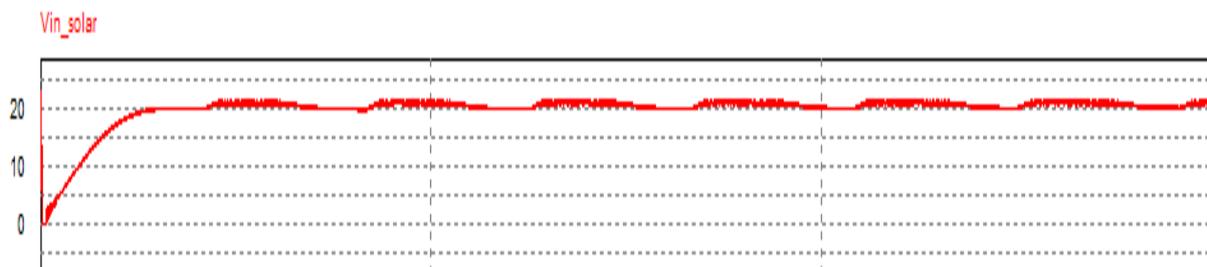


Figure 6: Input Voltage of DC-DC Converter

### Output Voltage of DC-DC Converter

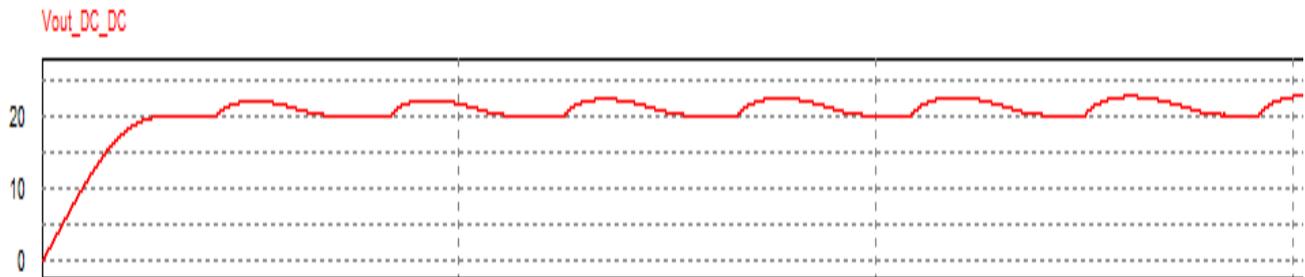


Figure 7: Output Voltage of DC-DC Converter

### Output Current of DC-DC Converter

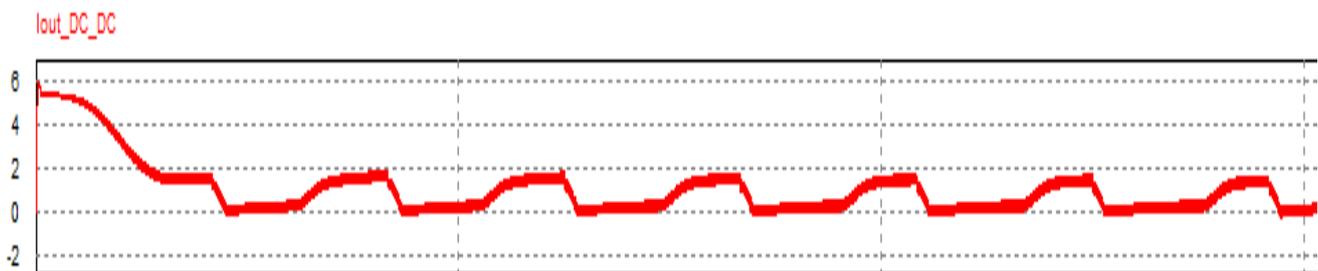


Figure 8: Output Current of DC-DC Converter

### Input Voltage of Bidirectional DC-DC Converter

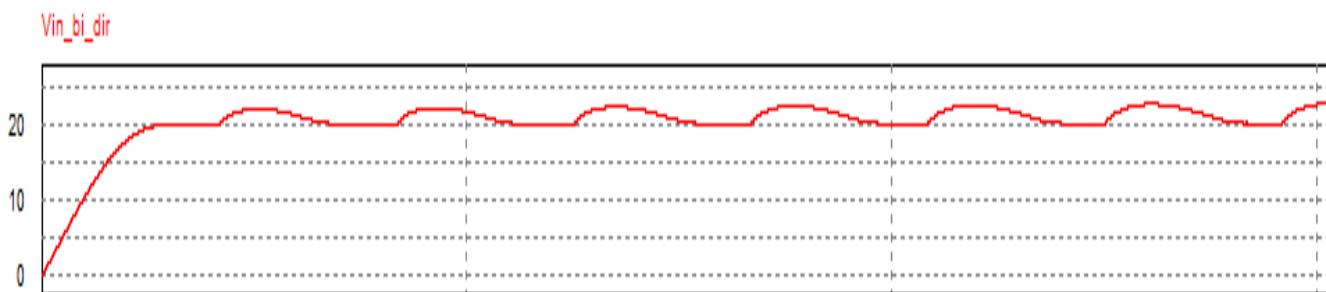


Figure 9: Input Voltage of Bidirectional DC-DC Converter

Output Voltage of Bidirectional DC- DC Converter

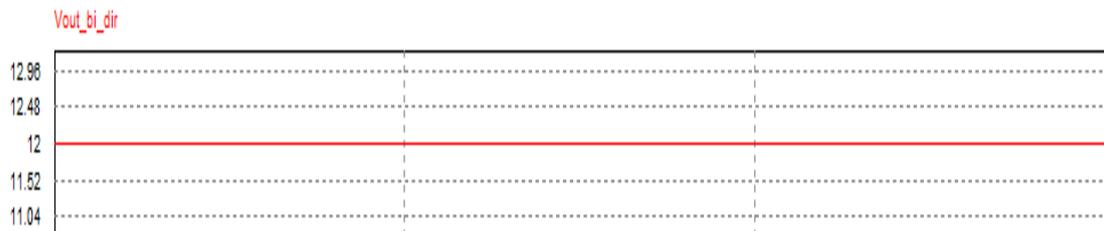


Figure 10: Output Voltage of Bidirectional DC- DC Converter

Output Current of Bidirectional DC- DC Converter

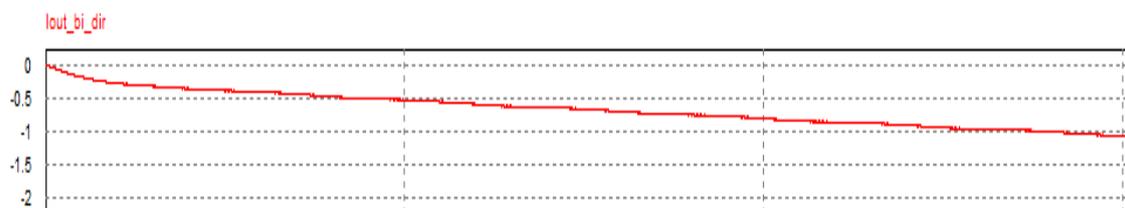


Figure 11: Output Current of Bidirectional DC- DC Converter

Output Voltage of Inverter

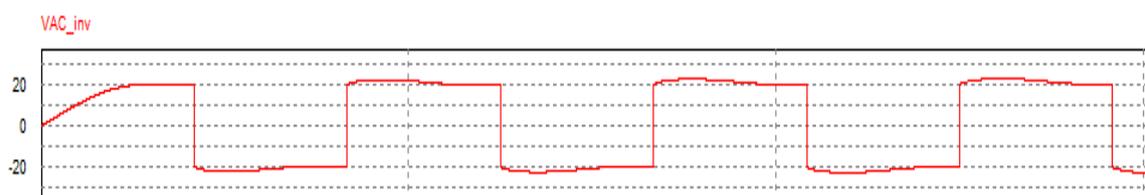


Figure 12: Output Voltage of Inverter

Output Current of Inverter

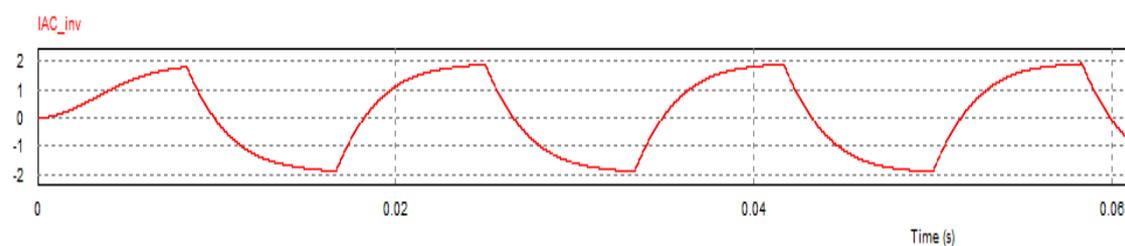


Figure 13: Output Current of Inverter

## V. RESULTS AND DISCUSSION

The schematic of the proposed system components which are

- 1) DC-DC converter
- 2) Bi-Directional Converter and
- 3) Inverter

are designed and simulated using PSIM simulation software.

The screenshot of the simulated proposed system schematic is shown in the figure. The screenshots of the input and output waveforms observed are shown in the figures above respectively. The simulation is executed and all the outputs are obtained as desired in the proposed system design.

## VI. CONCLUSION

Solar PV fed stand alone power generation system with DC-DC converter to supply an inverter and a bidirectional converter for battery storage and back up was designed and simulated. To appropriately employ the power output of the photovoltaic power generation system, we combined the bidirectional buck-boost converter developed in this study with a rechargeable battery storage system. Furthermore, we proposed a small-hybrid power supply provided by photovoltaic power generation system and battery storage. Whenever the load demand will not be fully met by the primary solar energy source it will be supported by the backup energy source. And on the other hand when the demand will be less than the generation, the primary solar source will energize the backup source. The schematics and simulation model was developed in PSIM and the input output waveforms are analyzed. Also the hardware prototype was build and tested expected results were observed. The results show that the proposed controller performs well and is effectively applied to real-time systems.

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