SolarFlex

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Abstract— **Recently, photovoltaic systems (PV) have gained tremendous attention as one of the most promising technologies for harnessing renewable energy sources. However, the fluctuation of output voltage with time due to due irradiance variation is one of the major drawbacks of PV solar system. Thus, in this paper, we propose a buck-boost converter based on Arduino microcontroller to maintain the output voltage of PV system at a desired value by controlling the duty cycle of the converter using pulse width modulator (PWM). The proposed system has been tested using both simulation and prototype to prove effectiveness of our design and obtain a fixed voltage at the output of solar panel regardless of irradiation conditions. The obtained results show that the developed converter performed well and attained 13 V constant output voltage in both modes (buck and boost).**

Keywords— PV system; buck-boost converter; Inverter; Arduino; PWM.

I. INTRODUCTION

The concern of environmental issue nowadays causing rising in demand of renewable energy that is cheaper and sustainable with less emission. Solar energy is considered a promising technology in harnessing renewable energy that considered cheaper and sustainable. However, the weather conditions and the fluctuation of sun irradiance are main limitations of this technology. Photovoltaic systems (PV) is module that built in a form of array solar panel where harnessing solar energy take place. PV cell consists of multiple thin layers of silicon which is a semiconductor material that generates electrical charges when it is exposed to light. It is directly converts solar energy into DC electrical energy. The DC voltage is available at the terminals of a PV module and can directly feed various loads such as Battery, LED lighting, DC motors or it may connect to a grid via a proper power converter.

Energy consumption has become a big challenge with the emergence of Internet of Things. Electrical power converter is one of the main components in the PV system which plays a critical role in controlling consumed energy. It serves the aim of providing the desired form of output current (DC or AC) and transferring maximum power from the solar PV module to the load. In addition, it is used to regulate the output voltage of PV system before connecting to the load. There are several types of DC/DC converters that can be utilized by PV system including buck converter, boost converter and buck-boost converter. Buck-boost converter (step-down and step-up) uses to control the output voltage and maintain it at a desired level regardless the variation in the input voltage. According to the duty cycle value, the output voltage of the buck-boost converter can be either higher or lower than the input voltage. Therefore, this type of DC/DC converters can be used with PV system to achieve the desired output voltage in spite of the variation of sun radiation. If the generated voltage from the PV cell is low due to low irradiance, the converter will cork in the boost mode to step-up the output voltage. In contrast, if the generated voltage is higher than the desired voltage, the converter will switch to buck mode to step-down the output voltage, thus always maintains the voltage at the proper level. The switching of buck-boost converter between two modes of operation can be achieved by controlling the its duty cycle.

In this paper, we have designed and fabricated a buck-boos converter for PV solar system in order to regulate and maintain the output voltage of the system regardless the changing in the input voltage. An Arduino Mega microcontroller was used to control the Duty Cycle of the converter via Pulse Width Modulator (PWM) output from the Arduino to regulate the output voltage. The developed converter acts as an interface between the solar cell and the load. The main benefits of this system include the maximizing of transferring power from the PV system to the load while maintain a fixed output voltage at PV terminal for instrumentations which are sensitive to voltage variations. This study adopted the following methodology and contributions:

(i) Design and fabrication of a buck boost converter for PV solar system;

(ii) Implementation of Arduino-based controller for controlling the duty cycle of the developed converter to continuously adapt the mode of operation based on the variation of PV voltage;

(iii) Evaluating the performance of the developed system using both simulation and prototype and analysis of the obtained results to assure the switching between the operation modes of the converter (buck and boost) according to the input voltage.

II. THE PROPOSED SYSTEM

The Solar Flex system is a hybrid solar power setup designed to deliver uninterrupted energy to household appliances. It begins with solar panels generating DC electricity, which is regulated by a charge controller and stored in a battery. A Battery Management System (BMS) monitors voltage and current to ensure safe charging. An Arduino Uno acts as the control centre, activating relays based on real-time battery conditions. When solar energy is available, the Arduino routes battery power through an inverter to produce AC for household use. If solar and battery power are insufficient, the system switches to grid power. A final relay chooses between inverter or grid output for appliances. The inverter converts 12V DC to 220V AC using MOSFETs and a centre-tapped transformer. A buck-boost converter allows dynamic voltage regulation from the solar panel. Real-time monitoring and relay logic optimize power use. This setup ensures energy efficiency and automation. It empowers users with reliable and smart energy management.

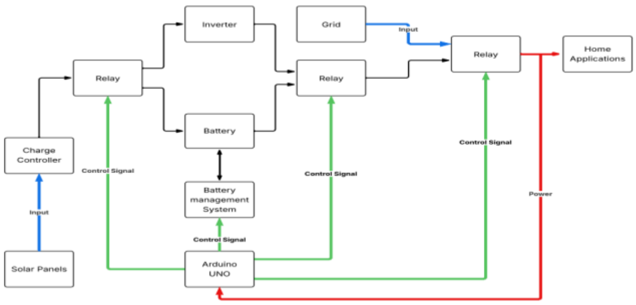


Fig. 1. Block Diagram of System

A. *Buck-Boost Converter Design*

In this section, we explain the theoretical background and complete component selection process for the buck-boost DC-to-DC converter used in the Solar Flex system. The converter is used to regulate the varying voltage from the solar panel for optimal battery charging. It consists of a single power switch transistor, Q1 (IRFZ44N MOSFET), and a freewheeling diode, Dm (SR5A0 Schottky diode), which provides a current path when the switch is turned off.

Additionally, the converter uses two critical energy storage elements a capacitor, C, and an inductor, L. These components are essential for maintaining stable output voltage and current, with the inductor controlling current ripple and the capacitor reducing voltage ripple. Their values must be calculated precisely to meet the required electrical performance. The output voltage of the buck-boost converter can be either higher or lower than the input voltage. If duty cycle, k is more than 0.5, output voltage will be higher, whereas if cycle, k is less than 0.5, output voltage will be lower than the input voltage. The electrical circuit diagram of the buck-boost converter is described in Fig. 2.

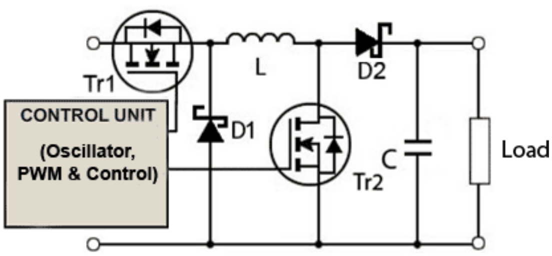


Fig. 2. Buck – Boost Converter Circuit

The converter's operation is controlled through PWM (Pulse Width Modulation) signals generated by an Arduino. It adjusts the duty cycle (k) based on the input from voltage and current sensors. The output voltage Vout of the buck-boost converter is determined by the equation:

$$V_{out} = \frac{k}{1-k} \cdot V_{in}$$

Here, k is the duty cycle, and VinV_{in}Vin is the input voltage. When k > 0.5, the converter works in boost mode, increasing the voltage. When k < 0.5, it operates in buck mode, reducing the voltage. The precise selection of L and C depends on the desired ripple specifications and switching frequency fs. The inductor value is typically chosen using:

$$L_c = L = -\frac{(1-k)R}{2f_s}$$

And the capacitor value is selected based on:

$$C_c = C = \frac{k}{2f_s R}$$

Where ΔI_L is the inductor current ripple, and ΔV is the allowable output voltage ripple.

This theoretical approach ensures stable output under varying solar conditions and enhances the converter's adaptability for integration with MPPT and intelligent battery management systems in future iterations.

B. *Simulation Design*

According to the theoretical calculations and component formulation described previously, the simulation layout of the designed buck-boost converter was developed and is shown in Fig. 13. In this study, the Multisim simulation environment was used to validate the functional behaviour of the converter under different operating modes. Multisim is a comprehensive tool for circuit design, analysis, and simulation, widely adopted in power electronics prototyping and PCB development workflows.

In our simulation setup, the PWM switching frequency was set to 60 kHz, corresponding to a pulse period (PER). The ON and OFF times of the switching MOSFET were adjusted dynamically based on the desired duty cycle (k) to ensure accurate performance across buck, boost, and transition states. The pulse width was determined as:

$$\text{Pulse Width} = k \times \text{PER}$$

Where k represents the duty cycle derived from input-output voltage requirements, and PER is the total time of one PWM cycle. The simulation was performed using real-time voltage and current probes to analyse the transient behaviour and steady-state response of the system.

The simulation tests were carried out for three primary operating conditions:

1. Buck Mode – when input voltage is higher than output voltage,
2. Boost Mode – when input voltage is lower than output voltage,
3. Idle Mode – when switching is disabled and the system is in standby.

The results of these simulation tests are illustrated is:

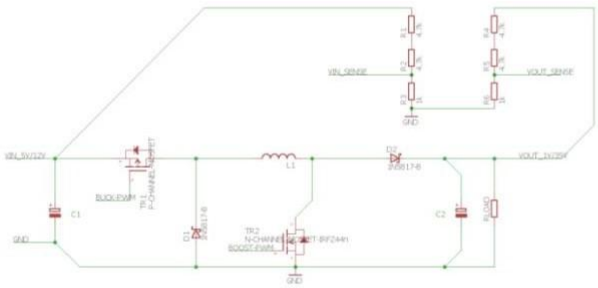


Fig. 3. Simulation design layout of buck-boost converter.

The inverter stage of the Solar Flex system was designed to convert the 12V DC output from the battery into a usable 220V AC output for household appliances. The simulated inverter circuit was implemented in Multisim Simulator, a robust schematic capture and simulation platform widely used in academic and industrial electronics design.

As illustrated in Fig. 4, the inverter design utilizes the CD4047 IC configured in astable mode to generate a stable 50 Hz square wave signal. This IC outputs two complementary signals Q and ~Q--180 degrees out of phase. These outputs are fed to two IRFZ44N N-channel MOSFETs, which alternately switch and drive a centre-tapped transformer.

The transformer used in the simulation was modeled to step up the low-voltage square wave signal from 12V to 220V AC, suitable for resistive loads such as fans and bulbs. The switching frequency was carefully adjusted using an external RC timing network to achieve the target 50 Hz AC output frequency. A 22kΩ variable resistor (potentiometer) was used in combination with a 0.22µF capacitor to fine-tune this frequency.

Simulation parameters included:

- Source voltage: 12V DC (from the battery module),
- Load: Resistive load representing typical home appliances,
- Waveform monitoring: Oscilloscopes were connected at both MOSFET gates and transformer output to observe signal symmetry and voltage levels.

The inverter was tested under full-load and no-load conditions. The output waveform at the transformer secondary exhibited a stable square wave with a frequency of 50 Hz, confirming the inverter's capability to deliver consistent AC output under ideal conditions.

The simulation results, output waveforms, and transformer behaviour is:

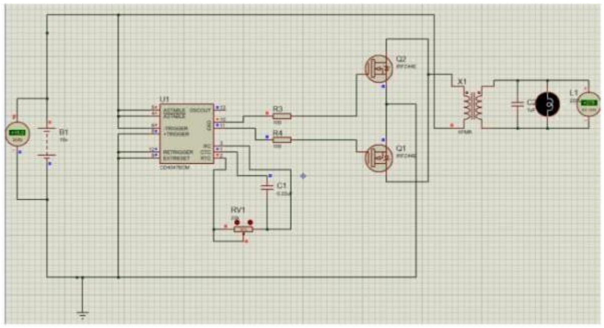


Fig. 4. Circuit Diagram of Inverter

C. Prototype Fabrication

The materials used to fabricate the prototype of the buck-boost converter in this study include MOSFETs (IRF540N and IRFZ44N), diode 1N5408, inductors (100 µH and 300 µH), capacitors (220 µF and 100 µF), a DC motor as the load, and the Arduino Atmega328 microcontroller. The Arduino was programmed to generate a 60 kHz PWM signal and adjust the duty cycle in real-time based on feedback from the output voltage, which was sensed using analog ports (A0–A5) through a voltage divider. This feedback loop enabled dynamic voltage control from varying solar panel inputs. A DC motor was selected for testing due to its visible and audible response to voltage fluctuations, making performance verification easier.

Fig. 5. Buck Boost converter prototype.

For the inverter prototype, the system used a CD4047 IC in astable mode to produce a 50 Hz square wave, which was fed into two IRFZ44N MOSFETs. These MOSFETs alternately switched a centre-tapped transformer to convert 12V DC to 220V AC. A 22kΩ variable resistor and 0.22 µF capacitor were used to tune the frequency. The output was tested on resistive loads like bulbs and fans, confirming consistent and stable AC output.

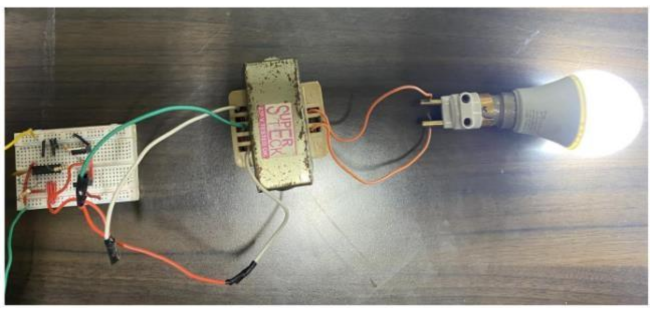


Fig. 6. Inverter

III. RESULTS AND DISCUSSION

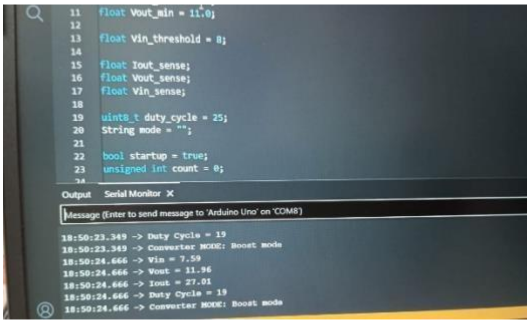
This section presents the results from both the simulation and prototype testing of the buck-boost converter and inverter systems. The goal is to validate the converter's ability to regulate voltage in various input scenarios and confirm the inverter's capability to deliver stable AC output from a DC source.

A. Buck-Boost Converter Performance

The buck-boost converter was tested under three different operating conditions based on input voltage levels of 7.59 V, 12 V, and 17.26 V. The desired constant output voltage was 12.98 V. The oscilloscope's Channel 1 (CH1) was connected to the input terminal of the converter, and Channel 2 (CH2) measured the output.

1. Boost Mode

This mode occurs when the input voltage is less than the desired 13 V. For this test, a 7.59 V input was applied to replicate reduced solar irradiance conditions. The Arduino dynamically increased the PWM duty cycle to exceed 0.5, enabling the converter to step up the voltage. In simulation, the duty cycle of 19. As expected, the output voltage was successfully boosted to 13 V. The practical implementation mirrored the simulation, with real-time PWM adjustments by the Arduino, confirming the converter's ability to self-regulate under varying solar inputs.

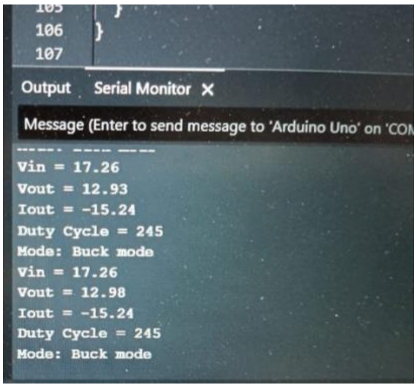


2. Idle Mode

In this state, the input voltage is exactly 13 V, equal to the target output. The converter operates in a neutral state with minimal duty cycle activity. Both simulation and hardware measurements demonstrated a stable pass-through behaviour with negligible voltage ripple, validating the controller's efficiency in maintaining output with minimal energy loss.

3. Buck Mode

When the input voltage rises above 13 V, as in the case of a 17.26 V input, the converter is required to step down the voltage. In simulation and practical tests, the Arduino adjusted the duty cycle below 0.5, reducing the pulse width. The resulting output remained regulated at 13 V, demonstrating effective buck operation. This confirms the converter's reliability under high-input scenarios typical during peak sunlight.

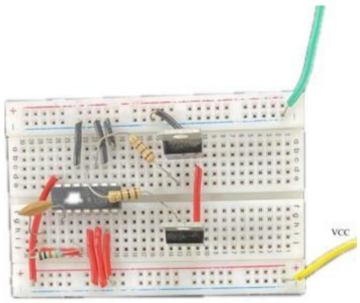


B. Inverter Performance

The inverter was designed to convert 12V DC to 220V AC using a square wave approach. It was tested in simulation and real-world scenarios using the CD4047 IC, IRFZ44N MOSFETs, and a centre-tapped transformer.

In simulation, the CD4047 generated a 50 Hz square wave, which alternately switched the MOSFETs to drive the transformer. The output waveform observed on the oscilloscope confirmed a stable 220V square wave AC signal at the secondary side of the transformer. The timing components (22kΩ variable resistor and 0.22µF capacitor) helped maintain the correct frequency.

In the hardware prototype, the output AC voltage was capable of powering simple resistive loads such as bulbs and fans. The system maintained consistent switching and voltage levels across test cycles. Though the output waveform was a square wave, it proved effective for non-sensitive appliances and validated the inverter's performance for practical household use.



IV. CONCLUSIONS

The Solar Flex prototype demonstrates the successful implementation of a multi-output solar energy conversion system designed for both DC and AC applications. The buck-boost converter, built using discrete components and controlled via PWM signals from an Arduino, was tested across a wide input voltage range from 6V to 21V. Throughout this range, the system maintained a regulated 12V DC output, validating the efficiency and stability of the converter design.

The inverter stage, constructed with MOSFET-based switching and driven by a CD4047 IC, generated a consistent 50 Hz square wave AC output. This output was verified to effectively power low-wattage AC appliances, such as LED bulbs and small fans, demonstrating reliable DC-to-AC conversion.

Overall, the Solar Flex system successfully integrates key power electronics—buck, boost, and inverter circuits—into a compact, hybrid solution. It proves suitable for decentralized and portable solar applications. The outcomes confirm that the system delivers stable and usable power under fluctuating solar inputs, laying a strong foundation for further enhancements such as MPPT algorithms, BMS circuitry, and custom PCB design in future iterations.

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