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Design and Hardware Realization of a Boost Converter for PV Applications

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Abstract

Off-grid photovoltaic (PV) systems play a vital role in delivering energy to regions with limited or unreliable infrastructure. In these systems, boosting the low input voltage to a higher output level is essential to ensure efficient energy utilization. However, traditional DC–DC converters often suffer from low efficiency, significant energy losses, and excessive heat generation, all of which limit the effective use of solar energy.

To overcome these limitations, this study presents the design of a high-efficiency DC–DC boost converter. Silicon Carbide (SiC) MOSFETs are employed for their superior switching speed, high voltage tolerance, and low energy loss characteristics, which collectively enhance the overall efficiency of the energy conversion process. Compared with conventional silicon-based MOSFETs and IGBTs, SiC MOSFETs offer reduced energy losses due to their high-frequency operation capability and ensure a more stable output performance.

The main objective of this project is to improve the efficiency of standalone renewable energy systems through the design and testing of a high-performance DC–DC boost converter. The study is conducted in two main stages: simulation and experimental validation. In the first stage, a detailed converter model is developed and analyzed in a simulation environment to evaluate its performance. In the second stage, the converter is physically implemented, including schematic design, printed circuit board (PCB) fabrication, and soldering. Finally, the experimental results obtained under real operating conditions are compared with the simulation outcomes to verify the accuracy and effectiveness of the proposed design.

Keywords: *Solar energy, photovoltaic systems, DC–DC boost converters, SiC MOSFETs, renewable energy.*

1. Introduction

Sustainable energy solutions have become essential, particularly in rural and isolated areas where access to energy is limited or infrastructure is insufficient. Off-grid photovoltaic (PV) systems provide an effective and sustainable alternative to overcome these challenges [1–2]. PV systems convert sunlight directly into electrical energy and offer a reliable, environmentally friendly, and cost-effective energy source [3–4]. They are critical for applications such as agricultural irrigation, telecommunication infrastructures, emergency energy needs, and mobile energy applications [5].

The energy produced by PV panels is generally at low voltage levels, which must be boosted to meet system requirements [6–7]. This highlights the importance of power-conversion technologies and the need for efficient system designs [8-13]. DC–DC boost converters play a key role by converting low input voltage into high output voltage, optimizing energy storage and usage while minimizing losses [14-18].

Conventional semiconductor devices such as silicon-based MOSFETs and IGBTs, commonly used in DC–DC converters, offer advantages like low cost and wide availability. However, their high switching losses, low efficiency, limited thermal endurance, and overheating problems pose limitations in high-performance standalone systems [19–21].

Recent developments in Silicon Carbide (SiC) MOSFET technology provide a solution to these challenges. Compared to silicon-based devices, SiC MOSFETs have lower switching losses, higher temperature tolerance, and faster switching capability, enabling more efficient high-frequency power conversion and longer device lifetime [22-23]. These advantages motivated the use of SiC MOSFETs in the DC–DC boost converter designed in this project.

The proposed converter boosts the 20 V input from solar panels to a 100 V output, improving energy storage efficiency and the overall use of harvested

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solar power. The design addresses the limitations of conventional converters and is particularly suitable for standalone PV applications. This project contributes to sustainable energy development and supports Türkiye’s 2033 Renewable Energy Roadmap [24-25].

This paper is organized into three main sections. The first section presents the simulation design of the boost converter, the second section details the experimental study, and the final section provides a comprehensive review and assessment of the project.

2. Design of Boost Converter

2.1. Calculation of Converter Parameters

The 20/100 V DC–DC boost converter for off-grid PV systems consists of the following stages. First, the duty ratio (D) is calculated using Equation 1, taking output voltage ripple (ΔV_{out}) is 1% of the output voltage (V_{out}). The inductor value is calculated using Equation 2. [26]. Here, Lis the inductor value (H), $f_s$is the switching frequency (Hz), ΔI_L is the allowable inductor current ripple (A), and $\Delta I_L$is taken as 1% of the output current.

$$D = 1 - V_{in}/V_{out} \qquad (1)$$

$$L = (V_{in} \times D) / (\Delta_{IL} \times f_s) \qquad (2)$$

In this study, with $V_{in} = 20$ V $V_{out} = 100$ V and D=0.8, the inductor value was calculated as 8 mH using the above formula, and the winding of L was designed accordingly.

To limit the output voltage ripple , the output capacitor is calculated as in Equation 3 [26]:

$$C = (I_{out} \times D) / (\Delta V_{out} \times f_s) \qquad (3)$$

Here, C is the capacitance (F) and I_{out} is the load current (A). The capacitor value was calculated as 80 µF using the above formula. The capacitor value is selected as 100 µF above the this value.

In this converter, a snubber circuit is used to protect the semiconductor devices from voltage spikes and to reduce stress during switching. It has a capacitor and a resistor that help absorb extra energy and limit voltage overshoot. In this study, the snubber capacitor is calculated using Equations 4, 5, and 6, while the snubber resistor is calculated using Equations 7 to make sure the converter operates safely and smoothly [27].

Here, I_{max} is the maximum current through the MOSFET, $t_k$is the turn-off time, $V_{max}$is the maximum voltage, $Q_g$is the gate charge of the MOSFET, and $I_g$is the gate current supplied by the driver circuit. is the leakage inductance of the transformer or inductor in the circuit, and $C_{sn}$is the snubber capacitor.

$$C_{sn} = \frac{I_{max} \cdot t_k}{2. V_{max}} \qquad (4)$$

$$C_{sn} = \frac{I_{max} \cdot t_k}{2. V_{max}} \qquad (5)$$

$$tk = \frac{Q_g}{I_g} \qquad (6)$$

$$R_{sn} = \frac{1}{2} \cdot \sqrt{\frac{L_s}{C_{sn}}} \qquad (7)$$

The leakage inductance $L_s$is 64 mH, and the snubber capacitor is calculated as 0.97 nF. The value of the snubber resistor, calculated using Equation 7 for fully discharging the capacitor, is 126.5 Ω. In practice, to reduce energy losses, a slightly lower resistance is chosen, and after rounding, 100 Ω is used.

2.2. Simulation Procedure of the System

In this study, MATLAB/Simulink is used to model and analyze the DC–DC boost converter, verify the theoretical calculations, and evaluate the design performance, as shown in Figure 1. In this model, a boost converter raises the input of a photovoltaic system from 20 V to about 100 V. The circuit includes an 8 mH inductor, MOSFET, diode, 100 µF capacitor, and 200 Ω load. A PWM signal controls switching, storing energy in the inductor and transferring it to the capacitor and load. The output voltage reaches nearly 100 V.

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The PWM signal of the switch is given in Figure 2. The PWM period was set for a 10 kHz frequency, and the duty cycle was adjusted to 80% to achieve the target output voltage of 100 V.

In the output-voltage graph across the 200 Ω load, the voltage rises briefly at the start and then stabilizes at approximately 100 V, indicating that the boost converter operates correctly. At a duty ratio of 80%, the output voltage reaches the target value. In addition, the relationship between duty ratio and output voltage was obtained as shown in Table 1, and a graphic is presented in Figure 4.

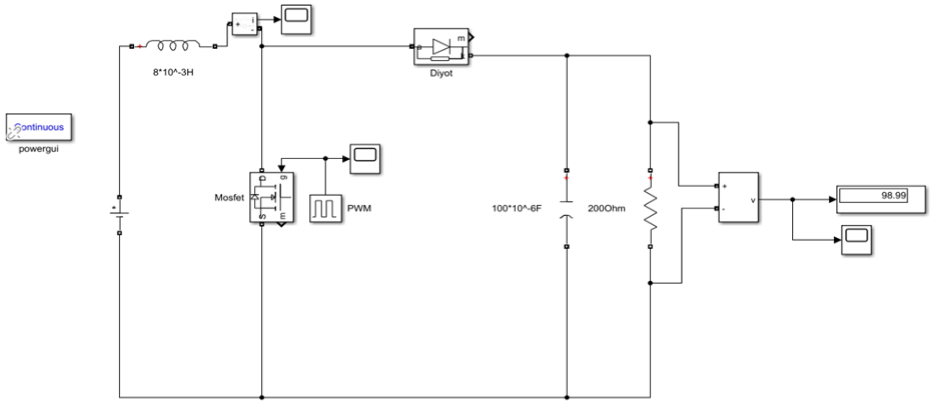


Figure 1. System modeling in MATLAB

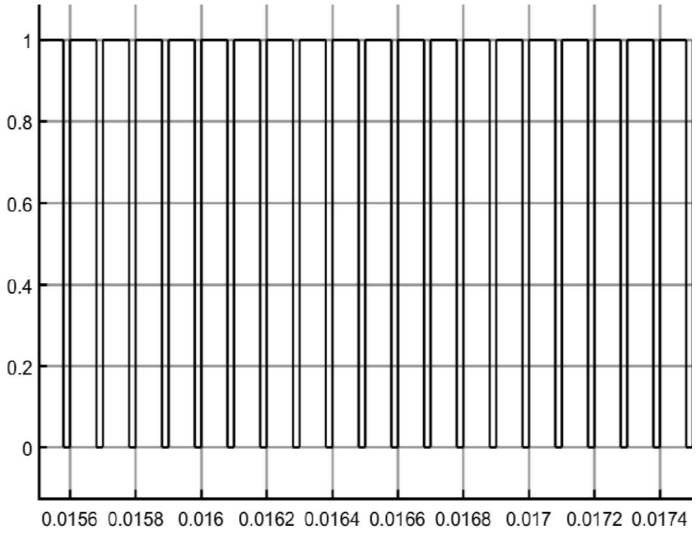


Figure 2. PWM signal of the switch

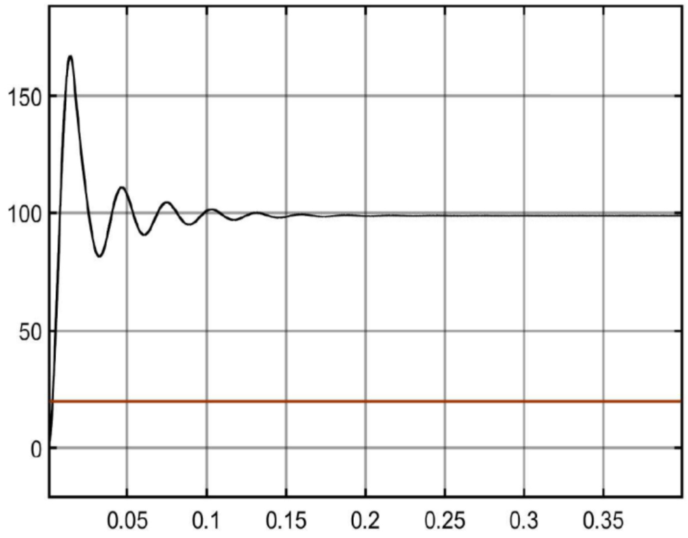


Figure 3. Input and output voltage of the converter

Table 1. Duty Ratio–Output Voltage Values

Duty Ratio (%)	Output Voltage (V)
70	88.3
75	90.5
77	93.1
79	97.5
80	100

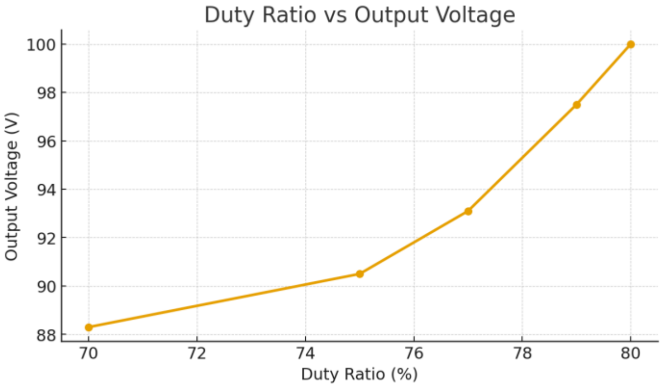


Figure 4. Duty ratio–output voltage graph

According to Figure 4, a duty ratio of 80% achieved the target output voltage of 100 V. The results show that the designed circuit met the desired performance with these settings.

3. Hardware Implementation

The designed converter is shown as Figure 5. It consists of a boost converter, power supply, driver circuit, microcontroller, snubber circuit, heatsink, and load.

The schematic of the driver circuit used for PCB design is shown in Figure 6.

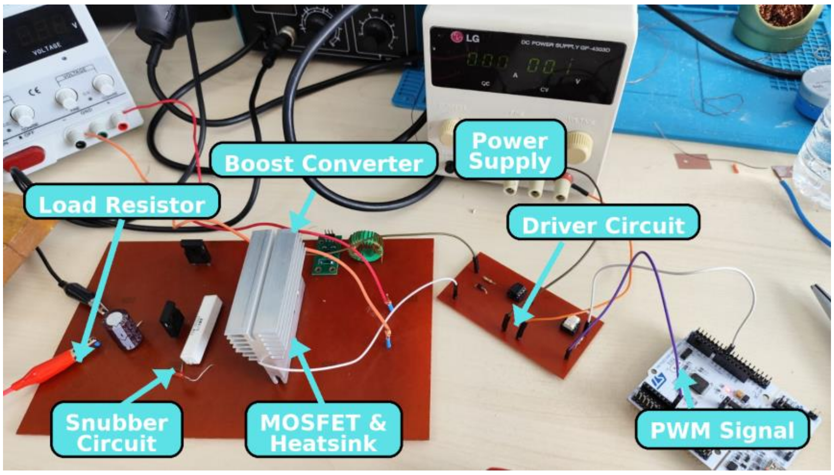


Figure 5. All details of the experimental system

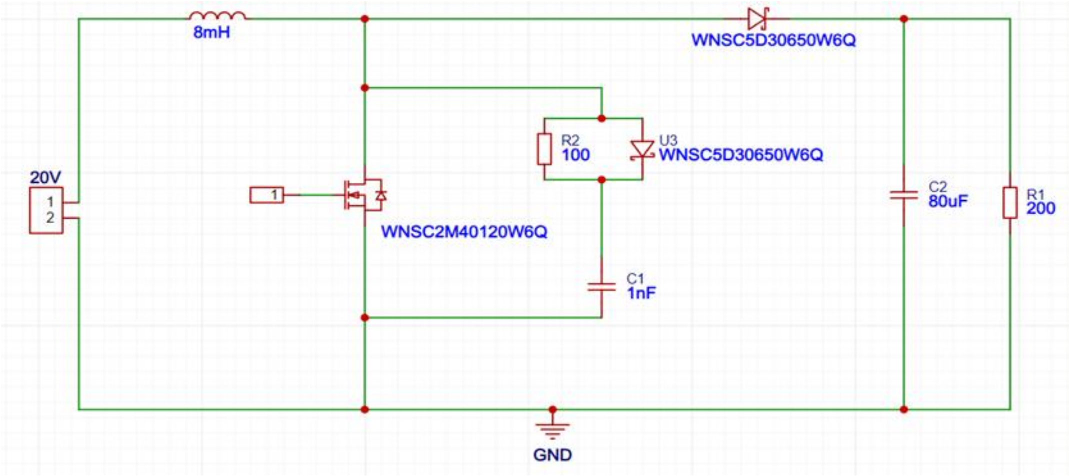


Figure 6. Boost converter schematic

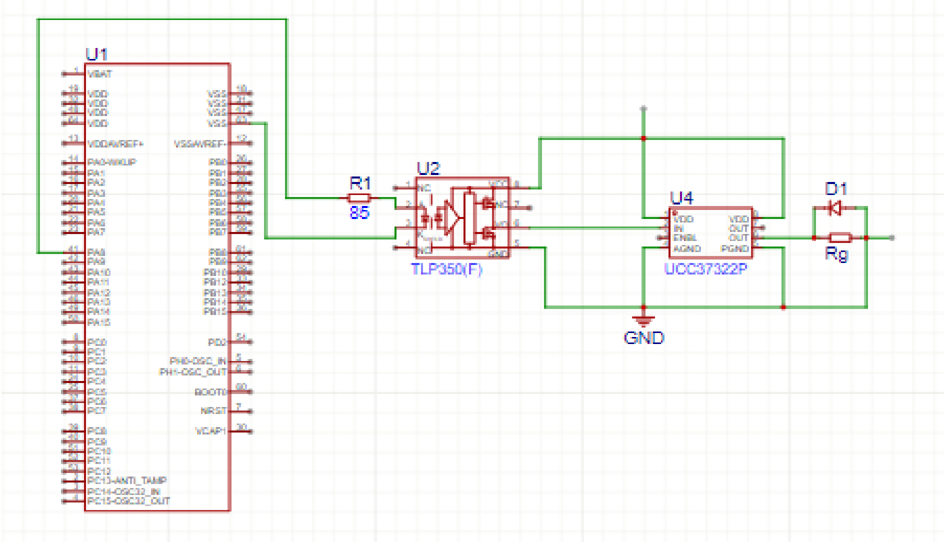
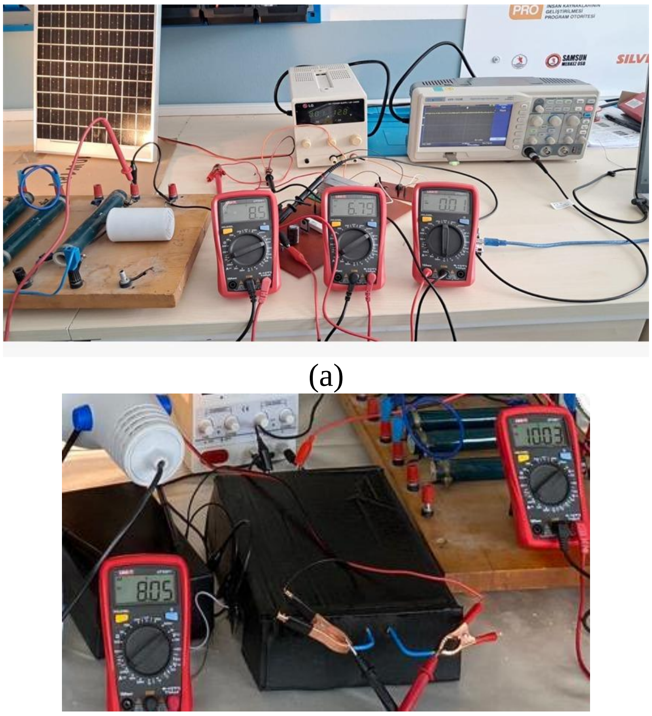


Figure 7. Driver circuit schematic

The driver circuit amplifies the PWM signal generated by the microcontroller to suitable voltage and current levels, ensuring effective switching of the MOSFET. Communication between the driver and the microcontroller was established through proper hardware configuration, allowing PWM signals with adjustable duty cycles to be generated for control and synchronization. The schematic of the driver circuit used for PCB design is shown in Figure 7.

To protect the MOSFET from voltage spikes and switching stress, a snubber circuit consisting of a resistor, capacitor, and fast-recovery diode was added. This circuit minimizes transient effects, reduces voltage stress, and improves system reliability. The MOSFET performs the main switching operation, while the heatsink dissipates the heat generated during operation, preventing overheating.

The system is powered either by a regulated DC source or a photovoltaic input. The PWM signal generated by the microcontroller controls the switching frequency and duty cycle, directly determining the output voltage. After assembling all components on the circuit board, the converter was tested under different operating conditions. The results showed that the circuit achieved the designed performance and provided a stable 100 V output at 80%duty cycle as shown in Figure 8.



(a)

(b)

Figure 8. Validation of the designed DC–DC boost converter (a) and measurement of output voltage (b)

4. Conclusions

In this study, the boost converter was designed to increase the input voltage of 20 V to an output voltage of 100 V. Both simulation and experimental tests showed that the system worked in a stable and efficient way after choosing the right switching frequency and duty cycle values for the MOSFET. When the duty cycle was adjusted to 80%, the output voltage successfully reached 100 V. The analyses made on circuit stability and energy efficiency also confirmed that the converter operated according to the design goals. The experimental results supported the simulation and theoretical calculations, proving that the system met the expected performance.

After building the DC–DC converter, future studies can focus on improving power quality by trying different switching combinations. The project can also be expanded and adapted for other systems that need DC–DC power conversion, such as electric vehicles. In addition, future work may include using digital control methods or MPPT algorithms to make the system react better to changes in sunlight. Developing multi-phase or modular SiC-based converter designs can also help improve thermal balance, reduce losses, and make the system more efficient and reliable for renewable energy applications.

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