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A Simplified Design and Modeling of Boost Converter for Photovoltaic System

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Abstract
The photovoltaic standalone system is becoming increasingly important, particularly for rural applications such as PV water pumping, solar lighting, and battery charging. Due to environmental concerns and the depletion of fossil fuels, there is a growing shift toward renewable energy sources. This paper presents the design of a basic boost converter circuit in MATLAB/Simulink with a constant DC source voltage. Additionally, a comparative analysis is conducted between a converter directly connected to a PV system and one integrated with an MPPT tracking technique. The Perturb and Observe (P&O) algorithm is implemented to generate the required duty pulse, ensuring the system operates at the maximum power point. When the boost converter is connected to the PV system without MPPT, it operates at a point other than the maximum power point, leading to reduced output voltage. However, with MPPT, the proposed system demonstrates improved performance.
Keywords: *PV, MPPT, Converter*

1. Introduction
The excessive reliance on fossil-based renewable energy sources such as coal, oil, and gas contributes significantly to global warming and environmental degradation, impacting populations worldwide. Among various renewable energy sources, photovoltaic (PV) technology plays a major role in global electricity generation [1], [2]. Solar energy can be harnessed through two main approaches: solar photovoltaics and solar thermal systems. However, due to fluctuating weather conditions, the output of solar panels varies based on irradiance and temperature, making it challenging to maintain a stable DC voltage supply for loads. To address this, boost converters are employed to regulate the variable DC voltage to a fixed level as required by the load. In cases where AC loads are used, an inverter is additionally required to convert DC voltage into AC [3], [4]. The efficiency of solar cells is influenced by factors such as temperature, soiling, and shading, all of which degrade performance. To maximize efficiency, Maximum Power Point Tracking (MPPT) techniques are implemented to ensure that the PV system operates at an optimal point, known as the knee point, delivering maximum power regardless of weather or load variations [5]. Researchers have proposed various MPPT techniques, including the Perturb and Observe (P&O) method, Incremental Conductance (Inc) method, Constant Voltage method, Short-Circuit Current method, Fuzzy Logic method, and Artificial Neural Network (ANN) method [6]. Among these, the P&O method is widely preferred due to its simplicity, whereas the Inc method offers better performance under changing weather conditions but increases circuit complexity [7-10]. Other methods are selected based on computational efficiency and system requirements. This paper details the design of a boost converter for voltage amplification. A photovoltaic system, depicted in Figure 1, powers the step-up converter, which is then connected to the load via the boost converter. The required duty cycle for the converter's switch is generated by an MPPT unit employing the Perturb and Observe (P&O) algorithm. Figure 1 shows Block Diagram for System.

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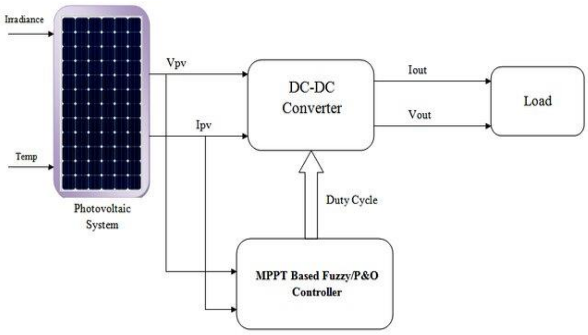

Figure 1 Block Diagram for System

1. Boost Converter: Fundamental

Boost converters are efficient power electronics devices that increase input voltage without a transformer. This voltage increase is accompanied by a corresponding decrease in current to maintain a constant power level. Pulse Width Modulation (PWM) is frequently used for switching control in basic designs. Boost converter operation occurs in either Continuous Conduction Mode (CCM) or Discontinuous Conduction Mode (DCM). The basic operating principle of a boost converter is shown in Figure 2.

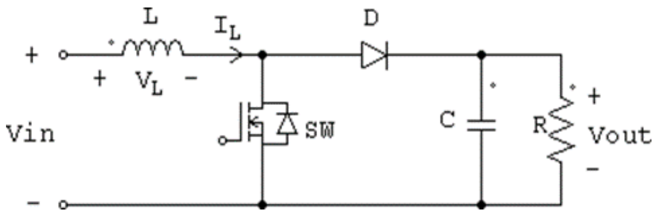

Figure 2 Boost Convert Layout

A DC-DC step-up converter functions in two distinct modes, primarily differentiated by the behavior of the inductor current. In the first mode, the inductor current flows continuously, whereas in the second mode, it drops to zero for a brief interval before the next switching cycle begins (as illustrated in Figures 5 and 6). The Continuous Conduction Mode (CCM) further operates in two phases: Current pass-through switch Mode (Mode 1) and Current block by switch (Mode 2). In Mode 1, when the power switch is turned ON (Figure 3), the supply current flows through the inductor and the power switch, causing energy to be stored in the inductor. During this phase, the resistive load receives power from the capacitor. In Mode 2, when the power switch is OFF, no current flows through the original path. Instead, the inductor releases its stored energy, directing current through the diode, capacitor, and resistive load (as shown in Figure 4). During this phase, the inductor discharges its energy to the load, resulting in an output voltage higher than the supply voltage, which is characteristic of a step-up or boost converter. Figure 2 Boost Convert Layout, [1-5]

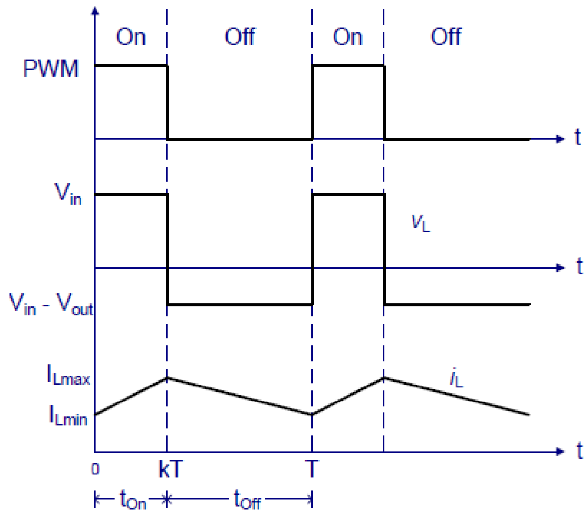

Figure 3 Continuous Conduction Mode

The figure illustrates the voltage and current waveforms during the operation of a boost converter in both CCM and Discontinuous Conduction Mode DCM. As observed in Figure 4, during DCM operation, the inductor current has a finite value when the inductor voltage is negative. However, it drops to zero during the interval when the inductor voltage becomes zero. Figure 3 shows Continuous Conduction Mode [6-10]

2. Boost Converter Design

This work begins by modeling a basic step-up DC-DC converter operating in continuous conduction mode, supplied by a fixed DC voltage, to analyze its voltage boosting capabilities and parameter calculations. Subsequently, the converter is powered by a PV system instead of the constant DC source. In both scenarios, PWM generates the switching pulses. Finally, the boost converter is connected to a PV panel, and a Maximum Power Point Tracking (MPPT) system, utilizing the Perturb and Observe method, controls the converter switch's duty cycle. Figure 4 shows Continuous Conduction Mode.

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3.1 Design Procedure

1) **Duty Cycle (D)**

$$D = 1 - \frac{Vin}{Vo}$$

2) **Value of Inductor (L)**

$$L = \frac{Vin \times D}{Fs \times \Delta Io}$$

3) **Capacitance (C)**

$$C = \frac{Io \times D}{Fs \times \Delta Vo}$$

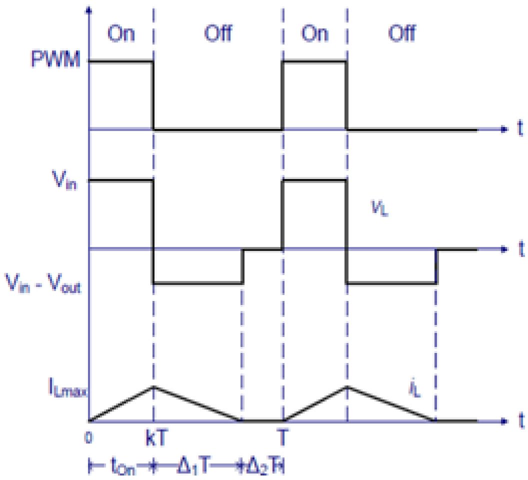


Figure 4 Continuous Conduction Mode

3. Modeling and Simulation

The MPPT system employs the Perturb and Observe algorithm, as illustrated in Figure 5. This method is widely used due to its simplicity, ease of implementation, and cost-effectiveness. In this approach, the instantaneous voltage and current values are measured, and the corresponding output power is computed. A small perturbation is then applied to the operating point. If the power increases, the algorithm checks whether the voltage change is positive. If so, the duty cycle is incremented; otherwise, the direction of adjustment is reversed. The proposed system is designed using MATLAB, utilizing various blocks from the Sim Power Systems toolbox. Figure 6 illustrates the simulation design of a step-up converter powered by a constant DC source and connected to a simple resistive load. An IGBT switch is employed as the power switch to control the circuit's operation. The required gate pulse for triggering the circuit is generated using a PWM pulse generator. In Figure 5, the converter is integrated with a solar system consisting of series-connected solar cells. Figure 5 provides a detailed representation of the proposed model, showcasing the step-up converter connected to the PV system and the MPPT control unit. The PV Panel detail is present in Figure 6. Figure shows 5 P&O Flowchart. [11]

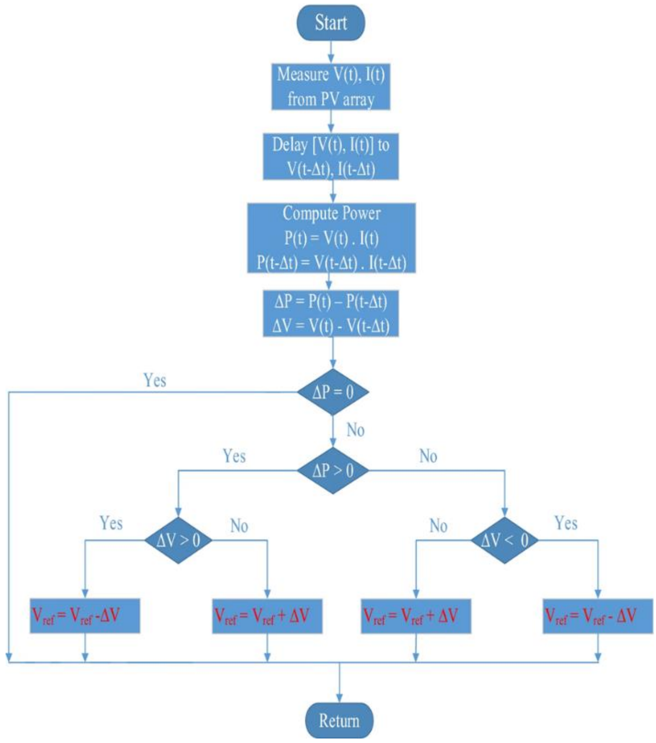
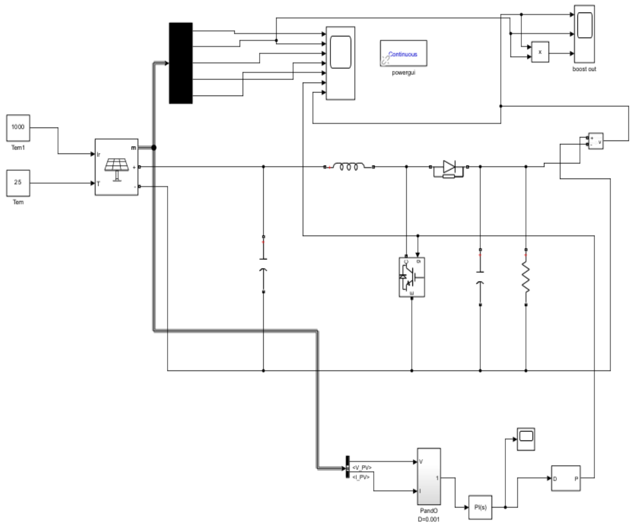


Figure 5 P&O Flowchart



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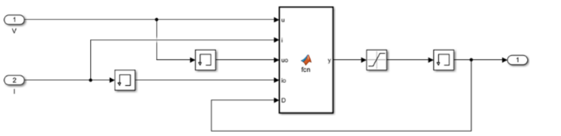

Figure 6 MATLAB Model for PV with Boost Converter

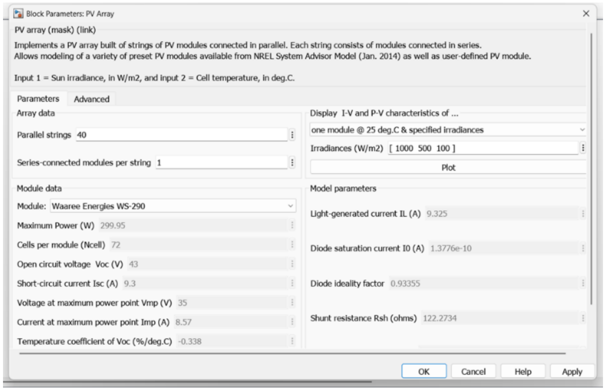

Figure 7 PV Panel Detail

4. Results and Analysis

Analysis was performed to verify the boost converter's operation using the pre-calculated parameters and to evaluate the proposed MPPT-controlled converter's performance. The power voltage and current voltage curve for 300 w panel is present in Figure8. The Figure 9 present panel voltage, Panel current and Irradiation 1000w/m^2. Figure 6 shows MATLAB Model for PV with Boost Converter Figure 7 shows PV Panel Detail. Figure 10. present boost converter IGBT switch, also present the boost voltage 80V.

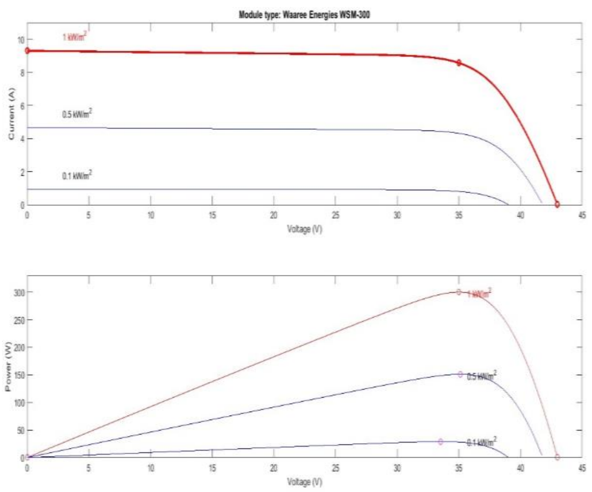

Figure 8 PV & IV Curve

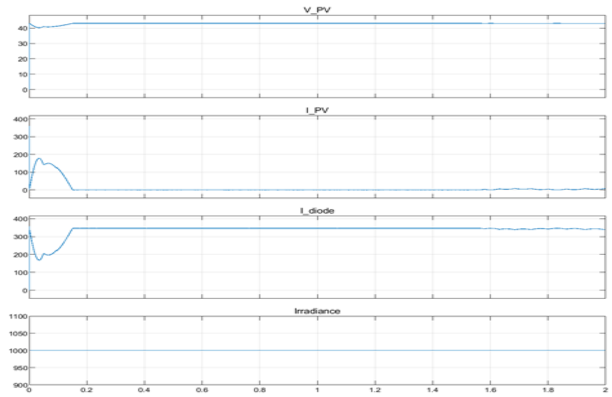

Figure 9 PV Voltage, Current and Irradiation

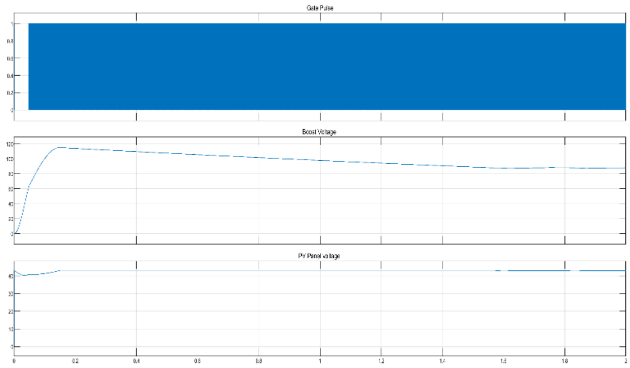

Figure 10 Gate Pulse, Boost Converter Input and Output Voltage

Conclusion

In this study, the MATLAB design and simulation of a 300W boost converter with Perturb and Observe (P&O) MPPT have been successfully implemented to optimize the performance of a photovoltaic system. The boost converter efficiently steps up the voltage to the desired level while maintaining a stable output despite variations in solar irradiance and load conditions. The P&O MPPT algorithm, integrated into the system, ensures maximum power extraction from the PV panel by dynamically adjusting the operating point to track the maximum power point (MPPT). Simulation results demonstrate the effectiveness of the proposed system, where the converter with MPPT outperforms the system without MPPT in terms of efficiency and output voltage. The study highlights the potential of using P&O MPPT in renewable energy systems, offering a cost-effective and straightforward solution for enhancing the performance of photovoltaic systems. Future work

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may explore the implementation of advanced MPPT techniques and further optimization strategies to further improve the system's overall performance and efficiency.

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