Energy Efficiency Optimization in PV Systems through the Implementation of Boost Converter Topology

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ABSTRACT

The performance of Photovoltaic (SPV) systems is greatly influenced by factors such as temperature, array configuration, solar insolation, and shade. The use of SPV modules to convert solar energy faces challenges due to changes in insolation conditions, which can affect the efficiency and output power of the modules. One way to improve the efficiency of solar energy conversion is to track the maximum power point of the PV module using the various Maximum Power Point Tracking (MPPT) charge controllers available on the market. The key component in an SPV is the dc-dc converter, which serves as the interface between the load and the SPV module. The use of this dc-dc converter can improve the performance of the MPPT algorithm, thereby improving the overall efficiency of the SPV system. In this study, modeling and simulation of the equivalent circuit of one diode of a solar photovoltaic module using MATLAB/SIMULINKTM was carried out, with the application of a boost converter that was able to achieve an efficiency of 93.29%.

Keywords: Photovoltaic System (SPV), Maximum Power Point Tracking (MPPT), photovoltaic cells, boost converter.

I. INTRODUCTION

In the era of climate change and increasing awareness of the need for clean energy, Solar Photovoltaic (PV) systems have become an attractive solution for generating electricity from renewable energy sources. However, despite its great potential, energy conversion efficiency in PV solar panels remains a major challenge that needs to be solved.

The efficiency of a PV system is significantly affected by the ability to convert power from PV solar panels to a load or energy storage system. Generally, the output voltage of PV solar panels tends to be lower compared to the voltage required by the load or energy storage system. Therefore, this is the critical point where the use of Boost Converter becomes very important.

A Boost Converter is an electronic circuit capable of converting low DC voltage into higher DC voltage. With the application of the Boost Converter, the output voltage generated by the PV solar panel can be efficiently increased to reach the level required by the load or energy storage system. Therefore, Boost Converters have a crucial role in improving energy efficiency in PV systems.

The use of Boost Converters in PV systems is primarily aimed at achieving maximum energy efficiency. By increasing the output voltage of the PV solar panels, the loss of power in the system can be minimized. This results in more efficient use of energy and increases the availability of stable and reliable electrical power.

In this study, we will conduct an analysis and exploration on the application of Boost Converters in PV systems with the aim of achieving optimal energy efficiency. We will investigate the basic principles of Boost Converters, the characteristics of PV systems, and the factors that affect energy efficiency. In addition, we will involve simulation modeling and practical testing to evaluate the performance of the system with specific parameter variations.

The purpose of this study is to provide a deeper understanding of the potential and limitations of the use of Boost Converters in improving energy efficiency in

PV systems. In addition, it is hoped that this study can present optimal design recommendations and operational parameters to achieve maximum energy efficiency in the implementation of PV systems using Boost Converters.

With the increase in energy efficiency in Solar Photovoltaic systems through the application of Boost Converters, it is hoped that we can accelerate the acceptance of renewable energy. This can reduce reliance on non-renewable fossil energy sources, while reducing greenhouse gas emissions that are detrimental to the environment and human health.

II. RESEARCH METHODS

A. Properties of Photovoltaic Modules

Solar panels are generally used by connecting solar cells in series or parallel combinations to increase current and voltage. Solar cells are often modeled with source currents and inverted diodes connected in parallel, along with intrinsic series resistance (Rs) and parallel resistance (Rp), as shown in Figure 1. Series resistance is caused by resistance to the flow of electrons from the junction n to p, while parallel resistance is caused by leakage current.

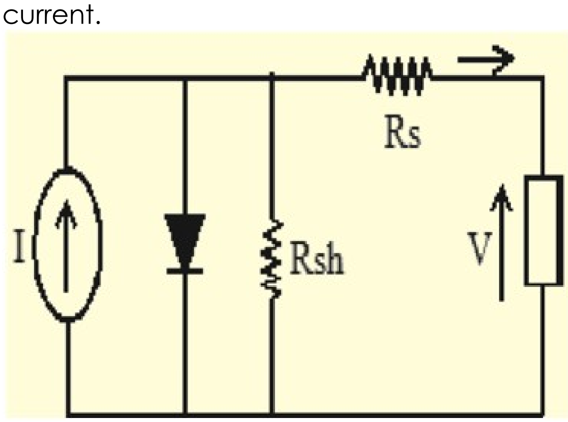


Figure 1 single diode SPV model

The currents generated by photovoltaic are:

$$I = I_{SC} - I_d \quad (1)$$

$$I_d = I_O\left(e^{q^{V}} d\text{¿}^{KT} - 1\right)$$

Io represents the reverse saturation current of the diode, q denotes the charge of an electron, and Vd is the voltage across the diode.
Voltage across the diode, k is the Boltzmann constant (1.38 X 10-23 J/K), and T is the temperature at the junction.

Kelvin (K) [9]. Using equations 1 and 2, it can be concluded that:

$$I = I_{SC} - I_O\left(e^{qV_{d\text{¿}^{KT}-1}}\right)$$

$$I = I_{SC} - I_O\left(e^{q^{V}} d\text{¿}^{KT} - 1\right)$$

In this context, I is the current of the photovoltaic cell, V is the voltage of the SPV cell; T is the temperature measured in Kelvin, and n is the ideal factor of the diode.

Table 1 Parameters of Tools Used

COMMERCIAL PARAMETERS OF 250W MODULE	
Module parameters	VALUE
Nominal output power (W)	250
Module efficiency (η,%)	15.00
Operating temperature range (0C)	-4- and 85
Voltage at PmaxVmpp(V)	30.7
CURRENT Pmax Impp (A)	8.16
OPEN CIRCUIT VOLTAGE Voc(V)	38.1
Short current citcuit (A)	8.58

Number of modules per pallet	28

The illustration in Figure 2 shows a commercially available 250W powered solar panel. The maximum power point of the solar panel changes along with the intensity of the sun, angle, and temperature of the panel. Simulations using the equivalent circuit of one diode were used to observe the I-V and P-V characteristics of the photovoltaic module, using the Matlab/SIMULINKTM platform as shown in Figure 4 [10].

Figure 2 250W solar panel

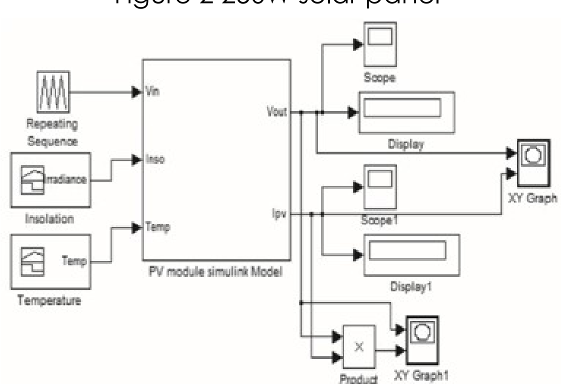


Figure 3 Simulink SPV model

Figures 5 and 6 show the I-V and P-V characteristics of the SPV panel. Meanwhile, Figures 7 and 8 illustrate the I-V and P-V characteristics of SPVs at different temperature levels.

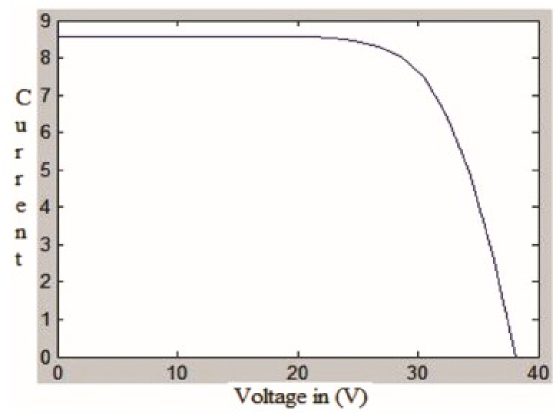


Figure 4 Characteristics of I-V solar panels

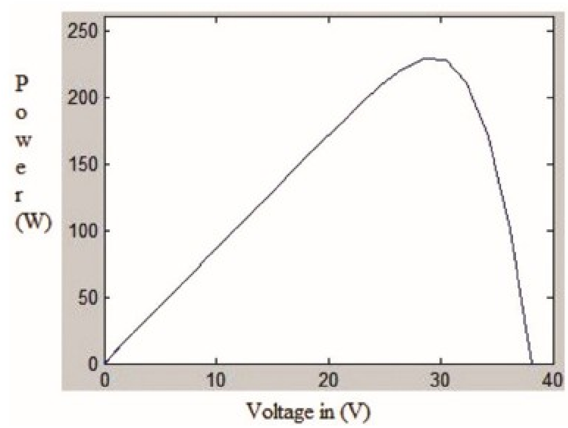


Figure 5 characteristics of solar panels P-V

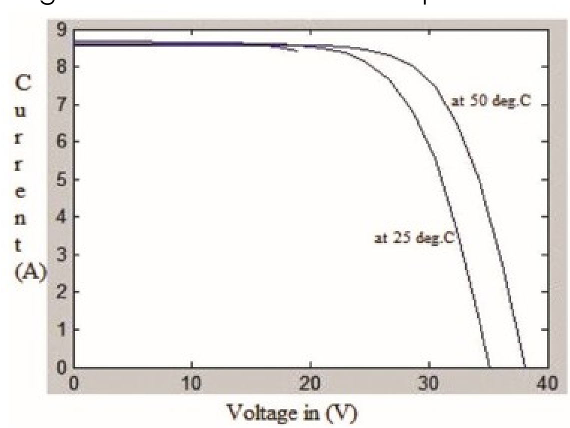
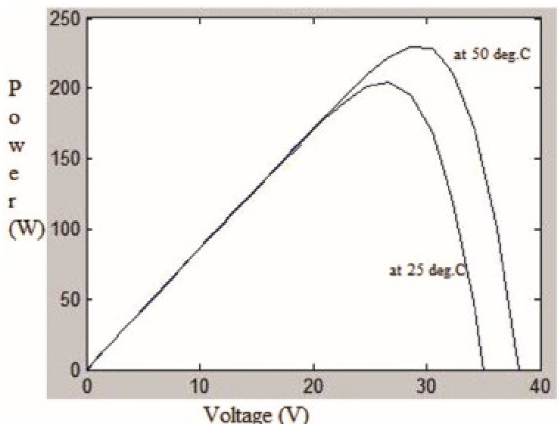


Figure 6 characteristics with varying temperatures I-V



B. DC-DC Converter

A DC-DC converter is an electronic circuit that converts direct current (DC) from one voltage level to another. DC-DC converters are often used in switchmode power resources and DC motor drive applications. The switch mode on a DC-DC converter is used to convert an unregulated DC input into a controllable DC output at the desired voltage level.

At the core of the Maximum Power Point Tracking (MPPT) hardware is the switch mode on the DC-DC converter. MPPT uses converters to achieve different purposes, such as regulating the input voltage on Solar Power Generation Systems (PLTS) at Maximum Power Points (MPPs) and facilitating load matching to transfer maximum power. A switch converter consists of a capacitor, an inductor, and a switch. Ideally, all of these devices do not consume any power, thus creating a high efficiency in the switch converter. When the device is in an active state, the voltage drop is close to zero, so the power lost becomes very small. During the operation of the converter, the switch switches at a constant frequency fs with DT time ON, and OFF time (1 - D)Ts, where Ts is the switching period (1/fs), and D is the duty ratio of the switch (D ∈ [0; 1]), as seen in Figure 9.

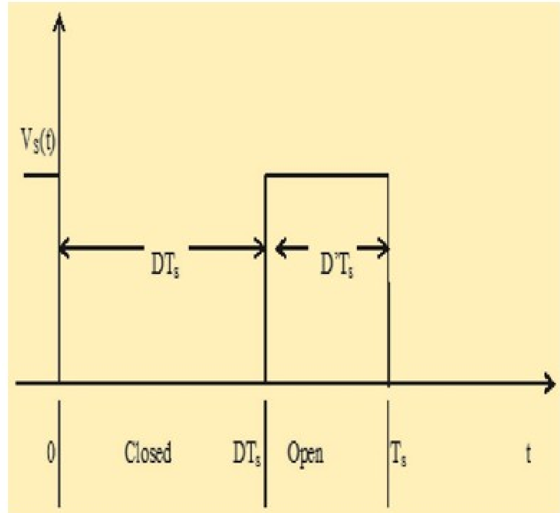


Figure 8 Ideal switching period

III. RESULTS AND DISCUSSION

A boost converter, also known as a step-up converter as seen in Figure 10, has a name that reflects its function of generally converting a low input voltage into a high output voltage, similar to the "reverse money" principle.

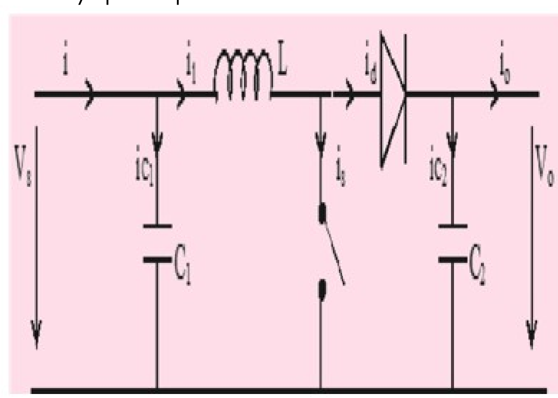


Figure 9 of the boost network

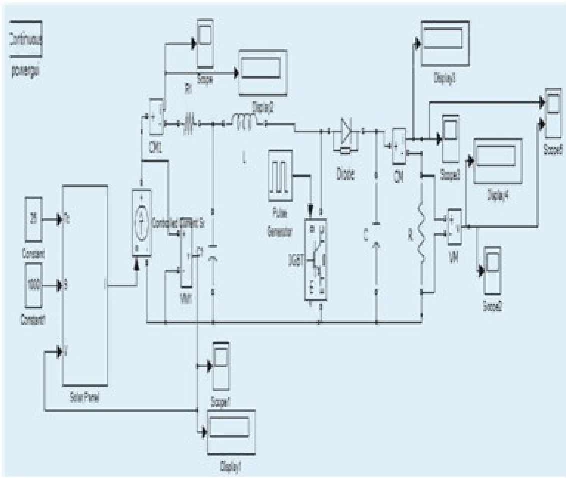


Figure 10 simulation of the converter boost circuit

During the ON DT time interval of the Ts switching period, the switch closes and connects the input through the inductor to ground, causing a high current flow. The diode, which is reverse-biased, serves to prevent the inductor current from flowing through the charge. Once the switch is opened during the OFF time interval (1 – DTs) of the switching period, the nature of the inductor prevents any discontinuities in the current flow, and the high current through the bias diode now causes a high voltage increase applied to the entire load.

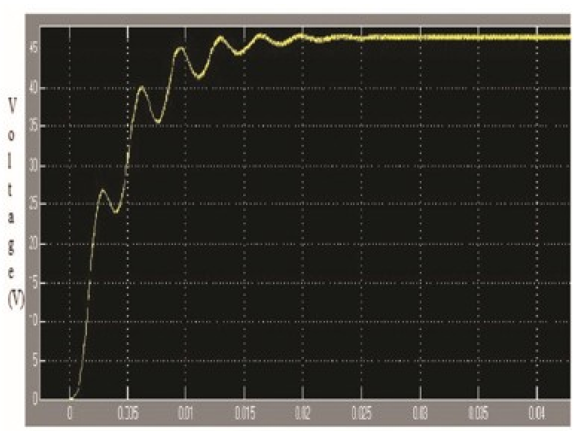


Figure 11 Output voltage of boost converter

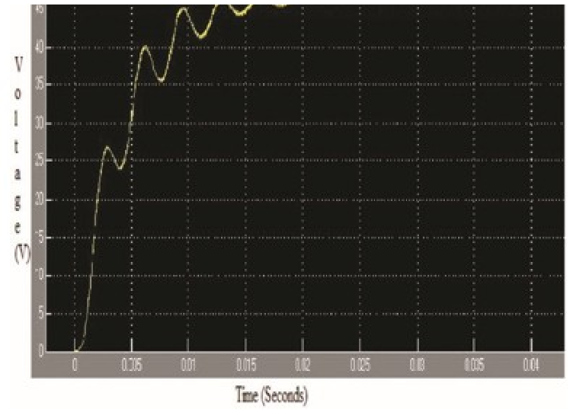


Figure 12 Output current of the boost converter

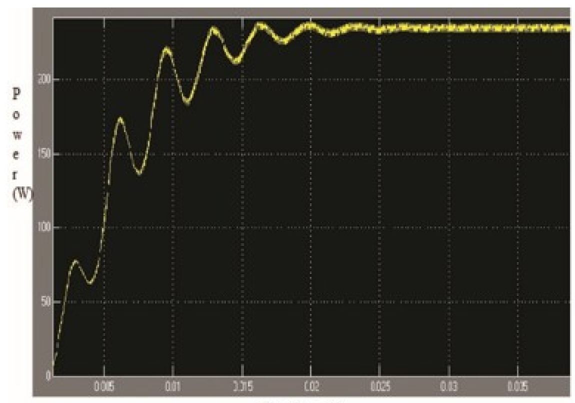


Figure 13 Input power of the converter boost circuit

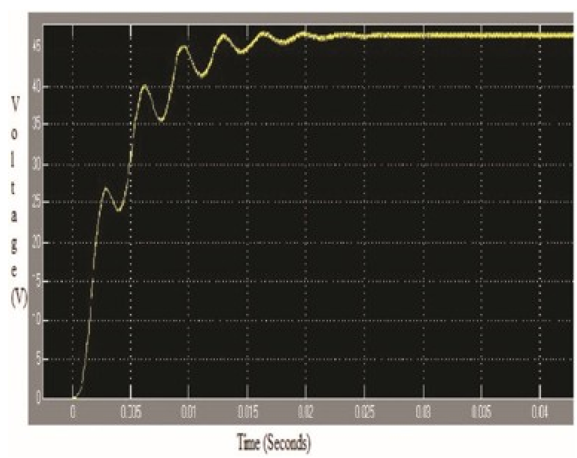


Figure 14 Output power of the converter boost circuit

Charts 12 and 13 show the output voltage and amplifier current of the converter respectively. The output ripple voltage variation ranges from 46.3V to 46.8V, while the output ripple current ranges from 5.03A to 5.08A. The input and output power of the converter are exemplified in Figures 14 and 15 respectively to calculate the thrust efficiency of the converter simulation. The measured input power from the circuit simulation is 251.9W, while the measured output power is 235W. The efficiency of this system reaches 93.29%.

IV. METHODOLOGY

A DC-DC converter is an electronic circuit that converts direct current (DC) from one voltage level to another. DC-DC converters are often used in switchmode power resources and DC motor drive applications. The switch mode on a DC-DC converter is used to convert an unregulated DC input into a controllable DC output at the desired voltage level.

At the core of the Maximum Power Point Tracking (MPPT) hardware is the switch mode on the DC-DC converter. MPPT uses converters to achieve different purposes, such as regulating the input voltage on Solar Power Generation Systems (PLTS) at Maximum Power Points (MPPs) and facilitating load matching to transfer maximum power. A switch converter consists of a capacitor, an inductor, and a switch. Ideally, all of these devices do not consume any power, thus creating a high efficiency in the switch converter. When the device is in an active state, the voltage drop is close to zero, so the power lost becomes very small. During the operation of the converter, the switch switches at a constant frequency fs with DT time ON, and OFF time (1 - D)Ts, where Ts is the switching period (1/fs), and D is the duty ratio of the switch ($D \in [0; 1]$)

V. RESULTS & DISCUSSION

The boost converter, which is also referred to as the step-up converter as shown in Figure 10, gets its name from its main task, which is to convert a low input voltage into a higher output voltage, on a principle similar to "reverse money". An example of a simple solar panel with standard insolation and temperature values has been shown. The simulated solar panels show differences in I-V and P-V characteristics with variations in insolation and temperature, as depicted. By using different dc-dc converter models, we can conduct simulations, and analyze the performance of solar photovoltaic systems. For example, the simulation of the boost converter circuit in MATLAB/SIMULINKTM produces an efficiency of 93.29% with an output voltage of 0.5V and an output current of 0.05A. With this boost converter model, various MPPT algorithms can be simulated and their performance can be analyzed.

1. Results

Graphs 12 and 13 show the variations in output voltage and current on the amplifier converter. The output voltage ranges from 46.3V to 46.8V, while the output current varies between 5.03A to 5.08A. The input and output power of the converter are shown in Figures 14 and 15, respectively used to calculate the efficiency of the amplifier converter simulation. The measured input power from the circuit simulation is 251.9W, while the measured output power is 235W. The efficiency of this system is about 93.29%.

2. Discussion

Figures 12 and 13 show fluctuations in output voltage and current in the amplifier converter. The variation in output voltage ranges from 46.3V to 46.8V, while the output current varies from 5.03A to 5.08A. To calculate the efficiency of the amplifier converter simulation, its input and output power are shown in Figures 14 and 15 respectively. The input power, measured through circuit simulation, is about 251.9W, while the measured output power is about 235W. The efficiency of the system in this case is around 93.29%.

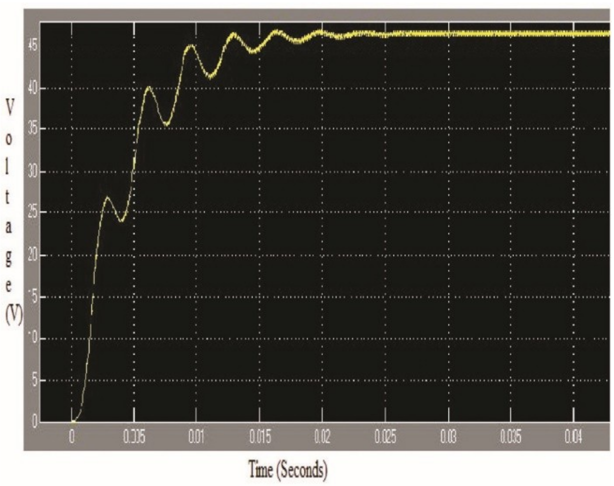


Figure 14 Output power of the converter boost circuit

VI. CONCLUSION

An illustration of a simple solar panel with standard values of insolation and temperature has been shown. The simulation of the solar panel displays variations in I-V and P-V characteristics with changes in insolation levels and temperatures. With the presence of diverse dc-dc converter models, solar photovoltaic systems can be simulated and their performance can be analyzed. For example, the boost converter circuit is simulated using MATLAB/SIMULINKTM, resulting in an efficiency of 93.29%, with an output ripple voltage of 0.5V and an output ripple current of 0.05A. Using this boost converter model, various MPPT algorithms can be simulated and their performance can be analyzed.

VII. CLOSING

1. Awards

With gratitude, we would like to thank Mr. Anggara and all parties who have made valuable contributions and very important support. Also, thank you to our family and friends who have provided moral support and full understanding during this research process.

Once again, thank you to all who have played a role in the success of this research.

Muhammad Rafli Maulana Rabbani

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