International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Advancements in PV System Modelling and Simulation with Boost and SEPIC Converters: A Literature Survey

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A B S T R A C T :

As the world shifts toward cleaner and more sustainable energy sources, photovoltaic (PV) systems have become a cornerstone of modern renewable energy strategies. To get the most out of these systems, it's essential to use Maximum Power Point Tracking (MPPT) techniques in tandem with efficient DC-DC converters. This study dives into the modeling and simulation of PV setups using Boost and SEPIC converters, with a particular focus on the performance gains achieved through the Perturb and Observe (P&O) MPPT algorithm. Beyond just comparing converter topologies, the paper takes a deeper look at how various control strategies influence system stability, response time, and overall power output. A review of existing literature sets the stage for understanding current best practices, while simulation results provide insight into real-world performance. In closing, we also touch on key technical challenges, gaps in current methodologies, and opportunities for future research in advancing intelligent energy systems.

Keywords: Photovoltaic (PV) systems, DC-DC Boost Converter, SEPIC Converter, MPPT technique.

1. Introduction

The increasing global energy demand due to industrialization and growth, as well as the environmental issues caused by the use of fossil fuels, have led to the rapid growth of renewable energy sources, especially photovoltaic (PV) systems, which are capable of converting solar energy directly into electricity. The continued dependence on fossil fuels and their negative effects on the environment such as greenhouse gas emissions, and depletion of influences [1] synchronous with the shift to clean energy solutions. Nevertheless, the performance of PV systems is inevitably constrained by low energy conversion rates, intermittency, and environmental conditions such as temperature extremes, partial shading, and dust accumulation, among others [2].

In order to overcome these issues, Maximum Power Point Tracking techniques increases the ability of the photovoltaic arrays to produce more energy output. Maximum power point tracking (MPPT) algorithms dynamically adjust the operating point of the photovoltaic (PV) system so that it provides maximum power [8].

Overview of MPPT Techniques

Maximizing the efficiency of solar panels is a big deal, and that's where MPPT (Maximum Power Point Tracking) techniques come in. These methods help solar systems get the most energy possible from sunlight, even when conditions aren't perfect. There are a few common approaches that are widely used:

- Perturb and Observe (P&O): This one's pretty straightforward—it tweaks the operating voltage slightly and watches how the power output responds. It's simple and easy to implement, but it tends to cause small fluctuations around the maximum power point (MPP), which isn't ideal [9].
- Incremental Conductance (INC): A bit more sophisticated, this method looks at how power changes with respect to voltage [10]. It's better at tracking the MPP accurately, especially when sunlight and temperature are changing quickly.
- Fuzzy Logic MPPT: This approach uses fuzzy logic control systems to make decisions based on multiple input conditions. It's great for adapting to changing environments and tends to be more stable than traditional methods [11].
- Artificial Neural Networks (ANN): These are machine learning models that learn from past data to predict the optimal power point [12]. They're highly accurate and fast but need a lot of training data and processing power.

Each of these methods has its strengths and weaknesses. For example, fuzzy logic is really flexible and reliable under different conditions, while neural networks are extremely precise—but they take more effort to set up.

Recently, there's been a lot of interest in hybrid MPPT techniques that mix traditional methods with intelligent algorithms. These hybrids aim to get the best of both worlds: fast, accurate tracking with better adaptability in real-world conditions like shifting clouds or temperature swings.

DC-DC Converters in PV Systems

DC-DC converters play a critical role in ensuring system stability and optimizing power transfer by regulating voltage and current levels. This review focuses on two widely used converter types:

- Boost Converter: A step-up converter that increases the input voltage, making it ideal for applications requiring higher output voltages [14].
- SEPIC (Single-Ended Primary Inductor Converter): A versatile converter capable of both stepping up and stepping down the voltage, making it suitable for systems with fluctuating input voltages [15].

While SEPIC converters offer superior voltage regulation in varying conditions, Boost converters remain popular due to their simplicity and higher efficiency [16]. The choice between these converters significantly impacts overall system performance. Key design and implementation factors—such as component stress, transient response, and power losses—must be carefully considered to ensure optimal functionality [17].

Modelling and Simulation of PV Systems

To maximize the performance of photovoltaic (PV) systems, accurate modeling and simulation are essential. Several key components are considered in the modeling process:

- Solar Cell Modeling: The behavior of a solar cell is typically characterized using current-voltage (I-V) equations that represent its electrical properties under varying conditions [18].
- Converter Modeling: Electrical circuit models are employed to analyze the performance of power electronic converters such as SEPIC and Boost converters. These models help evaluate their response under different operational scenarios [19].
- MPPT Algorithm Simulation: To extract the maximum possible power from PV systems, Maximum Power Point Tracking (MPPT) algorithms are simulated using MATLAB/Simulink and other specialized software tools. These simulations help in optimizing the algorithm's performance under various irradiance and temperature levels [20].

Figures 1–4 illustrate the simulation models of the SEPIC and Boost converters, showcasing their configurations and operational parameters used in the analysis.

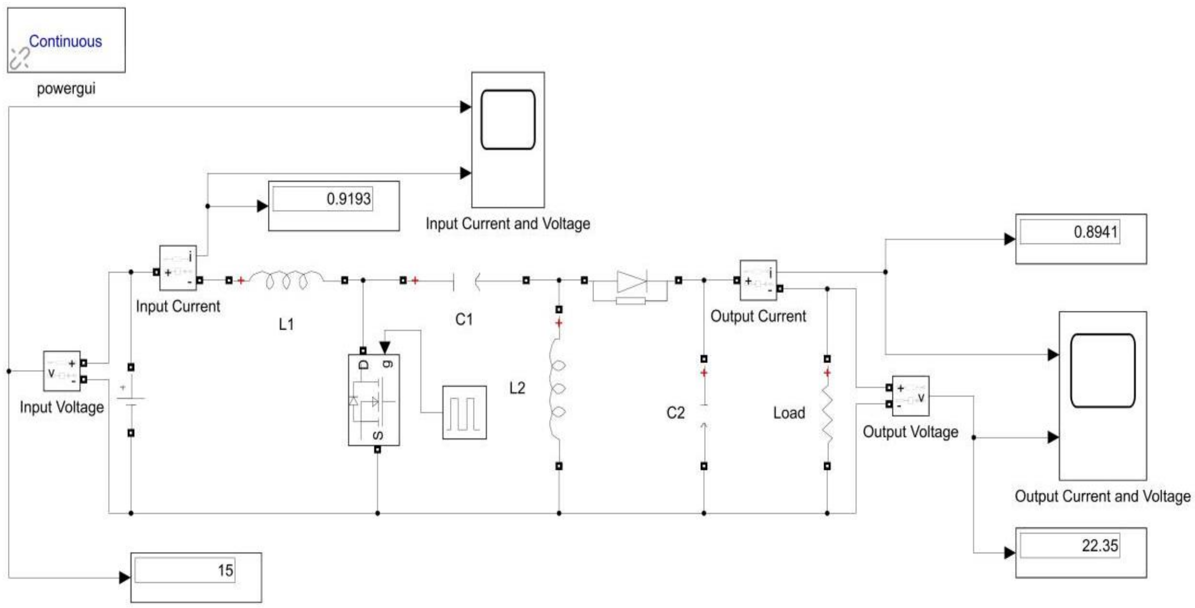

Fig. 1 Simulation model of DC-DC SEPIC Converter

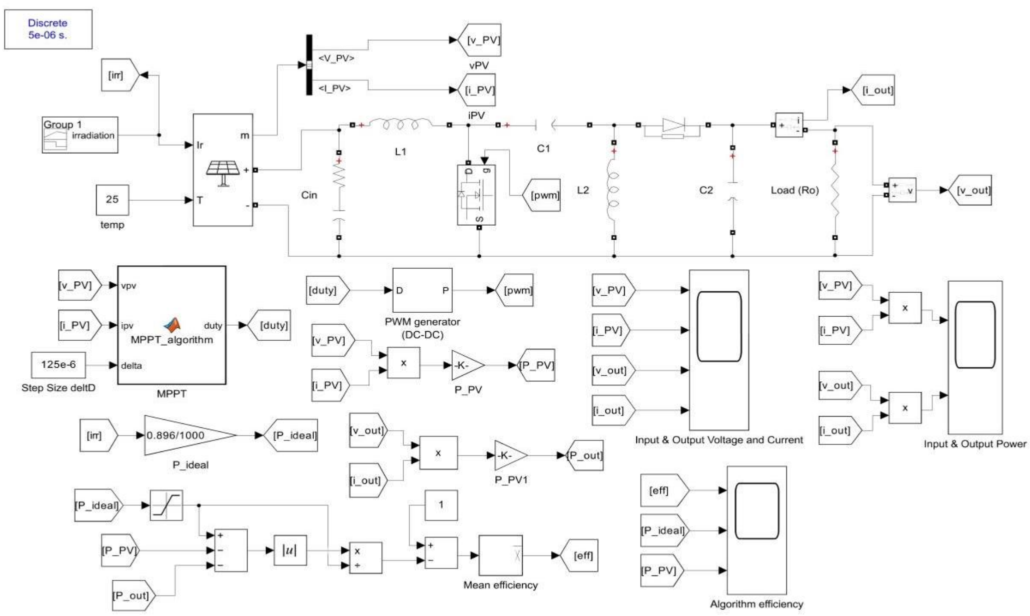

Fig. 2 Fourth model of P&O MPPT with a DC-DC SEPIC Converter

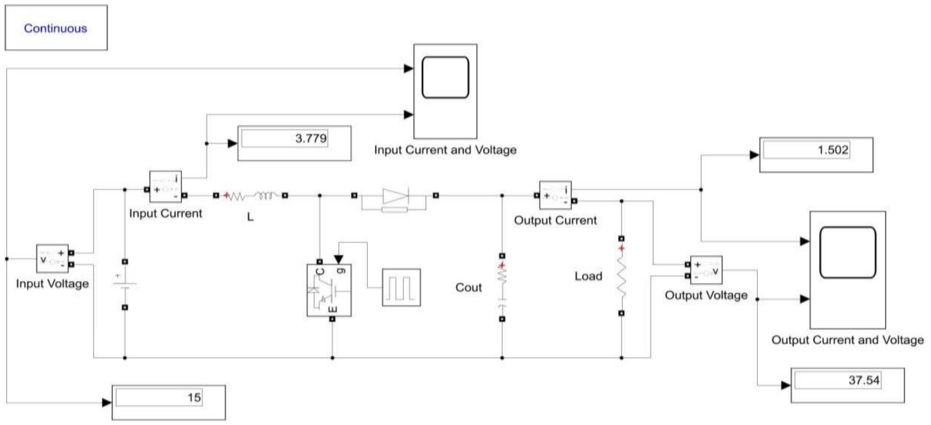

Fig. 3 Simulation model of DC-DC Boost Converter

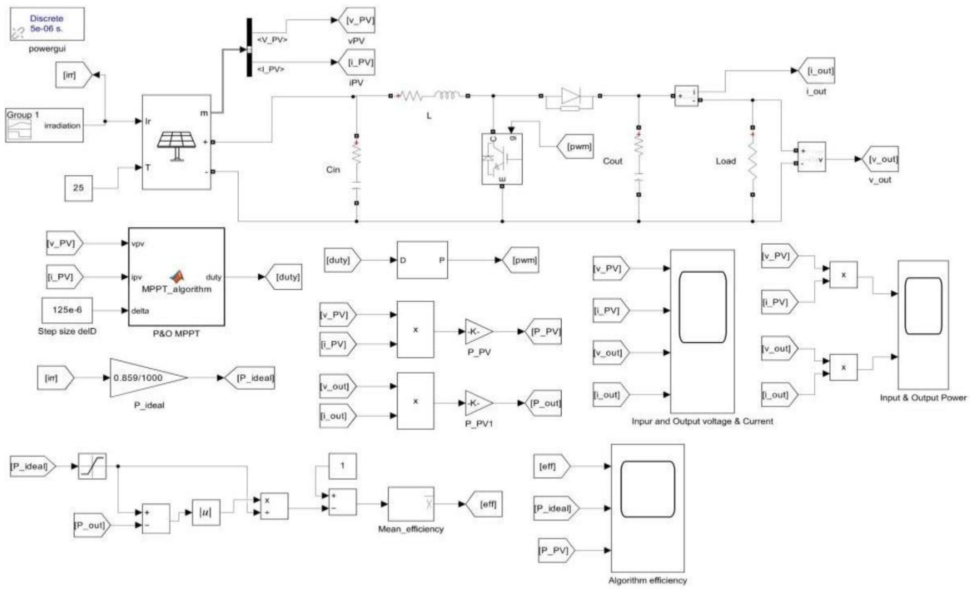

Fig. 4 Model of P&O MPPT with a DC-DC Boost Converter

Through simulation, researchers can assess power losses, efficiency improvements, and dynamic response under varying irradiance and temperature conditions. The integration of AI-based predictive models is further enhancing the accuracy of PV system simulations [21].

Challenges in PV System Efficiency Improvement

Despite advancements in MPPT techniques and converter technologies, several challenges remain in improving PV system efficiency:

- Partial Shading Effects: Variations in irradiance can lead to multiple power peaks, reducing MPPT accuracy [22].
- Power Losses in Converters: Switching and conduction losses in DC-DC Converters impact overall efficiency [23].
- Environmental Factors: Dust, temperature variations, and degradation over time affect PV performance [24].

Addressing these challenges requires a combination of improved MPPT algorithms, optimized converter designs, and real-time monitoring solutions [25].

Future Research Directions

Future research in PV systems should focus on:

- AI-Based MPPT Optimization: Developing machine learning-based MPPT algorithms for real-time efficiency improvements [26].
- Advanced Converter Designs: Exploring new topologies to reduce power losses and improve performance [27].
- IoT-Based Monitoring: Integrating IoT for remote monitoring and predictive maintenance of PV systems [28].

Conclusion

This paper has thoroughly examined the efficiency gains of photovoltaic (PV) systems using Boost and SEPIC converters in conjunction with the Perturb and Observe (P&O) Maximum Power Point Tracking (MPPT) method. Despite notable advancements in optimizing PV power conversion, challenges such as environmental variability, converter losses, and partial shading continue to constrain overall efficiency. Future progress in areas like energy storage integration, AI-driven MPPT algorithms, and innovative converter topologies holds promise for improving the reliability and performance of PV systems. Continued research in these domains will be instrumental in promoting the widespread adoption of solar energy as an efficient and sustainable power source.

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