International Journal of Computer Engineering in Research Trends
ISSN: 2349-7084/ https://doi.org/10.22362/ijcert.v10i12.915
Volume 10, Issue 12, December 2023

Review Paper

A Systematic Review of Boost Converter Design Methodologies for Optimizing Photovoltaic Output

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Received: 11/10/2023, Revised: 29/10/2023, Accepted: 22/12/2023, Published: 30/12/2023

Abstract:- *This paper offers a systematic review of boost converter design methodologies, a pivotal component in optimizing photovoltaic system outputs. It comprehensively analyzes various converter topologies, focusing on their operational principles and efficiency in solar energy conversion. The study delves into the intricate challenges of maximizing efficiency under diverse environmental conditions, emphasizing the need for adaptive and robust converter designs. It explores recent technological advancements, highlighting how they address these challenges and contribute to improved photovoltaic performance. The review aims to provide a broad understanding of current trends in converter technology and suggests future research directions, particularly in developing more versatile and efficient converters to better harness solar energy. This work serves as a foundational resource for practitioners and researchers in renewable energy, offering insights into enhancing the efficacy of photovoltaic systems. This comprehensive review examines various boost converter designs for optimizing photovoltaic output, revealing key findings. It was found that certain topologies offer significant advantages in terms of efficiency and adaptability to environmental changes. The paper also highlights the evolving nature of converter technology, showing promising directions in handling solar energy fluctuations. These insights are crucial for advancing photovoltaic system efficiency and reliability, offering a roadmap for future research in renewable energy technology.*

Keywords: *Boost Converter Design, Photovoltaic Systems, Solar Energy Optimization, Converter Topologies, Renewable Energy Efficiency*

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1. Introduction

One of the most essential types of energy in the world is electricity, which is usually produced by conventional methods. But in reality, conventional energy sources like coal, oil, natural gas, and biomass are causing global warming. When conventional energy production methods are used, greenhouse gases and carbon dioxide are emitted [1] [2]. In order to offer sustainable energy services, renewable energy sources including solar, wind, hydropower, biomass, and geothermal energy should be emphasised as additional clean, endless, and competitive energy sources [2]. Malaysia is one of the several nations making the shift to a zero-energy approach [3] [4]. Malaysia has made a commitment to low-carbon development with the goal of reshaping the economic environment to be more sustainable. In order to transition Malaysia's energy systems from fossil fuel-based to cleaner, low-carbon systems, the National Energy Transition Roadmap (NETR) has created the Responsible Transition (RT) Pathway 2050 [5] [6].

A rise in the number of photovoltaic (PV) generating systems are being installed as a result of worries about environmental problems including global warming and energy security. Step-up converters, often referred to as boost converters, are crucial parts of photovoltaic (PV) systems that maximise energy extraction and overall system efficiency [7]. PV systems may function successfully in a variety of settings as a consequence to boost converters, which also guarantee that the energy produced is efficiently captured and put to use for a number of uses [8]. They are particularly important when the PV panels' output voltage is less than what the load or storage system requires.

This paper presents a comprehensive review of the various design methodologies for boost converters in photovoltaic systems. Emphasizing both the theoretical and practical aspects, the review aims to elucidate the key factors influencing photovoltaic output optimization. This study serves as a valuable resource for researchers and practitioners in the field of renewable energy, offering insights into the latest trends and advancements in boost converter technology.

2. Basic Principles of Boost Converter

Being that DC–DC boost converters are so effective at raising the voltage of the input signal, they are widely used in photovoltaic (PV) systems. In the boost converter, the input capacitor is essential because it acts as a store of energy and guarantees a steady output voltage [12]. The input capacitor charges when the converter's switch is in the closed position. When the switch is opened, the stored energy is released into the output, which helps maintain voltage stability. The design and analysis of input capacitors in DC-DC boost converters for PV systems has been the focus of several research. These studies examine the effects of several capacitor characteristics on the operational performance of the converter, such as capacitance, ripple current rating, maximum voltage rating, equivalent series resistance (ESR), and equivalent series inductance (ESL). The capacitance per unit volume of an input capacitor, which measures the amount of energy stored in relation to its physical size, is a crucial consideration when selecting one for a boost converter. Above all, as compared to tantalum and ceramic capacitors, aluminium electrolytic capacitors have a higher capacitance per unit volume. [11] Because of this feature, they are a favourable option for PV systems, particularly in situations where space limitations are common. The design of a DC-DC boost converter for a grid-connected photovoltaic application system with a constant output voltage is covered in this study [13]. A boost converter is used to raise a solar panel's erratic voltage to a higher, steady DC value. Its control system is a microcontroller, and it makes use of a voltage feedback mechanism to keep the output voltage steady. For a grid-connected solar system, the boost converter can be linked to a grid-tied inverter.

3. Electrical Characteristics Relevant to PV Applications

Renewable energy systems depend substantially on photovoltaic (PV) technology, and PV cells must be accurately modelled in order to maximise their performance [14]. This review of the literature looks at the state of the art in parameter estimation for PV cells with an emphasis on employing evolutionary techniques. The chosen work under review uses evolutionary algorithms to highlight the open circuit, short circuit, and maximum power points of the I-V characteristic curve and estimate parameters at those locations [14] [15].

The researcher in [16] found out the possibility of DC arc failures is a significant difficulty brought about by the surge in large-scale photovoltaic systems, which are characterized by increased DC voltage levels. DC series arc faults are more likely to develop but are more difficult to identify than parallel arc faults. The usage of specialized arc fault detectors (AFDs) or arc fault circuit interrupters (AFCIs) is required to handle this issue because conventional overcurrent protection devices are insufficient. According to the literature, a number of things can make these detection systems less reliable, including inverter harmonics, crosstalk, and antenna effects. Regulatory requirements like the National Electrical Code (NEC) require AFCIs to be used in specific PV systems. Numerous defect detection techniques, each with advantages and disadvantages, have been studied in the past. These techniques range from artificial neural networks to parallel capacitors. By providing a unique AFD particularly intended for DC series arc fault prevention in PV systems, this study makes a substantial contribution to the field. Tested on an experimental photovoltaic platform, the suggested AFD shows an astounding 100% detection accuracy, outperforming commercial alternatives in terms of detection speed and robustness against false operations while switching transient states. All things considered, this study adds to the conversation on PV system protection by highlighting how crucial it is to solve DC arc faults in order to improve solar energy technology in a safe and sustainable manner.

According to the researcher in [17], the use of renewable energy has increased over the past 20 years, especially with regard to photovoltaic (PV) systems. This has led to the development of various solar plant configurations that must function and perform correctly in terms of efficient power transfer with regard to all of the involved components, including inverters, grid interface, storage, and other electrical loads. Depending on internal and external variables, the power characteristics of the plant modules together serve as the primary drivers of power extraction in these kinds of applications. Under certain external dynamic situations, conventional maximum power point tracking systems could not have an appropriate conversion efficiency. In order to assess their conversion efficiency in partial shading scenarios with pertinent and dynamic changes in the environmental conditions, this paper proposes an evolutionary-based maximum power point tracking algorithm that can function under dynamic partial shading conditions. It then compares its performance with classical maximum power point tracking methods. The efficacy and constraints of the suggested method in comparison to standard methods were demonstrated by simulations that considered various dynamic shading circumstances.

4. Common Topologies Used in PV Systems

This study in [18] proposes a novel design for grid-tied PV applications. The main advantages of the suggested topology are that it uses a common ground connection, which eliminates leakage current components; it can generate a five-level output voltage waveform, achieve a high boosting factor of the low PV voltage to the grid level, and use a minimal number of power switches and passive components [18]. Furthermore, a strategy for the model predictive controller (MPC) is suggested to regulate the suggested topology. The suggested MPC technique aids in obtaining a quick and precise tracking response while controlling the different currents and voltages of the suggested topology with a single objective function [18] [19].

In [20], the researcher talks about how to build and analyse the input capacitor of a DC-DC boost converter for solar-powered systems. To get the most electricity possible from the photovoltaic (PV) source, systems must operate efficiently. A DC-DC converter and the maximum power point tracking (MPPT) algorithm are utilised to accomplish this [21]. The design of the boost converter's input capacitor and how it relates to the output capacitor are the main topics of this paper. By using average state-space modelling to construct an input capacitor formula, the researchers were able to demonstrate that the input capacitor operates most effectively when its value is half that of the output capacitor. The document also addresses the converter's stability and evaluates the system's performance at various irradiance levels. The results indicate that the stability and performance of the converter are highly dependent on the value of the input capacitor. As per the researcher's findings [20], it is important to choose the right value for the input capacitor in PV-based systems to get the intended level of system performance. Subsequent research endeavours may investigate diverse control algorithms and assess their efficacy through adjustments to the capacitance value.

According to this study [22], the short-term forecasting surrounding solar power generation acknowledges the importance of PV systems in the changing energy environment. Accurate forecasting techniques are required because to natural variables that impact PV production. The drawbacks of existing methods are mentioned, such as chaotic feature extraction and two-dimensional sequential filling frameworks. In response, a novel method for optimised forecasting using long and short memory neural networks is presented in this research. The literature study identifies the inadequacies of existing approaches, providing background information for the contribution of the suggested solution to resolving these issues.

The surrounding SiC MOSFETs in power electronic converters, according to the researcher in [23], emphasise the vital necessity for efficient thermal management because of their small size and sensitivity to temperature changes. The invasiveness, impracticability of changes, and electromagnetic interference susceptibility of current junction temperature, Tj estimate approaches provide issues. In order to provide a precise and non-invasive method of estimating Tj, the research suggests an electro-thermal model specifically made for SiC MOSFETs in a DC/DC converter. Tj-dependent electrical loss estimates and a one-dimensional Foster thermal model based on RC networks are included in this model. As shown by experimental validation on a three-phase Interleaved Boost Converter (IBC), the paper's contributions are focused on overcoming the shortcomings of current approaches and offering an effective electro-thermal model suitable to real-world circumstances.

The researcher in [24] says that the Proportional-Individual-Derivative (PID) Controller for the Boost converter is optimised in this work using the Dynamic Levy Flight Chimp optimisation (DLFC) approach. One potential usage for the tuned PID controller is voltage adjustment while using renewable energy sources [25]. Based on the irradiance and ambient temperature, the maximum power point tracking control technique based on machine learning (ML) is utilised to predict the reference voltages for the solar system. This reference signal is used by the tuned PID controller to control the maximum power point (MPP) voltages. Grey wolf optimiser (GWO), Harris hawk optimisation (HHO), and particle swarm optimisation (PSO) techniques are compared in order to fine-tune the PID controller. Less oscillations and less tracking time are needed for the adjusted PID controller to adjust to shifting load and environmental circumstances. Furthermore, statistical analysis is provided, including Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) between the output voltage and the reference voltage. In photovoltaic (PV) system applications, the DLFC tuned PID controller may be a potential method for optimising PID controller tuning for boost converters since it outperforms HHO, GWO, and PSO in terms of RMSE and MAE.

A novel method for maximum power point tracking (MPPT) in solar power systems is presented by the researcher in [26]. To accomplish effective MPPT under a variety of environmental circumstances, the approach makes use of a modified SEPIC converter and an MPPT algorithm based on model predictive control (MPC). By using just one voltage sensor and one current sensor, the suggested approach lowers the hardware requirements and produces a solution that is reasonably priced. The PV system's voltage and current levels are managed by the improved SEPIC converter, and the converter's operation is dynamically adjusted by the MPPT algorithm based on maximum power point calculation using an MPC. To estimate and maximise the power output, the programme integrates a predictive model of the photovoltaic system. It is shown that the suggested method performs better in terms of power extraction efficiency and cost-effectiveness than conventional MPPT methods [27]. The efficacy of the suggested approach in attaining efficient power extraction under diverse operating situations is confirmed by simulation and experimental outcomes. The article offers a thorough analysis of the MPPT methods that are currently available in the literature as well as a discussion of the benefits of MPC-based methods. The suggested method presents a viable way to improve PV systems' economic performance and efficiency, especially in sand-filled weather.

For determining the maximum power of photovoltaic (PV) systems, the researcher in [28] introduces a revolutionary real-time method. PV system energy efficiency is to be increased by means of an algorithm that is based on estimation-based extremum-seeking control (ESC). The fluctuating solar irradiance and temperature of the PV modules cause the maximum power of a PV system to fluctuate constantly, hence real-time methods of determining the maximum power values are required. The approach addresses PV output power, an unknown function that must be maximised, by taking use of its strong concavity property. The gradient of the goal function with respect to the PV voltage is found using an adaptive estimate approach, and the optimal voltage value and matching maximum power point are found using a direct gradient-based adaptive controller. There is evidence of convergence for the suggested method, demonstrating accurate steady-state and quick transient performance. It is a robust model-free method that works well in unpredictable, time-varying weather. Only typical weather with constant solar irradiation and PV temperature is suitable for the algorithm. Results from the simulation show how reliable and efficient the suggested approach is.

The researchers of [29] highlight the need for a worldwide transition to renewable energy, especially photovoltaic (PV) technology, in order to counteract the environmental damage brought on by the burning of fossil fuels. PV systems provide energy for both large- and small-scale applications, but adequate energy storage is necessary to overcome the problem of power intermittency. In severe temperatures, lithium-ion batteries—which are frequently employed for this purpose—have difficulties. In off-grid photovoltaic applications, the research suggests swapping them out for hybrid supercapacitors. Hybrid supercapacitors offer improved performance at colder temperatures, longer cycle lifetimes, and higher power density by combining the advantages of Li-Ion batteries and Electric Double-Layer Capacitor (EDLC) supercapacitors. The research describes a model for PV, storage units, and charge management for iterative simulations to optimise storage capacity. Sizing issues are important. According to the study's findings, hybrid supercapacitors are competitive substitutes for lithium-ion batteries, especially for outdoor applications where they offer greater efficiency and need less capacity.

The researchers in [30] highlight how, in order to combat environmental degradation and the depletion of fossil fuels, there is a growing emphasis worldwide on renewable energy sources (RES), particularly wind and solar. The intermittent nature of electricity generation poses issues for the integration of Renewable Energy Sources (RES) into the grid, which is being driven by efforts such as the Indian Government's objective of 175 GW RES by 2022. The disparity between supply and demand has an impact on system dependability and power quality, which highlights the crucial function of Energy Storage Systems (ESS) as power balancers. The importance of Energy Storage Systems (ESS) in several energy sectors is highlighted by regulatory agencies like the Central Electricity Regulatory Commission (CERC) and organisations like the India Energy Storage Alliance (IESA). The literature presents a variety of approaches to ESS selection, size, and economics, with a particular emphasis on Particle Swarm Optimisation (PSO), which exhibits potential for hybrid energy storage system optimisation. In order to improve load levelling and microgrid reliability, the paper at hand emphasises the crucial importance of appropriate ESS sizing and uses the Analytical Method (AM) and Improved Particle Swarm Optimisation (IPSO) to optimise standalone PV/Wind and Battery Energy Storage hybrid systems. The comparison highlights IPSO's quicker convergence, demonstrating the effectiveness of IPSO in system optimisation.

5. Conclusion and Future Scope

This paper has systematically reviewed boost converter design methodologies for optimizing photovoltaic output as well as highlighting the critical role of boost converters in enhancing the efficiency of photovoltaic systems. Despite notable advancements, there remain areas for improvement, particularly in adapting to varying environmental conditions and load demands. Future research should focus on developing more robust and adaptive converter designs that can efficiently manage the fluctuations in solar energy generation, thereby ensuring a more stable and reliable power supply from photovoltaic systems.

6. Acknowledgement

The researchers express their gratitude to Universiti Tun Hussein Onn Malaysia for the ongoing support and for hosting the research platform.

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