INVESTIGATION OF PV FED MULTI-SOURCE DC-DC CONVERTER USING PI

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Abstract: This research paper proposes a novel design for a multi-source DC-DC converter that can control the output DC voltage obtained from multiple renewable energy sources. To achieve this, you would typically employ a power conditioning system or a DC-DC converter. The DC-DC converter would be responsible for regulating and controlling the output voltage based on the input from the renewable energy sources. The main objective of this research is to develop a converter design and control strategy that can effectively adjust the output DC voltage gained by multiple-source renewable energy systems. By employing a non-isolated double boost converter, the system can effectively regulate and control the bidirectional power flow, ensuring efficient energy transfer between the renewable energy sources and the storage system. This converter topology is particularly suitable for applications where bidirectional power flow and energy storage are essential components, allowing for effective management and utilization of the available energy resources and its additional advantages such as low profile, condensed component count, and double advancing ability. The converter employs a non-isolated double boost converter due to its compact structure, reduced component count, and double boosting capability. Additionally, an inverted controller strategy is assumed to handle disturbances originating from the source end. circuits models are established to derive the response of the controller, and simulations are conducted to validate the proposed control strategy. The results show a significant reduction in current ripple percentage and improved output voltage regulation. A converter is also implemented and tested, confirming the superior dynamic performance of the proposed converter. Furthermore, an adaptive optimal controller is developed to regulate voltage under demanding load conditions without requiring knowledge of converter dynamics.

Key-words: photovoltaic, DC-DC converter, PI controllers, hybrid renewable energy system, energy storage

1. Introduction

In response to the rising global energy demand and the adverse impacts of climate change, policymakers have shifted their focus towards renewable energy sources [1, 2]. The urgency to address this issue is driven by the escalation of global temperatures and the resulting consequences, including heat waves, forest fires, and floods. The Paris Accords have emphasized the need to limit the increase in global temperatures to below 2°C, and countries have pledged to achieve carbon neutrality by 2050 by reducing carbon emissions as demonstrated at the 26th Conference of Parties (COP) in Glasgow. However, with population growth and economic development, incorporating distributed generation systems into national grids to reduce reliance on conventional centralized generation systems remains a significant challenge. It is becoming increasingly important to rely on hybrid renewable energy systems that utilize multiple sources of renewable energy. These systems are not only reliable but can also support the energy demands of various sectors in a sustainable manner. Effective energy management is crucial for these plants to maintain a smooth power flow and enhance performance. By utilizing hybrid models, renewable energy can greatly expand its potential and contribute to a more sustainable energy landscape. Hybrid renewable energy systems face a significant obstacle in their intermittent nature, caused by changing ecological circumstances such as wind speeds and solar intensity. To overcome this issue, researchers have implemented power electronic components such as controllers, active filters, voltage regulators, and DC-DC converters. Of these devices, DC-DC converters are extremely operative in regulating the DC voltage and enhancing the overall efficiency of renewable energy systems [3-5]. They are essential in hybrid renewable energy systems as they convert unregulated energy from diverse sources into a regulated voltage output. Hybrid renewable energy systems require multiport power converters as an alternative to the single-input (SI)power converters when integrating many renewable energy source. SI converters show low efficiency and require multiple design devices due to the need for multi-stage conversions when integrating multiple sources. Traditional methods using series or parallel topologies need an extra switch to regulate power flow for every source connected in series. On the other hand, when multiple sources are connected in parallel, only one source can work at any given time. This approach does not enable each source to operate simultaneously during different operational modes.

Multiport converters have emerged as a solution to overcome the constraints of traditional power generation systems, enabling the integration of multiple renewable energy sources. These converters enable the efficient tapping of energy from various sources with different power levels, resulting in benefits such as reduced cost, simplified structure, and improved efficiency. Hybrid renewable energy systems can leverage the advantages of multiple energy sources more effectively by using multiport converters. The paper [6] presents a MISO DC-DC converter that has the benefit of reducing the number of power electronic components. However, the efficient functioning of the MISO system was hindered by duty ratio limitations. Moreover, the duty cycle constraints imposed a limit on the maximum attainable voltage gain. In a study conducted in [7], researchers examined the limitations of the multi-input converter's duty cycle and proposed a solution that involved coupled inductors to overcome these constraints. Nevertheless, it's important to consider that the use of coupled inductors may have an impact on the overall size of the converter. Additionally, in reference [8], a dual-input boost converter was introduced specifically for street-lighting applications. This converter utilizes a switched inductor network to improve voltage gain and minimize ripple. However, it's important to note that this approach increases the complexity of the system. The converter switch encounters issues such as power dissipation and voltage spikes caused by the Leakage Inductance (LI) of the transformer, despite the implementation of an active clamp and non-dissipative snubber circuit to address these problems. However, this solution leads to higher costs due to the inclusion of additional power switches [9]. In reference [10], a classical PI controller was used to regulate the non-inverting buck-boost chopper. In the field of controlling various DC-DC converters, other controllers such as fractional-order, Type-II, and Type-III controllers, have also been employed. To prevent voltage surges in the converter switch, researchers have implemented a method where LI energy is recycled in order to power the load [11]. Banerjee et al. in [12] have proposed the Type-III controller for boost and interleaved boost converters, while another study suggested a novel clamp-mode and high step-up converter to improve efficiency and increase voltage. Nevertheless, even with these countermeasures, the issue of high-voltage spears and power loss remains present due to the leakage inductor of the CI. To tackle this problem, the energy from the leakage inductor is recycled, and a clamping circuit is implemented to limit the voltage level of the switch [13]. Moreover, an additional diode is introduced on the front side of the converter as a protective measure in case of reverse current flow. To regulate the switching pulse of the converter, a combination of PI and NN controllers is employed. For example, in [14], a fractional-order PID controller was specifically developed to regulate the conventional DC-DC buck converter. In [15], different control methods are mentioned for managing the voltage of DC-DC converters under changing conditions, particularly in the domain of renewable energy. Nevertheless, it is worth highlighting that the conventional PID controller has received considerable interest [16]. According to source [17], a DC-DC converter with high voltage gain has been developed to tackle problems associated with voltage stress and reversed recovery currents. The converter employs Neural Network (NN) and Proportional-Integral (PI) controllers to efficiently regulate the output voltage. Nevertheless, it's important to note that the incorporation of additional passive components in the converter has led to an enlargement in size and expenses.

After reviewing the literature on DC-DC converter design and implementation, it is apparent that traditional converters are not well-suited for hybridizing renewable energy sources due to their limitations in supporting self-governing and instantaneous operation of sources, decreased efficiency, and transformers. The multi sources converter is a better option for crossing sources due to its high efficiency and fewer transfers, enabling independent and simultaneous operation. However, the coupling between state variables can negatively impact system performance. The inverted decoupler addresses this issue by transforming the system into three independent loops, improving dynamic response and stability. This study introduces a new converter that precisely regulates output voltage and is impervious to disturbances. It aims to mitigate mutual-coupling properties of dual sources, resulting in high efficiency, reduced settling time, minimized peak overshoot, and system stability. The proposed controller has undergone thorough validation through simulations and hardware implementation, providing further confidence in its effectiveness.

2. System model

2.1. Multi-source DC-DC Converter

The purpose of this study is to introduce a multi-source DC-DC converter that is designed for hybrid renewable energy systems. The main objective is to enhance the performance of hybrid renewable energy systems by minimizing power conversion losses and improving overall system efficiency. In fact, Enhancing the performance of hybrid renewable energy systems by minimizing power conversion losses and improving overall system efficiency is indeed a crucial objective. By achieving this goal, we can maximize the utilization of renewable energy sources and make these systems more economically viable and sustainable. By optimal sizing and configuration, one can roperly sizing and configuring the hybrid renewable energy system components such as solar panels, wind turbines, batteries, and inverters can significantly improve system efficiency. This involves determining the right capacity of each component based on the energy demand, resource availability, and load characteristics. Sophisticated modeling and simulation techniques can be employed to find the optimal configuration. Implementing MPPT algorithms for solar panels and wind turbines allows them to operate at their maximum power output. MPPT techniques continuously track the available power from the renewable sources and adjust the operating parameters, such as the voltage and current, to extract the maximum energy. This minimizes power conversion losses and enhances overall system performance. Efficient energy storage is crucial for hybrid renewable energy systems to ensure a continuous and stable power supply. Optimal control strategies for charging and discharging the batteries can be employed to minimize losses and improve the overall efficiency of the storage system. Advanced algorithms can be used to optimize the scheduling and dispatch of stored energy based on demand patterns and renewable resource availability. The converter is capable of independent operation of renewable energy sources, thanks to its double boosting capability. This research also includes a control technique that enhances both the static and dynamic performance of the system. The converter's topology offers several advantages, such as faster response times, the elimination of the need for a transformer, and flexibility in the number of inputs utilized. These benefits contribute to improved performance and increased versatility in the operation of the converter. These advantages can greatly reduce operational expenses. The Figure 1 illustrates a multi-source DC-DC converter that combines V1 and V2 power sources with a battery for energy storage. This converter is used in a hybrid model that includes PV, FC, and battery sources. The two input inductors, L1 and L2, are critical in converting the input power sources into current sources and generating a stable output current from the two inputs. The multi-source DC-DC converter is designed to support the integration of PV and Fuel Cells, ensuring efficient power conversion and management. The converter takes inputs from PV and Fuel Cells, while also incorporating a battery as the energy storage element. Power flow control within the hybrid model is managed through the use of four semiconductor switches - S1, S2, S3, and S4. To obtain a linear model of the converter, a small-signal model based on the mathematical model is constructed, accounting for nonlinearity in the system through small perturbations. The averaged state-space equation is derived from the perturbed model, and the transfer function can be obtained by solving the linear model.

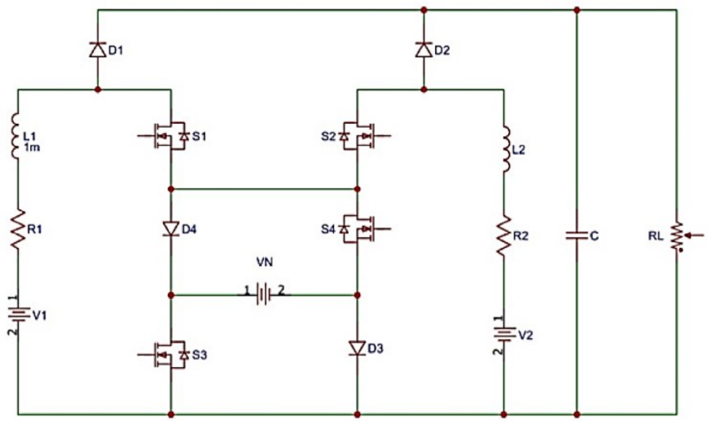


Fig. 1. The proposed schematic diagram for energy supply system

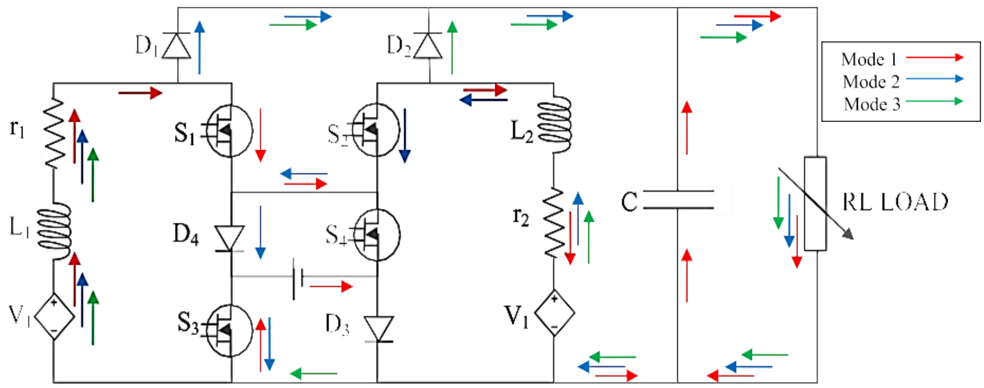


Figure 2. schematic diagram with deferent MODE

2.2. Proposed controller

To enhance system response and minimize steady-state error, the use of an Integral (I) controller was implemented. However, the I controller had a downside of potentially destabilizing the system. To address this challenge, a solution was proposed in the form of a Proportional Integral (PI) controller. The PI controller was introduced as a means to overcome the mentioned challenge and improve the performance of the system. By incorporating the PI controller into the system, it becomes possible to regulate and stabilize the operation of the converter, thus achieving the desired control objectives. The PI controller performs the same function as the I controller in reducing steady-state error, but without compromising system stability. It does this by producing an output that is proportional to the error signal and also considers the integral of the fault signal. By utilizing the PI controller, steady-state error can be reduced without introducing instability into the system. The synoptic of the PI controller is represented in Figure 3.

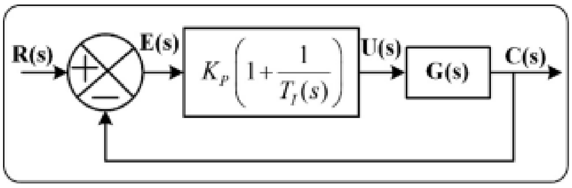


Fig. 3. PI controller block diagram

The controller suggested involves a combination of a PI controller, negative feedback, and the transfer function of a small signal buck converter, illustrated in Figure 4. The desired output voltage magnitude is represented by Vref(s), while the controlled output voltage is represented by Vo(s) in the diagram. The input signal to the controller, E(s), is the difference between the output of the converter and the desired voltage level.

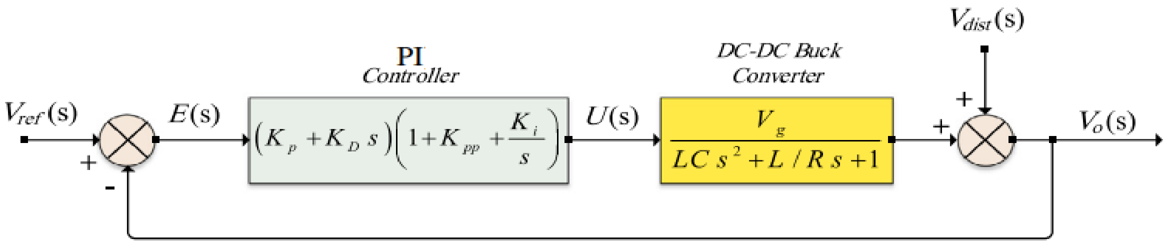
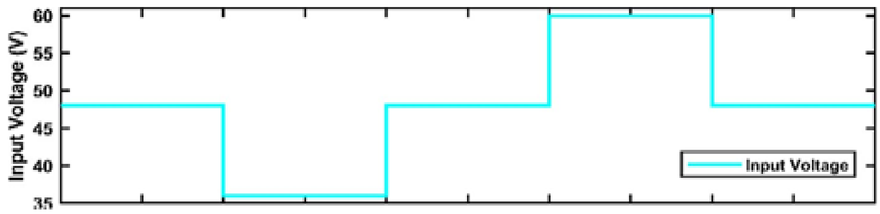


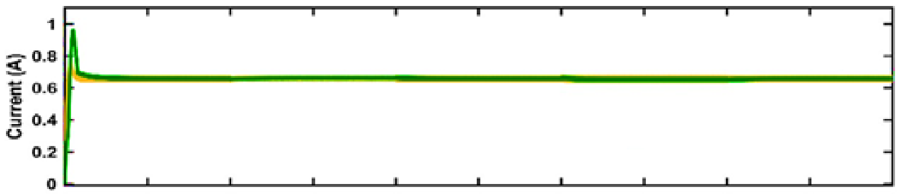
Figure 4. proposed controller diagram

3. Simulation results

Figure 5 shows the results of the source voltage variation test. At 0.02 s, When the source voltage decreases to 36 V, the output voltage of the CSMC (Converter A) experiences a drop of 0.5 V. However, in contrast, the output voltage of the ASMC (Converter B) remains stable at 23.5 V. This observation highlights the high accuracy and stability of the system, as the ASMC successfully maintains a constant output voltage despite fluctuations in the source voltage. On the other hand,
At 0.06 seconds, when the source voltage increases to 60 V, the output voltage of the CSMC (Converter A) increases by 0.5 V and stabilizes at 24.5 V. However, in contrast, the output voltage of the ASMC (Converter B) remains at 24 V without any significant change. This behavior demonstrates that the CSMC is responsive to the increase in the source voltage, resulting in a corresponding increase in its output voltage, while the ASMC maintains a stable output voltage despite the change in the source voltage. The proposed ASMC approach demonstrates improved robustness and stability when subjected to changes in the input bus voltage, as evidenced by its response to reference voltage monitoring.



(a)



(b)

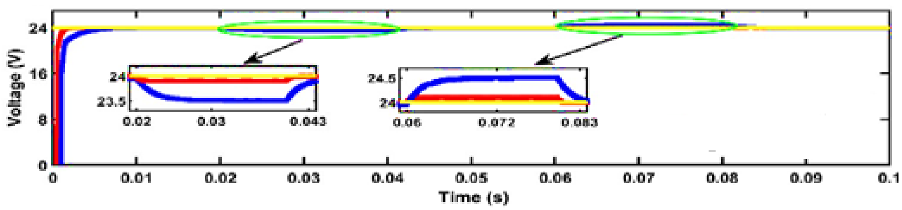


Fig. 5. Simulation results of source voltage variation test for deferent mode yellow (MODE I), red (MODE II) and blue (MODE III).

Figure 6 illustrates that the proposed technique reduces the number of Mosfet switchings more effectively than the PI controller during the transient response at 1 second. The PI controller relies on a constant and fixed PWM frequency (10 kHz) technique, which necessitates a consistent number of MOSFET switchings, while the proposed strategy employs an RL-based controller to directly control the MOSFETs. When faced with a significant increase in load current, the proposed technique intelligently keeps the input MOSFET activated for an extended period to prevent a substantial decrease in the output voltage. In contrast, the PI controller results in a large number of switchings within the same interval. The proposed voltage control algorithm not only improves the performance of the system but also has a positive impact on the durability and lifespan of the power MOSFETs. By effectively regulating the voltage, the algorithm ensures that the power MOSFETs operate within safe and optimal conditions, reducing the likelihood of excessive stress, overheating, and premature failure. This enhanced durability of the power MOSFETs contributes to prolonging their lifespan and increasing the overall reliability of the system.

Figure 7 illustrates the proposed control for the BLDC motor, which displays the terminal current. It is noticeable that when the load connected to the DC generator (rheostat) and the setpoint for the speed of the BLDC motor are maintained at their initial values throughout the process or experiment. There are no alterations made to these parameters during the specific timeframe or scenario being discussed., the speed of the PI controller reacts by reducing (or increasing) the duty cycle of the BLDC motor driver.

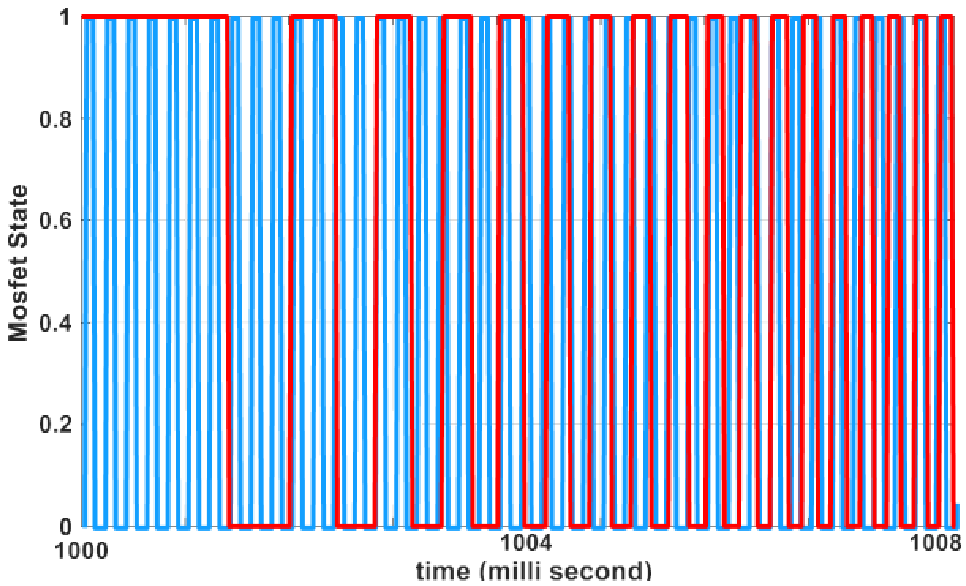


Fig. 6. Switching of the input MOSFET during transient response; single-loop PI controller (bleu), proposed PI controller (red)

As a result, the current flowing through the windings of the BLDC motor decreases (or increases) as well. This outcome leads to the provision of a nearly constant power supply to the BLDC motor, except When modifications are made to the DC generator load or the setpoint for the BLDC motor speed, it implies changes in the operating conditions of the system.

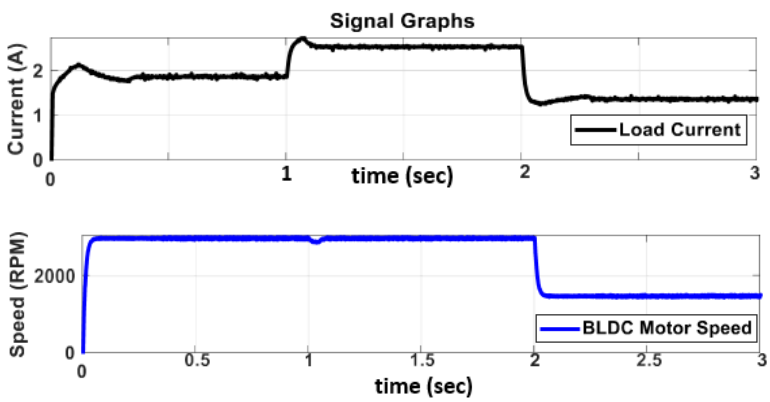


Fig. 7. Simulation results of the suggested controllers

These modifications can be intentional adjustments made by the operator or changes that occur due to external factors. The specific effects and consequences of these modifications would depend on the nature and magnitude of the changes, and how the system responds to them. It could result in variations in the generated voltage, motor speed, power consumption, or other relevant parameters

Conclusion

The objective of this study is to present a DC-DC converter structure that can combine multiple energy sources to power significant loads. The proposed converter features a single switch and various modes of operation, thus eliminating the need for duty cycle constraints. It can also be extended to accommodate multiple inputs. The paper highlights the suitability of this topology for photovoltaic and fuel cell applications. Furthermore, the study explores the fault-tolerant capability of the proposed topology when faced with source faults. This investigation aims to assess how the system can handle and adapt to faults occurring in the energy sources. Additionally, a control algorithm is developed to effectively match the load demand with the available energy sources. This algorithm ensures that the system optimally utilizes the available energy sources to meet the required load demand, even in the presence of faults or fluctuations in the energy sources. The control algorithm plays a crucial role in maintaining the stability, efficiency, and reliability of the system under various operating conditions. The results demonstrate the superiority of this configuration in various scenarios.

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