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Comparative Performance Analysis Between Multi-Input Boost Converter and Multi-Input SEPIC Converter for Renewable Energy Sources

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Abstract: *This paper focuses on a comparative performance assessment between the two Multi-Input DC-DC converters, Boost and SEPIC (Single Ended Primary Inductor Conductor) that are widely used in different sectors of technologies. Most importantly, in the field of renewable energy, power electronics circuits like DC-DC converters are widely used because of the low voltage produced by renewable energy sources (RES), especially PV modules. Boost and SEPIC, both converters have the capability of boosting the low voltage to a higher voltage. Whereas the boost converter can only raise the voltage level, the SEPIC converter can step up and down the voltage in accordance with the switching circuit's duty cycle. In this literature, the SEPIC converter is run in boost mode to present a perfect comparison. Furthermore, the comparison is made between the modified SEPIC and Boost topologies where both of the converters are made to take input from more than one source. Primarily, the hybridization of solar modules and wind turbines are used as the input energy sources for the converters in this project. MATLAB/Simulink simulation tool is used for the comparative experiment, and constant irradiation level from the sun and wind speed is maintained throughout the simulation phase for both of the converter topologies. Validation of the comparative assessment is substantiated by the findings from the Simulink result. With less initial ripple, the Boost converter shows a promising outcome over the SEPIC converter topology and also it delivers higher output voltage.*

Keywords: Power Electronics Circuit; DC-DC Converter; Multi-Input; Hybrid Energy Sources; Renewable Energy.

1. INTRODUCTION

Due to the rising global energy demand and adverse effects on the environment initiated by fossil fuels during energy generation, renewable energy is gaining rapid popularity among countries worldwide. Moreover, Renewable Energy Sources (RES) like PV panels or wind turbines show an abundant and sustainable characteristic which proved to be more advantageous when fossil fuel reserves are depleting quickly. And, being the most prevalent form of energy in the world, renewable sources like solar and wind energy are viewed as a significant replacement for fossil fuels in electricity production [1, 2]. The low voltage makes it difficult to deliver energy to the loads that RES generates at the output terminal. Low-level DC voltage from photovoltaics along with other sources needs to be boosted before being injected into the loads [3, 4]. In this case, by transforming the low voltage level to a higher one, DC-DC converters can be very beneficial. DC-DC converters are part of power electronics circuitry that changes the voltage level by the continuous switching action of the switching elements such as MOSFET (Metal Oxide Semiconductor Field Effect Transistor), SCR (Silicon Controlled Rectifiers) or IGBT (Insulated Gate Bipolar Transistor). The most prevalent converter topologies include Buck, Boost, Buck-Boost, SEPIC, etcetera for renewable energy applications [5]. How much the output voltage will differ from the input voltage is determined by the duty cycle, which also controls the switching period of the switching elements. Unlike the Buck Converter, the Boost Converter always enhances the generated voltage whereas SEPIC, ZETA, and Buck-Boost Converters can carry out both reduction and increment operations, contingent upon the duty cycle [6, 7]. SEPIC Converter is derived from the Buck-Boost topology and it is a member of the fourth-order converter family. However, unlike the Buck-Boost converter, SEPIC gives a non-inverted output [8]. At present, power generation from non-conventional renewable sources is gaining momentum as fossil fuel sources are deteriorating the climate by producing greenhouse gases in large quantities. Furthermore, high prices of fuels such as oil or gas are hurting the consumer at the end level and so clean and green energy production is getting much focus at the moment. Study shows that Europe as a continent consumed 21.8% of the energy produced from renewable sources in 2021. Among the European nations, Iceland has the largest share of consumption from the renewable sectors [9]. According to the U.S. Energy Information Administration (USEIA), the United States produced 13.2 quadrillion Btu (British Thermal Unit) of energy from renewable sources in 2022 [10]. Most importantly, the energy produced from renewables is cheaper compared to fossil fuels ones, and also the price is stable as this does not depend on the volatile cost of fossil fuels. Furthermore, fossil fuels cost consumers indirectly also as the health and economic consequences of air pollution from fossil fuels had an economic impact of 2.9 trillion US Dollars in 2018 which can be reduced significantly by increasing the consumption share of renewable energy [11]. On the other hand, it is well-regarded that the greater use of renewable energy can lead to the reduction of energy poverty worldwide [12]. By considering the fact and important roles that the DC-DC converter plays in renewable energy sectors, this research manifests a thorough comparative assessment between the two common DC-DC converter topologies, Boost and SEPIC Converter. The system will not have to be dependent on a single source as the converters are developed in a way that allows them to accept input from multiple energy sources, substantially improving the system's efficiency. Moreover, since multiple energy sources will use a single circuit layout, resulting in fewer circuit components and lower power consumption, the economic benefits will be greater [13]. This paper presents the performance comparison assessment between the two very common modified DC-DC converter topologies, Boost and SEPIC Converter in boost mode operation as selecting the appropriate converter topology can raise the effectiveness of the overall renewable energy system by a significant margin. The principle objective of this research work is to assess the operational capability of the converters and to show the best performer among the aforementioned converter topologies. Ultimately, simulation results from Simulink give a clear insight into the assessment to draw a conclusion. Figure 1 manifests the visual representation of the proposed system built for comparative analysis.

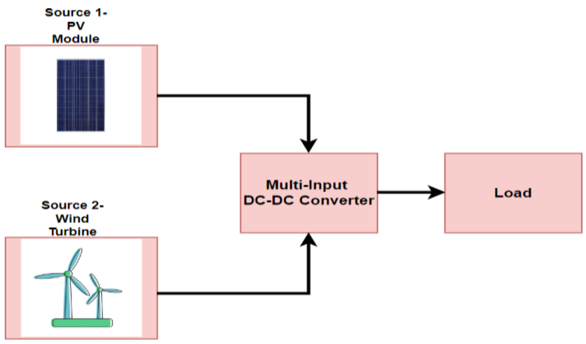

Figure 1. Diagram of the Proposed System

2. LITERATURE REVIEW

Several studies have already been conducted on the comparative examination of various DC-DC converter designs for renewable energy. Zhou et al. in their paper presented the comparison between six types of converter topologies offshore wind High-Voltage Direct Current (HVDC) applications. Their study includes a new transformerless topology and five standard transformer-based topologies [14]. Choung and Kwasinski in their paper showed the comparative assessment between ten different multi-input DC-DC layouts and their report is based on four key criteria of the converters such as affordability, potential modularity, reliability, and adaptability [15]. In Mahmud's literature, a comparative study between single-input SEPIC and multi-input SEPIC for renewable energy is exhibited. According to the study, a multi-input SEPIC converter increases the efficiency of the whole system [16]. Rashmi et al. through their study delineated the comparison between the synchronous SEPIC and ZETA converter for solar energy [17]. In Pataru's study, a detailed comparative work is provided between analog compensated SEPIC and Buck-Boost topology in an MPPT system. And, due to the higher efficiency and size of the layout, the Buck-Boost converter performs better in their study [18]. Four DC to DC converter circuits that can step up and down the electrical voltage level were compared in Seguel's paper. They investigated and contrasted the efficiency of the converters Buck-Boost, SEPIC, Zeta, and Cuk [19]. In her research, Kumari provided a thorough comparison of the cascaded boost-SEPIC converter with the traditional single-input SEPIC as the analysis was supported by both the developed model and the MATLAB/Simulink tools [20]. The performance of conventional and diode-assisted DC-DC converter circuits for RES was compared in Zhang's work. Their results verified that the diode-assisted converter has a higher efficiency [21]. Dahale et al. in their paper presented various DC-DC converter layouts for DC microgrid systems. Their study concluded that newer topologies like Buck-Boost, SEPIC and Cúk converters have reduced switching loss leading to higher efficiency during conversion [22]. The three DC to DC converter architectures for solar power systems were demonstrated by Graditi et al. The converters used for comparison are Buck, Boost and Buck-Boost Converter and based on their examination data and results, in the areas of effectiveness and versatility, Boost topology outweighs the other two converters [23].

3. BACKGROUND OF THE PROPOSED CONVERTERS

The proposed converters to use in this literature are based on Boost and SEPIC Converter layouts. Boost and SEPIC, both of them have the capability to step up a low-level voltage to a higher level, and most importantly, both of the converters will give a non-inverted output at the output terminal.

3.1 Conventional Boost Converter and Multi-Input Boost Converter

The boost converter, as its name implies, has the capability to raise the low level and the boosting amount depends on the duty cycle provided to its semiconductor switching elements (i.e., MOSFET). The output voltage will rise in comparison to the input voltage in direct proportion to the higher duty cycle ratio. The single set of an inductor, a capacitor, and a diode makes up the simplest sort of switch mode converter. Continuous switching action and assistance from the energy storage elements help to increase the input voltage to a significant amount. To lessen the ripple voltage effect, a filter capacitor is fitted to the converter's output side. With a single power source attached at the input terminal, Figure 02 depicts the basic setup of a standard boost converter.

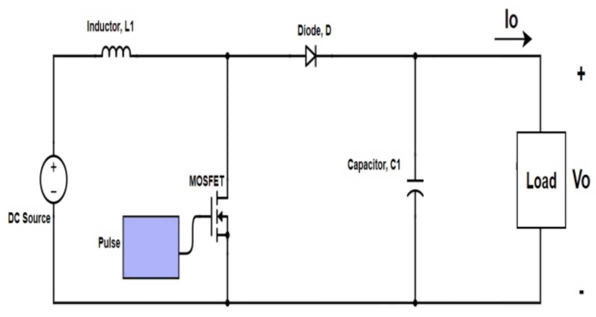

Figure 2. Traditional Boost Converter Layout (Single Input DC Power Source)

The boost converter can be run in two modes, such as CCM (Continous Conduction Mode) and DCM (Discontinuous Conduction Mode). DCM mode is when the current passing through the inductor becomes zero and this mode is for low power and standby operation. On the other hand, in the CCM mode, the current through the inductors never becomes zero, and this mode is suitable for efficient power conversion [26]. In this literature, the converters are kept in CCM mode. The relationship between the input-output voltage, and the duty cycle is defined by the following equation [27].

$$V_o = \frac{V_{in}}{1-D} \qquad \text{(i)}$$

Multi-Input topology enables the single boost converter circuit to amalgamate more than one power source and it surely increases the efficiency of the system by reducing the circuit size. Figure 3 delineates the modified boost converter layout that can accommodate more than one energy source. In fact, this topology can have n number of sources in its input terminal. The layout will have n number of switches and duty cycle generators for n number of energy sources. It will also have two modes, CCM and DCM, just like the traditional boost converter. The following equation describes the relationship between the input-output voltage and the duty cycle of the dual input boost converter which is appropriate for two input sources [28].

$$V_o = \frac{V_1 D_1 + (D_2 - D_1) V_2}{1-D_2} \qquad \text{(ii)}$$

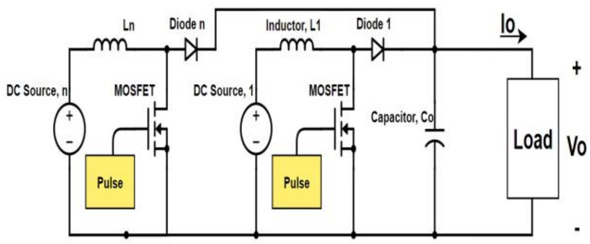

Figure 3. Multi-Input Boost Converter with n Number of Input DC Power Source [24]

3.2 Conventional SEPIC Converter and Multi-Input SEPIC Converter

A conventional SEPIC converter in its basic configuration is depicted in Figure 04. The SEPIC converter or known as Single Ended Primary Inductor Converter is part of fourth order converter family and is an improved version of the Buck-Boost converter with non-inverting output. It has the capacity to reduce or increase the supply voltage, contrary to the boost converter. The MOSFET will function as a buck converter if its duty cycle is below fifty percent and as a boost converter if it is greater. And, in this literature, the SEPIC converter is run in boost mode. The subsequent equations describe the connection between the input, output voltage, and duty cycle of the typical SEPIC converter [16].

$$V_o = \frac{V_{in} D}{1-D} \qquad \text{(iii)}$$

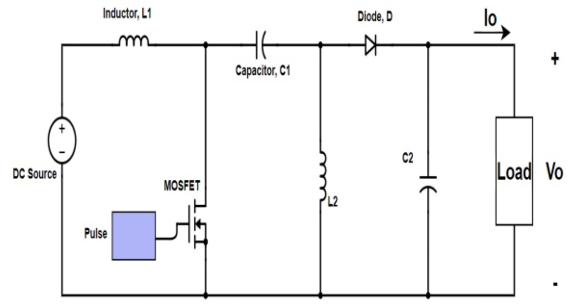

Figure 4. Traditional SEPIC Converter Layout (Single Input DC Power Source)

For handling the multiple energy sources at the input terminal, the basic SEPIC converter is modified and Figure 5 is the improved version of the traditional layout which can take inputs from n number of energy sources. Individual MOSFET will work as switches individually for every source. With multiple sources of power at the input but only one load, the modified converter will operate in multi-input, single-output mode. The following formula, which works with two input sources, connects the input voltage, output voltage, and duty cycle [25].

$$V_o = \frac{(D_2 - D_1) V_1 + D_2 V_2}{1-D_1} \qquad \text{(iv)}$$

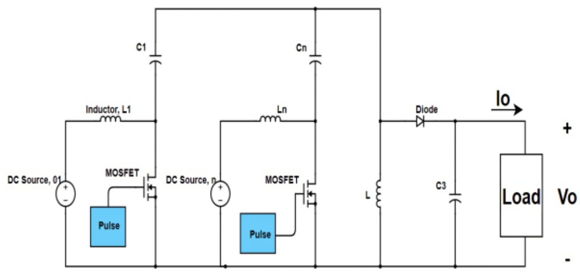

Figure 5. Multi-Input SEPIC Converter with n Number of Input DC Power Source [25]

In the abovementioned formulas, Vo is the output voltage, Vin is the input voltage, D is the duty cycle provided to the MOSFET, D1 is the duty cycle provided to source 1 and D2 is the duty cycle provided to source 2.

4. MATLAB/SIMULINK SIMULATION

To obtain the results needed to support the comparative assessment, Simulink is used to simulate both of the proposed structures. Outcomes from the Simulink software tool can give an important insight into the topic and a solid verdict can be given between the two layouts of the DC-DC converter. Figure 6 and 7 present the modified multi-input layout of the boost and SEPIC converter.

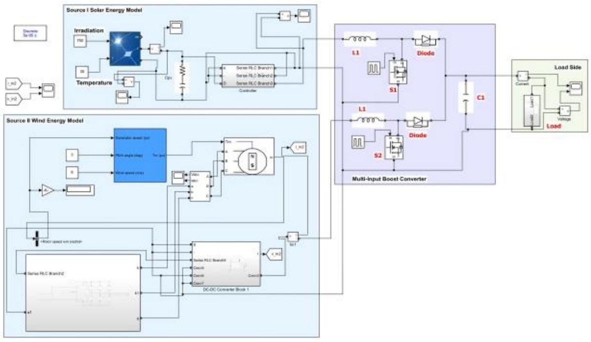

Figure 6. Modified Multi-Input Boost Converter with PV Module and Wind Turbine Input Source

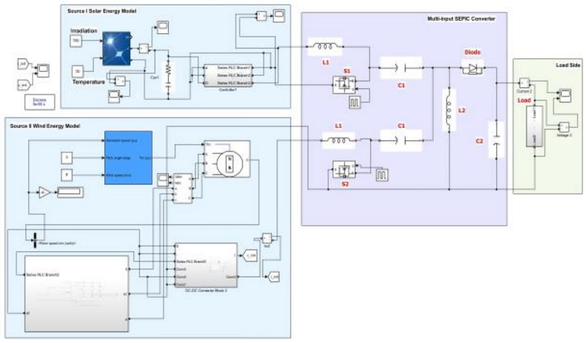

Figure 7. Modified Multi-Input SEPIC Converter with PV Module and Wind Turbine Input Source

The photovoltaic module and wind turbine are connected as sources I and II, respectively, for both converters. For the PV module, one SOLTECH 1STH-215-P model is used. Since it is well established that the output voltage from the panels greatly depends on the temperature of the atmosphere and irradiance of the sun, fixed values for both of the parameters are used during the simulation. For example, in this simulation, the temperature is fixed at 30°C and irradiance is fixed at 750 W/m2. Similar to solar panels, output from wind turbines is also very much dependent on a nature-controlled phenomenon, the wind speed. And, for this research work, wind speed is also fixed at 8m/s. But for the practical case, wind speed, solar irradiance and temperature will not remain the same. A controller block is deployed and connected to the sources for a constant output voltage from the sources to input to the converters. The inductor value needs to be set perfectly to ensure that the converters are in the Continuous Conduction Mode. Otherwise, the converters would give erroneous results. The optimum values for the passive components and duty cycle have been maintained during the simulation. Since a converter's performance is well dependent on the components' values and varies with it, the values in this study are fixed using rigorous calculation. The components that are used to design the converter are shown in Table 1.

Table 1. Components of the Proposed Converters

Name of the Components	Multi-Input Boost Converter	Multi-Input SEPIC Converter
Duty Cycle	Switch 1= 65% Switch 2= 75%	Switch 1= 65% Switch 2= 75%
Switching Frequency	25000Hz	25000Hz
Inductor, L1	0.1H	0.1H
Inductor, L2	—	0.15H
Capacitor, C1	0.1mF	0.1mF
Capacitor, C2	—	1mF
Resistive Load	0.05kΩ	0.05kΩ

From the table, it is shown that the duty cycle and component values are kept the same for a solid comparative assessment. Otherwise, the output result would have an effect due to the different passive components that are used to design the converter circuits.

5. RESULT ANALYSIS AND DISCUSSION

The graphs generated by the simulation software Simulink are used to make the comparative assessment in this section. For both of the converters, all the parameters are kept similar for an accurate comparison. Only the position of the components is changed according to the configuration of the converter circuits. The converters are fed with almost constant 12V voltage input from the two renewable energy sources, a wind turbine and a PV module. As the outputs of the two abovementioned sources are highly dependent on the wind speeds, solar irradiation and the temperature of the atmosphere, and fluctuate severely along with them, this simulation is performed with a constant value of wind speeds, temperature of the atmosphere and solar irradiance. Figure 8 and Figure 9 depict the output voltage graph from the solar panel and wind turbine respectively.

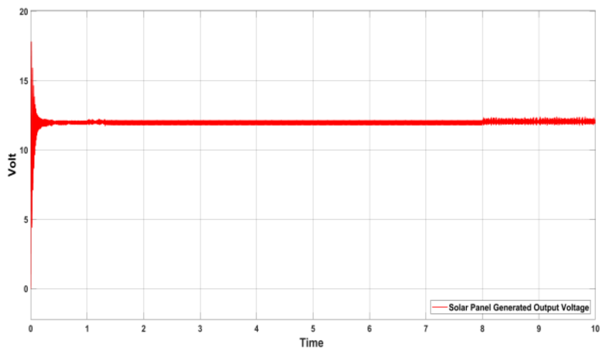

Figure 8. Output Voltage from Solar Panel

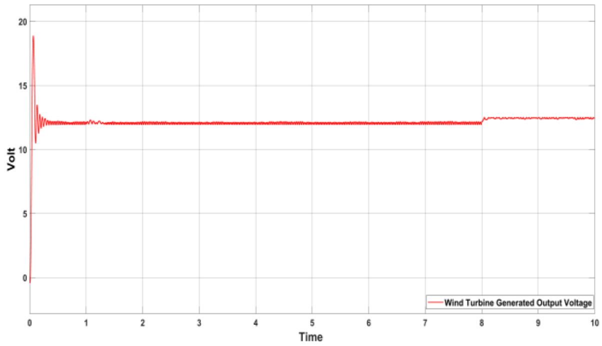

Figure 9. Output Voltage from Wind Turbine

Though there is some fluctuation in the very beginning, both of the sources almost give outputs of 12V to the input terminals of the converters. Next, Figure 10 displays the output voltage graph for both converters.

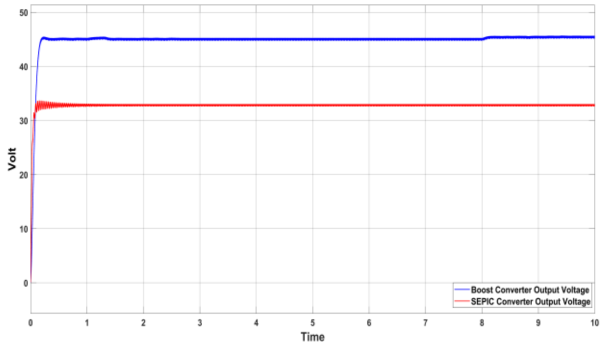

Figure 10. Output Voltage of the Multi-Input Boost and Multi-Input SEPIC Converter

The voltage graph shows that with similar passive components and the same duty cycle applied to the switches of the converters, the Boost converter gives higher voltage output at the load terminal. Though both of the converter topologies get similar voltage input from the PV module and wind turbine (12V from each source), the boost converter gives almost 13V more than the SEPIC configuration. The boost converter supplies close to 45V at the output load point, more than 87% voltage gain whereas the SEPIC converter supplies almost 32V at the output, close to 34% voltage gain. Moreover, the output of the SEPIC converter exhibits more fluctuation and initial ripple, whereas the boost converter exhibits very little ripple at the initial stage. Figure 11 delineates the output current graph of the proposed converters.

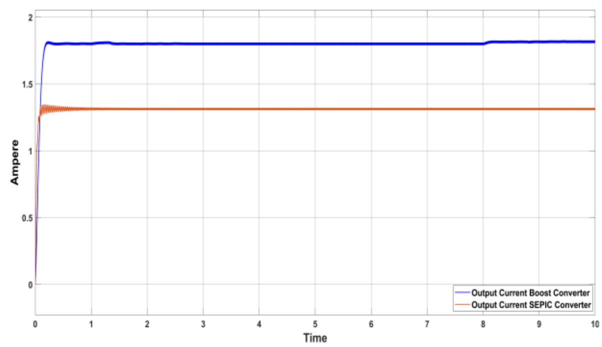

Figure 11. Output Current of the Multi-Input Boost and Multi-Input SEPIC Converter

Similar to the output voltage graph, the boost converter performs better for current supply. The boost converter supplies 1.8 Amperes of current to the load which is much higher than the SEPIC converter's supply of 1.3 and most importantly, the SEPIC converter has a higher initial ripple in the current graph, unlike the boost converter. Since the boost converter manifests both a higher current and voltage compared to the SEPIC converter, it also gives a higher output power than the SEPIC layout.

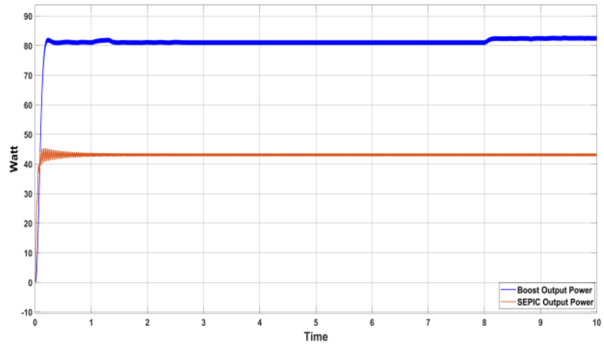

Figure 12. Output Power of the Multi-Input Boost and Multi-Input SEPIC Converter

To deliver power to the devices worked better with less ripple, the Boost converter can be a better option compared to the SEPIC converter. Also, the Boost converter gives a slightly higher output voltage than the SEPIC and it proves to be beneficial to use the Boost converter rather than using the SEPIC converter.

6. CONCLUSION AND FUTURE WORKS

This paper presents a comparative analysis between the modified layout of two very common power electronics DC-DC converters, Boost Converter and SEPIC Converter. The SEPIC and Boost converters of the past have been highly enhanced to support several renewable energy sources. Though the modified converter circuits can facilitate n number of input sources, in this study only two renewable input sources are used for simulation. MATLAB/Simulink results are used which give a solid insight into the topic before making a proper decision. The input port of the converter receives 12V of power from both of the renewable energy sources that are employed in the simulation. The Simulink results clearly show that the multi-input boost converter topology delivers a higher voltage with very much less initial ripple compared to the multi-input SEPIC Converter. The trend also stays identical in terms of current and power delivery. The boost converter architecture would be preferable to the SEPIC structure if the primary goal of employing DC-DC converter circuits is to increase the input voltage at the load terminal. Furthermore, using a single multi-input DC-DC converter for multiple renewable energy sources will perform better in terms of less heat dissipation as well as reduced power consumption which will lead to performing more efficiently. Other modified converter topologies, like the Buck-Boost converter, the Ćuk converter, etc., can be studied in the future. And also, other renewable energy sources such as biomass or biofuel can also be added up during the performance analysis of the modified converter topologies.

7. ACKNOWLEDGMENT

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