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Comparative Performance Analysis Between DC-DC Multi-Input ZETA and Multi-Input SEPIC Converter for Hybrid Renewable Energy System

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***Abstract*— In response to the rapidly rising global energy demand, as an alternative to conventional fossil fuel-based resources, the production of energy from renewable energy sources is becoming more and more popular. Due to the low voltage level at the outputs of solar photovoltaics or other renewable energy sources, as well as to improve the efficiency of power conversion, DC-DC converters are widely used for supplying power to the loads. Among the many DC-DC conversion topologies, ZETA and SEPIC converters are well regarded for their higher operational efficiency. The development of a modified DC-DC Multi-Input SEPIC and a Multi-Input ZETA converter, as well as performance-based comparisons between them, are covered in this work. The converters are deployed between DC loads and hybrid renewable energy sources. Both of the converters have the capability to facilitate more than one energy source at the input terminals. PV panels and wind turbines are employed as hybrid energy sources for both converters in the experiment. The simulation is performed in MATLAB/Simulink for assessment with constant irradiation level and temperature for PV panels, and fixed wind speed and altitude level of wind turbine for ease of analysis. Finally, the comparative assessment is validated through simulation results where both converters were operated in boost mode.**

Keywords*— *Multi-Input, SEPIC Converter, ZETA Converter, Hybrid Renewable Energy, Photovoltaic System.

I. INTRODUCTION

A DC-DC converter's main function is to alter the voltage levels. Applications for power DC-DC converters include hybrid automobiles, satellite applications, energy systems and portable electronic equipment [1]. Depending on duty cycle provided to the switching elements, for example, MOSFET (Metal Oxide Semiconductor Field Effect Transistor) or IGBT (Insulated Gate Bipolar Transistor), the voltage level changes. Continuous application of different switching methods and the use of passive components cause variations in the output voltage level. There are a number of well-known converter topologies and among them, SEPIC, Ćuk, Buck-Boost and ZETA can step up or step down the voltage level using the same circuitry. Though Buck-Boost and Ćuk converter gives inverted output, SEPIC and ZETA can provide the non-inverted output which helps to eliminate the rectifier circuitry in a system [2]. The use of power produced by the renewable energy sectors is on the rise, because of the significant rise in electricity usage and growing concern over climate change fueled by global warming. As an alternative to conventional energy sources, renewable energy sources get the spotlight. According to statistical data, Europe and Asia produced 40.7% and 25.3% of their total energy from renewable energy sources (RES) respectively in 2021. In addition to that, India, one of the most populated nations in the world, has around 40% installed renewable energy capacity as of 2022 of the total power capacity. [3, 4]. More and more energy production from RES means the lesser emission of greenhouse gases into the atmosphere which will ultimately curb the effect of global warming. An increase in nonrenewable energy use results in increases in CO_2 emissions of 1.9% and 1.07% over the long and short terms, respectively, which could signal a dangerous situation in the days ahead [5]. With the increasing importance of RES worldwide, power electronics DC-DC converters become a major consideration for stepping up the voltage as the voltage generated by the RES is too low for the conventional loads [6]. DC-DC converters enhance the performance and efficiency of renewable energy sources. This research shows the design and comparison between the Multi-Input SEPIC and ZETA converters for hybrid renewable energy systems. Both the proposed converters are modified to allow the input of more than one renewable energy source. Multiple input converters manifest a more efficient and economical approach for multi-power sources compared to the distinct conventional converters used for separate sources [7]. This literature aims to combine more than one RES via a single converter circuit and unveil the analytical comparison between the SEPIC and ZETA converter topologies. The topologies are thoroughly investigated by MATLAB/Simulink simulation to corroborate the performance.

II. Literature Review

Previously, several research works were conducted on the comparative evaluation of DC-DC converter topologies. Mahmud et al. developed and presented a performance comparison between Single-Input and Multi-Input SEPIC converters for multiple hybrid RES. They showed that Multi-Input Multi-Output (MISO) SEPIC converter outperformed the Single Input Single Output one in terms of efficiency [8]. Chavan et.al. in their research manifested the analysis of DC-DC ZETA and SEPIC converters based on performance to improve the power quality. The investigation found that the Zeta converter outperformed the SEPIC because it had less output voltage ripple and easier adjustment. [9]. Research conducted by Joseph et.al. exhibited the performance assessment of three converters: ZETA converter, SEPIC converter and Z-Source converter. Their goal was to determine which of the three converters has the lowest total harmonic distortion and the highest efficiency suitable for electric vehicle propulsion systems [10]. Using different factors Sivakumar assessed different non-isolated DC-DC converter architectures. Studies of a non-isolated DC-DC converter's properties, including switching and output power losses, total power losses, and efficiency have been made. with a certain power rating for green energy purposes [11]. Siddharthan and Balasubramanian in their study examined the performance of SEPIC, ZETA and Luo converters. Comparisons were made between the parameter values of the suggested three alternative converters, including ripple voltage, switching losses, and efficiency. [12]. Rashmi's work compared and analyzed the performance of synchronous DC-DC Single Ended Primary Inductor Converter (SEPIC) and Zeta converters utilizing a photovoltaic system with MPPT configuration [13]. Manikandan et al. in their literature depicted the landsman, SEPIC, and ZETA converters to determine their performance and efficiency. Its overall efficiency had been determined via particle swarm optimization [14]. In the study of Kanimozhi, the SEPIC converter and Zeta converter for MPPT operation of a PV system were investigated using a fuzzy logic controller (FLC). Outcomes from the setup and simulation of the SEPIC and Zeta converters were gathered and compared. [15]. In their article, Soedibyo et al. presented a contrast of the Buck-Boost, SEPIC, ZETA, and Ćuk converters as an MPPT device. Perturb and Observe technique (P&O) was used. The parameters they used for comparison were ripple current signal, input & output voltage and power [16]. Seguel's paper examined the performance of various DC-DC converter architectures of the fourth-order family, utilizing three of the most widely used MPPT techniques. The techniques included Fuzzy Logic Controller (FLC), P&O and Incremental Conductance [17].

III. Theoretical Overview of SEPIC and ZETA converter

SEPIC and ZETA converters are known for their highly efficient output and non-inverting voltage at the output terminal.

A. Conventional Single-Input SEPIC and ZETA Converter

Both ZETA and SEPIC converter topologies function like the Buck-Boost DC-DC converter since they offer greater, lesser or equal output voltage highly dominated by the duty cycle. SEPIC and ZETA belong to the fourth-order converters family, giving a positive non-inverted output. In their circuits, SEPIC and ZETA both use two sets of capacitors and inductors. Figs. 1 and 2 depict the basic circuit diagram of SEPIC and ZETA converters respectively.

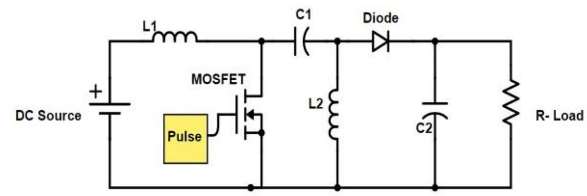

Fig 1. Conventional SEPIC Converter Single Input Mode

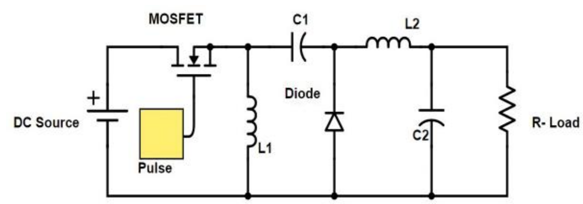

Fig 2. Conventional ZETA Converter Single Input Mode

In the above diagrams, C2 is the output capacitor that bounds the current ripple to a certain limit and R is the load for both of the topologies. In addition to that, for both of the circuits, When the current via L1 and L2 never reaches zero, the condition is known as continuous conduction mode (CCM), and when it does, it is known as discontinuous conduction mode (DCM). The converter's duty cycle dictates whether it operates in Boost mode or Buck mode. Power MOSFET is working as a switch here which controls the power flow from the source to the loads [16]. MOSFETs are used here since the converters handle low to medium currents and voltages. The converters' connection to their input and output voltages is described below,

$$V_0 = \frac{D}{1-D} V_{in} \tag{1}$$

Here V_0 and V_{in} are the output-input voltage respectively of the converters. D signifies the duty cycle value that determines the switching time of the MOSFET.

Mainly the DC-DC converters function by the continuous switching action of the switching elements. For the SEPIC, when the switching circuit is in active mode, the inductor (L1) charges itself by the input source and the capacitor (C1) charges the L2. At that moment, the output terminal is influenced by the C2 (Output Capacitor). However, when the switching element is inactive, the charged L1 discharges itself through the output terminal and simultaneously charges the C1. On the other hand, the ZETA converter also works more or less like the SEPIC converter. When the switch of ZETA topology is ON, current passes through the L1 and it stores energy and next, when the switch is OFF, L1 charges the C1 through the forward biased diode. In the next cycle, L1 once again is charged by the source and the C1 releases the energy through the L2 and load path. For both of the converters, the output voltage level depends on the duty cycle provided to the switching elements. The greater the time of the duty cycle is high, the greater the output voltage will be.

B. Multi-Input SEPIC and ZETA Converters

Multiple-input DC-DC converters are frequently used to interface various energy sources. The efficiency of the common DC-DC converters can eventually be significantly improved by a Multi-Input converter (MIC) which can handle several input sources [18]. The multi-input converters used in this literature for comparison can take input from PV panels and wind turbines simultaneously. Moreover, power sources can supply a load separately or simultaneously in the proposed model. Multi-Input converters reduce power loss because a single converter can handle numerous sources, and high efficiency is achieved by reducing power loss as fewer components are used. Additionally, smaller circuits and component sizes lower building costs also. Fig. 3 presents the block diagram of the working principle of the proposed model.

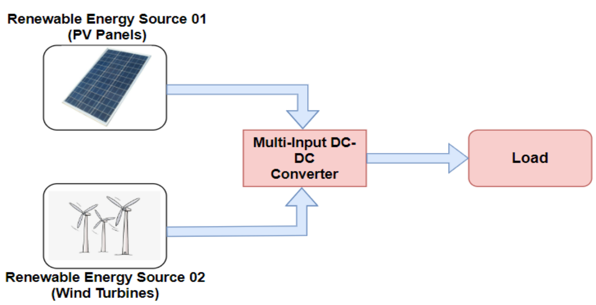

Fig 3. Block Diagram of Multi-Input DC-DC converter-based model

Streamlined circuit illustrations of the proposed multi-input topology of the proposed converters are shown in Figures 4 and 5 respectively. The suggested systems setup demonstrates that the number of the input terminal may be modified by adding or disconnecting the additional power sources even further. In fact, it can accept n numbers of sources.

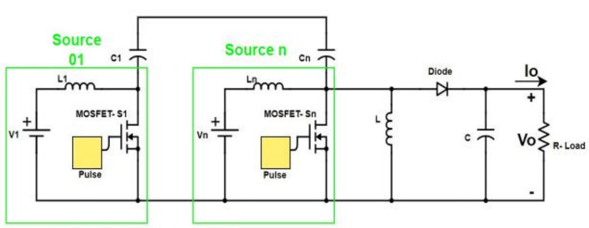

Fig 4. Conceptual Circuit Diagram of n-port SEPIC Converter [18]

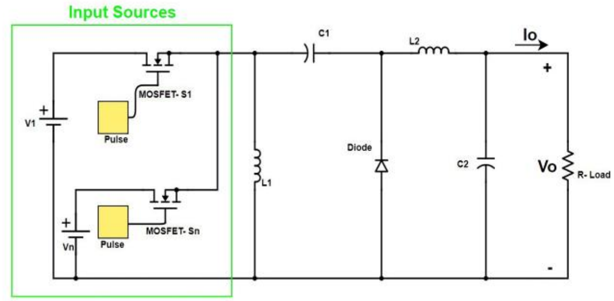

Fig 5. Conceptual Circuit Diagram of n-port ZETA Converter [19]

The following equations can be used to define the relation between the input and output voltage of the converters [18, 19].

For Multi-Input SEPIC and ZETA converters,

$$V_o = \frac{D_2 V_2 + D_{eff} V_1}{1 - D_1} \quad (2)$$

Here, Vo is the output voltage and V_1 & V_2 are the input voltage. D_1 is the duty cycle of the first switch and D_2 is the duty cycle of the second switch. D_{eff} is the difference between D_2 and D_1.

IV. SOFTWARE SIMULATION

MATLAB/Simulink has been used to design the Multi-Input converter systems and the proposed converters' performance has been assessed. The photovoltaic panel with a rated output of 12V is employed as Source I. Temperature and Irradiance values influence the output power from the photovoltaic panels. In the simulation, for analysis, constant irradiation of 750 W/m^2 and temperature of 30°C is used though the irradiation and temperature values will differ every hour as solar radiation doesn't remain the same all day in a practical scenario. Source II is the wind turbine, deployed as the secondary RES in the system. The wind speed at that specific altitude determines the power output of the wind turbine. And for this simulation, wind speed is considered constant at 7 m/s. The components value used for both converters is shown in Table 1.

TABLE I. COMPONENTS VALUE OF THE CONVERTERS

Components	*SEPIC*	*ZETA*
Inductor L1	100mH	100mH
Inductor L2	150mH	150mH
Capacitor C1	100μF	100μF
Capacitor C2	1mF	1mF
Load (Resistive)	50Ω	50Ω

For comparison purposes, parameter values of the passive components of the circuit are kept constant for both of the circuit topologies. Moreover, the duty cycle for both converters remains unchanged. A controller block is used along with the photovoltaic panel to make sure that output from the panel stays consistent close to 12V. Figures 5 and 6 show MATLAB/Simulink simulations of multi-input SEPIC and ZETA converters.

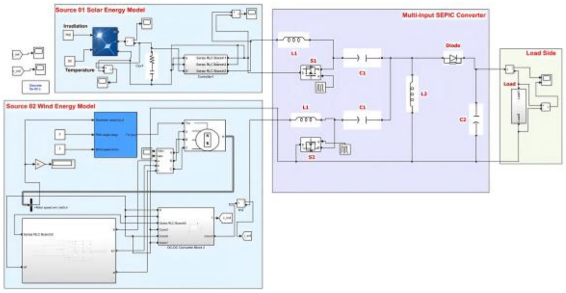

Fig 6. Multi-Input Proposed SEPIC Converter in MATLAB/Simulink

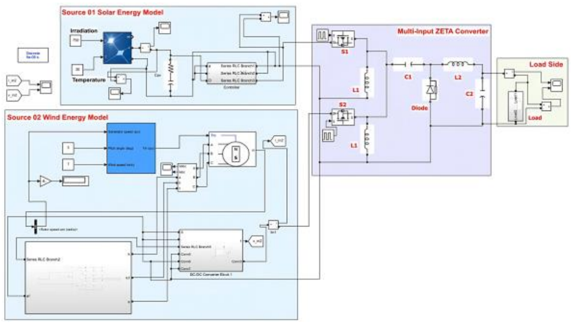

Fig 7. Multi-Input Proposed ZETA Converter in MATLAB/Simulink

In the simulation, power MOSFETs (S1 and S2) are used for switching where the switching frequency is 25kHz. The duty cycle for S1 is 75% and for S2 is 65%. During the simulation, it is confirmed that the converters are running in CCM (Continuous Conduction Mode) as the current passing through the inductors never touches zero level by applying the appropriate value for the inductors.

V. Result Analysis

For result analysis, the software results of the Multi-Input SEPIC architecture and the ZETA architecture have been compared based on similar values of the passive components, irradiation, and temperature of the solar modules. As shown in figure 8, apart from the very initial fluctuation, the PV panel voltage is constant close to 12V. For the sake of simplicity, the solar irradiation and PV surface temperature are considered to be constant in this PV simulation phase. Figure 9 is the output voltage diagram of the wind turbine. Wind turbine output mainly depends on the altitude and speed of the blade. It shows the input voltage to the converters from the turbine is 12V also, similar to the solar panel.

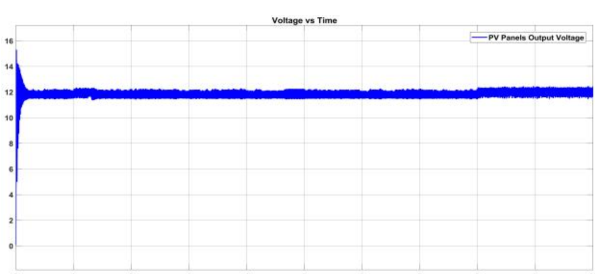

Fig 8. PV Module Output Voltage

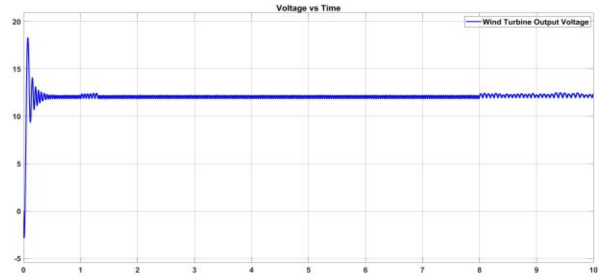

Fig 9. Wind-Turbine Output Voltage

For 12V input voltage from renewable energy sources (RES), the output current and output voltage settle in almost 1.3A and 33V in figures 10 and 11 respectively. For ease of comparison, output results from both of the converters are put in a single diagram for the abovementioned figures. From figure 10, it is noticeable that the output current from the Multi-Input ZETA converter has a higher overshoot value than the Multi-Input SEPIC converter. But, the output current ripple is higher in the Multi-Input SEPIC converter before reaching the settling point. The output voltage behaves similarly to the current results for both of the converters. The output voltage settles at 33V, but before that, the ZETA converter exhibits a larger overshoot and the SEPIC exhibits a greater ripple.

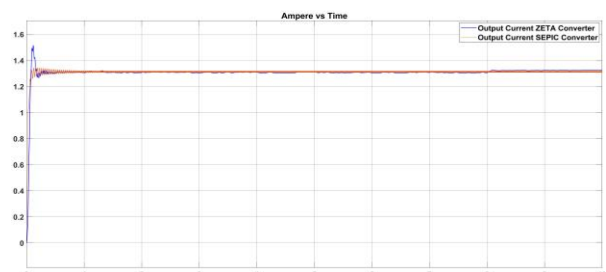

Fig 10. Load Terminal Output Current of the Converters

Fig 11. Load Terminal Output Voltage of the Converters

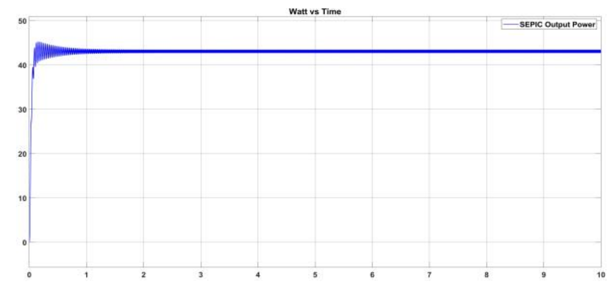

Fig 12. Output Power from the SEPIC Converter

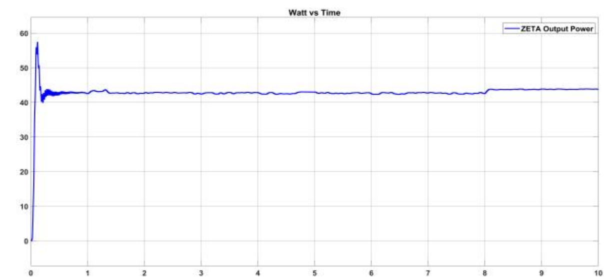

Fig 13. Output Power from the ZETA Converter

At a constant temperature of 30°C fed into the PV panel, the output power from the converters is the same as both of them display almost similar current and voltage output results according to figures 12 and 13. This investigation provides substantial insight into the ZETA converter, revealing that it performs better in terms of reducing output terminal ripple. These converters produce an output voltage of 33V from a total input voltage of 24V, which indicates a 137.5% increase in the output voltage.

VI. Conclusion and Future Works

In this literature, traditional SEPIC and ZETA converters are improved to support more than one renewable energy source, and a comparative performance analysis is presented. The simulation is carried out using a photovoltaic module and a wind turbine of 12V each. Observing the result, it can be concluded that the Multi-Input ZETA converter is better in ripple handling but this comes with a trade-off as the overshoot is significantly higher than the Multi-Input SEPIC converter. To avoid heating issues and noise in the system, the Multi-Input ZETA converter should be chosen over the Multi-Input SEPIC converter. Multi-Input converters themselves show greater efficiency as they require fewer components to design, leading to reduced power consumption and heat dissipation. In the future, performance analysis can be done with more than two sources in the input terminal. Additionally, analysis between other Buck-Boost family converters can be carried out for better insight. Furthermore, an intelligent Fuzzy-Logic controller (FLC) can be added so that it can increase the efficiency of the converters by handling the energy sources appropriately.

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