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DESIGN OF A HIGH-GAIN INTERLEAVED ZETA CONVERTER INTEGRATED WITH A HYBRID ENERGY POWER MANAGEMENT SYSTEM FOR EV APPLICATIONS

[1]T. Sai Subhash, [2]N. Venkata Siva Rama Krishna Teja, [3]T. Srinivas Kalyan, [4]Dr. V. Suresh
[1]UG Student, [2] UG Student, [3] UG Student, [4] Assistant Professor
[1,2,3,4] Department of Electrical and Electronics Engineering,
[1,2,3,4] Godavari Institute of Engineering and Technology (Autonomous), Rajahmundry, A.P., India.

Abstract: A viable strategy to tackle the current challenges in electric vehicle (EV) power systems involves the creation of a hybrid energy-based high-gain interleaved Zeta converter, coupled with an advanced power management system. This paper introduces a hybrid energy management system that employs a high-gain interleaved Zeta converter specifically designed for EV applications. The system effectively combines photovoltaic (PV) panels and fuel cells to enhance energy conversion and storage, thereby facilitating efficient power distribution. The high-gain interleaved Zeta converter is crucial for elevating the low voltage generated from renewable sources, significantly improving the system's overall performance. A comprehensive control strategy, utilizing a Flying Squirrel Search optimized Proportional-Integral (PI) controller, regulates the output voltage and maintains stability under varying load conditions. Simulation results indicate that the proposed hybrid energy management system achieves enhanced efficiency, dynamic performance, and reliability, positioning it as a promising solution for future electric vehicle technologies. This research contributes to the advancement of electric vehicle systems by integrating renewable energy sources, ultimately fostering sustainable transportation solutions.

Index Terms **- Sensorless Brush Less DC Motor (SBLDC); High-gain Interleaved Zeta Converter; Photovoltaic System (PV); Electric Vehicles (EV)**

I. INTRODUCTION

A significant change in the automobile industry, hybrid electric vehicles (HEVs) combine internal combustion engines and electric motors to offer a range of mobility alternatives. The primary attraction of hybrids is their capacity to lower pollutants and improve fuel economy while preserving the ease of use and adaptability of gasoline-powered automobiles. The hybrid vehicle's architecture is based on a dual powertrain system that consists of an internal combustion engine and one or more electric motors powered by a rechargeable battery pack shown in figure 1. Depending on driving habits and battery condition, this setup enables the hybrid to function in a variety of modes, including pure electric, pure gasoline, or a mix of the two.

This modification enables hybrids to use less energy, particularly when driving in cities, where older cars burn a lot of fuel when stopped and driven. Among these is better fuel efficiency when compared to conventional gasoline-powered automobiles. By running the engine at low speeds and idling, hybrids can save fuel. The regenerative braking system of the vehicle uses the energy lost when braking to generate power that charges the battery. Over time, this procedure lowers maintenance expenses by improving the vehicle's overall performance and lowering brake equipment wear and tear. For consumers who wish to reduce their impact on the environment and fuel expenses, hybrids are a good choice because of their superior fuel efficiency when compared to gasoline-powered automobiles.

The newest advancement in electric vehicle technology is represented by extended range electric vehicles (EREVs), which provide special answers to some of the drawbacks of plug-in hybrids and even electric vehicles (EVs).

The ability of EREVs to withstand high-pressure driving, a typical worry for EV buyers, is one of their main advantages. Buying an all-electric car can be significantly hampered for many buyers by their concern that the battery will die before they can reach a charging station. By providing gasoline-powered alternatives that successfully transform the car into a hybrid when the battery runs out, EVs continue to allay this worry. Because of their dual-fuel capacity, EVs are especially well-suited for longer trips and offer EV drivers who are always on the go peace of mind.

Figure 1. Hybrid Electric Vehicles (HEVs)

Electric vehicle (EV) adoption is heavily influenced by infrastructure and charging alternatives, which have an impact on user convenience and the whole driving experience. Payment options come in a wide variety, each tailored to a particular set of requirements and circumstances. Although Level 1 chargers are excellent for overnight charging at home using a home generator, charging an electric automobile can take a while. Usually found in homes and businesses, level 2 chargers offer quicker charging times—they can often charge an automobile battery in a few hours, making it appropriate for daily use.

II. LITERATURE SURVEY

Most vehicles rely on natural resources, primarily utilizing fossil fuels for operation. The consumption of these fossil fuels contributes to global warming and air pollution. In contrast, electric vehicles (EVs) do not utilize gasoline or diesel, resulting in zero emissions. Consequently, the adoption of electric vehicles helps mitigate certain environmental challenges. Additionally, electric cars are generally more cost-effective to operate and produce less noise compared to traditional vehicles. A significant drawback of electric vehicles is their limited performance. However, utilizing regenerative charging can enhance the driving range of these vehicles. Electric vehicles are characterized by three main types of motors: DC motors, asynchronous motors, permanent magnet brushless (PMBL) motors, and switched reluctance (SR) motors.

Boris V. Malozyomov et al [2024] have presented the mathematical model of the electric vehicle, which includes the battery traction module, the electric vehicle electric traction system, and the generator traction force calculation system, is used to determine the depth of battery discharge during the operation of the electric vehicle. Create a functional concept for the general model of the traction force in electric vehicles [1].

Muhammad Usman Nawaz et al [2024] have suggested a thorough evaluation of solar electric vehicles' (SEVs') financial and environmental effects in comparison to electric automobiles. One excellent strategy to lower carbon emissions and lessen reliance on fossil fuels is to include solar technology into electric cars (EVs). Energy consumption, greenhouse gas emissions, and resource depletion are all evaluated throughout the SEV's life cycle, encompassing manufacture, operation, and end-of-life phases [2].

Alejandro Jimenez et al [2024] have suggested to discuss the integration of renewable energy into the power island. In order to discover renewable energy concerns, the energy sector is first examined utilizing the smart energy concept. Electricity is assessed to ensure it satisfies stability and safety standards. Energy The new approach combines in-depth energy consumption research with a thorough energy system analysis from an energy planning viewpoint [3].

Khalid S. Mohammad et al [2022] have presented Comparison of main electric motors used in electric cars and electric car drive system requirements. Many people are working on the development of electric vehicles (EVs) to replace hybrid electric vehicles (ICE) and reduce environmental pollution. The driving power has a beneficial impact on the performance of electric cars, and the electric motor should be of high performance and excellent responsiveness [4].

Yen-Chu Wu et al [2022] have brief that to a nonlinear integrated numerical programming architecture to optimize the allocation of financial support. Electric vehicles should reduce transportation costs. To promote EV use and meet reduction goals, develop and disburse incentives and finance infrastructure improvements [5].

Nikita V. Martyushev et al [2023] have suggested to a simulation model was developed to determine the driving behavior of an electric vehicle from a moving point. This energy storage can be measured in many ways and the results of these measurements vary. Therefore, the design based on these circuits is a very important task for electric car manufacturers [6].

Emilia M. Szumska et al [2023] have presented to check the availability of existing charging stations with fast charging points for electric vehicles in EU countries. The competitive advantage between electric cars and plug-in hybrids is that their batteries can be charged quickly. Best of all, the process doesn't take much longer than refuelling a car [7].

Masooma Nazari et al [2023] have described a three-step analysis to the application of clustering methods for different problems related to EVs. Due to the introduction of a large amount of unknown load, the increasing use of electric vehicles presents a number of difficulties for power networks, particularly distribution systems. Due to differences in tastes, travel habits, and battery capacity, analyzing these issues becomes computationally costly as the number of electric vehicles increases [8].

Objectives:

- To implement a hybrid energy management system utilizing a high-gain interleaved Zeta converter for electric vehicle (EV) applications.
- To improve electric vehicle performance, this project implements a hybrid high-gain interleaved Zeta converter to enhance energy efficiency, reduce power losses, and minimize ripple currents.
- To achieve high voltage step-up, leveraging the Zeta converter's capability for effective energy transfer.
- To optimize power management by adapting energy distribution, enhancing vehicle performance, and extending range.

III. CONFIGURATION OF THE CONVENTIONAL SYSTEM

The rapid increase in car ownership around the world has led to pollution, fossil fuel shortages, and increased fuel prices. The National Oceanic and Atmospheric Administration (NOAA) releases annual climate data. It is predicted to be the sixth warmest year since 1880 based on global climate data. The World Health Organization (WHO) advises against breathing in more pollutants than 99 percent of people do. Vehicles with internal combustion engines are the global source of pollution and human mortality. Making the transition to electric vehicles (EVs) is a crucial step in preserving and improving the health of the planet.

The economy has benefited from the electric vehicle industry, and the nation is home to numerous significant initiatives and subsidies aimed at encouraging the transition to electric vehicles. The most populated nation where sales of plug-in electric vehicles are supported is China. The second-most populous nation, India, is producing a large number of start-ups and developing electric vehicle technologies. All governments are trying to pay more to meet charging needs and attract more EV users.

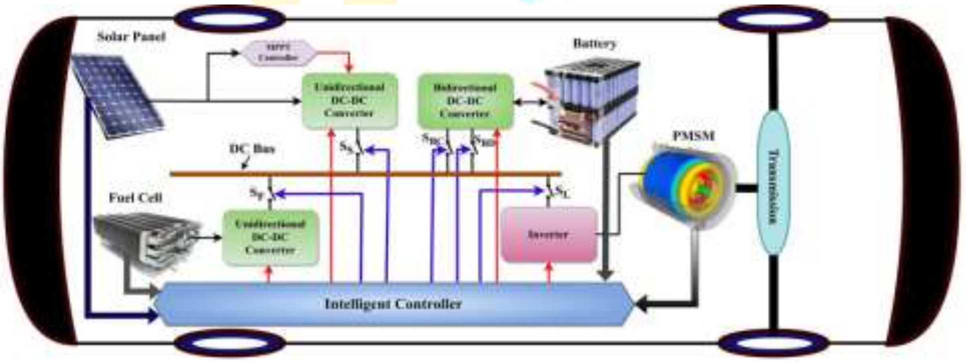

Figure 2. Block Diagram of Existing System

In this existing system presents, a hybrid energy storage system integrating solar panels, batteries, and fuel cells, managed by an intelligent controller shown in figure 2. The solar panel and battery are connected to a DC bus via bidirectional DC-DC converters, allowing power flow in both directions. The fuel cell is connected through a unidirectional DC-DC converter, enabling power flow in one direction only. An inverter is linked to a Permanent Magnet Synchronous Motor (PMSM), converting DC to AC power for motor operation. The intelligent controller optimizes the power distribution among these components, ensuring efficient energy management.

Drawbacks of the Conventional System:

- This existing controller's complexity and dependency on real-time data may pose challenges in varying operational conditions.
- The system's effectiveness could be limited by its reliance on instantaneous reference current-based power management, potentially complicating integration with diverse energy sources and dynamic load conditions.

IV. DESIGN AND IMPLEMENTATION OF THE PROPOSED SYSTEM

The Zeta converter, a versatile DC-DC power converter that may step up or step down, is a crucial part of modern power management. Zeta converters are created by merging buck and boost converters, just like auk converters. They are renowned for their capacity to regulate the output current, which is crucial for lowering electromagnetic interference (EMI) and enhancing dependability. This converter uses inductors and capacitors to store and convert energy between its input and output, making energy conversion efficient. One of the greatest features of the Zeta converter is its adaptability to many applications. Due to its high performance and ability to control different electrical products, it is widely used in electric batteries, solar energy harvesting, and telecommunications.

Zeta converters can enhance overall performance and maximize energy extraction in these systems by monitoring the PV array's maximum power point (MPPT). In power management, Zeta converters play an important role in ensuring that the power supply receives stable and consistent power. They can reduce input and output current ripple to increase the life and reliability of electronic equipment. Zeta converters can also provide input and output isolation, increasing their versatility in many applications. This isolation is particularly useful for electrical systems where noise and interference must be minimized.

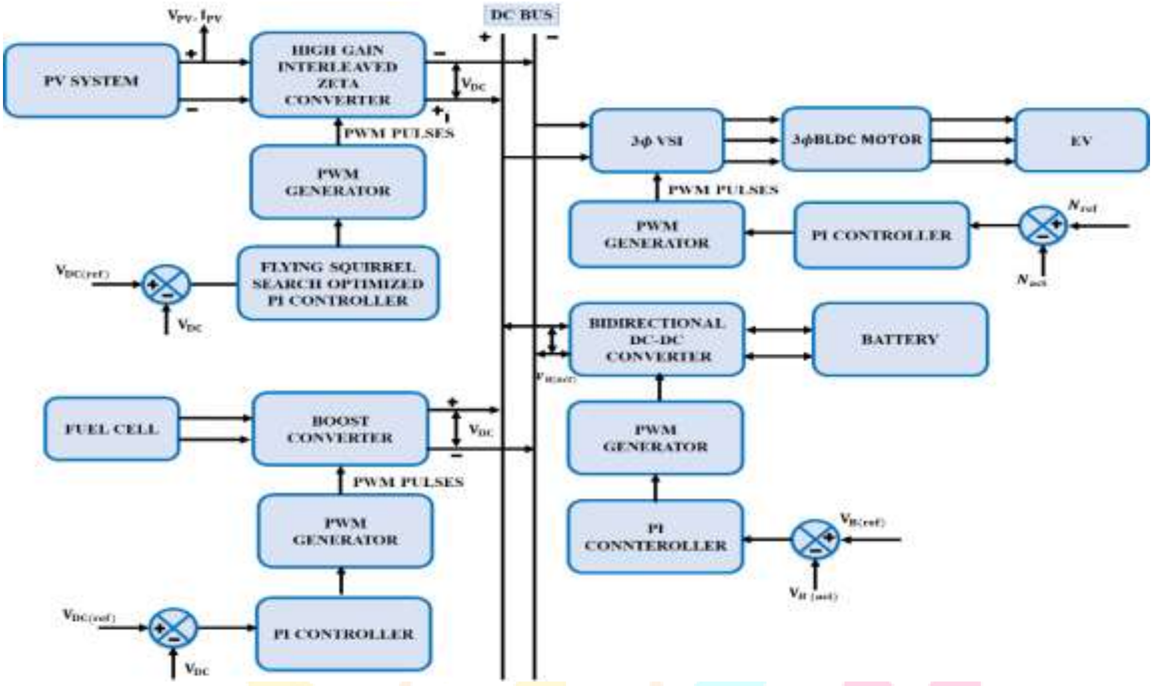

Figure 3. Block Diagram of Proposed System

This proposed system is proposes the hybrid energy management system for electric vehicles (EVs) integrates photovoltaic (PV) systems and fuel cells to optimize energy usage is shown in figure 3. It begins with the PV system converting solar energy into electrical power, which is then boosted to a higher voltage using a high-gain interleaved Zeta converter. This converter operates with PWM pulses generated by a dedicated PWM generator, while a Flying Squirrel Search optimized PI controller regulates the output voltage to maintain it at a desired reference level. The boosted DC voltage is supplied to a common DC bus, which distributes power to various components, including a three-phase voltage source inverter (VSI) that converts the DC into three-phase AC for driving a Brushless DC (BLDC) motor. A second bidirectional DC-DC converter manages the energy flow between the battery and the DC bus, enabling efficient charging and discharging. This converter is also controlled by a PI controller to ensure the battery voltage remains at its target level.

PV System:

One dependable and eco-friendly energy source is the sun. Utilize solar energy directly and use photovoltaic power generation to create electricity. Photovoltaics (PV), which use the photovoltaic effect to turn sunlight into electricity, is one of the primary methods of exploiting solar energy. The core part of photovoltaic modules, which use the photovoltaic effect to transform light energy into electrical power, is the solar cell. The effectiveness of a photovoltaic module depends on how the solar cells are physically applied and how they are installed within the module. The efficiency of solar modules to convert sunlight into electricity is around 12-29%. The maximum efficiency of gallium arsenide solar cells is 29%, while the efficiency of silicon solar cells is between 12-14%. The efficiency of a photovoltaic module can also decrease depending on the temperature of the photovoltaic module. Therefore, in order to improve the power production of photovoltaic modules, it is very important to operate the module at the best power point.

The equivalent diode structure of the photovoltaic cell is shown in figure 4 [9,10].

The PV model constitutes current sources, diode Shunt resistanceR_{sh}, Series ResistanceR_s. Shunt Resistance R_{sh} represent the cell surface leakage through the edges.

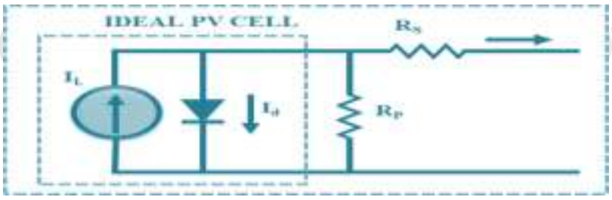

Figure 4. Equivalent Circuit of PV Cell

High Gain Interleaved Zeta Converter:

The Interleaved Zeta converter has a wide range of output power, configurable step-up/down output voltage, low input current distortion, minimal output voltage ripple, and good efficiency. Two identical Zeta converters connected in parallel make up the Interleaved Zeta converter, the circuit arrangement of this converter is depicted in Figure 5 [11]. The modes of operation of converter is shown in figure 6.

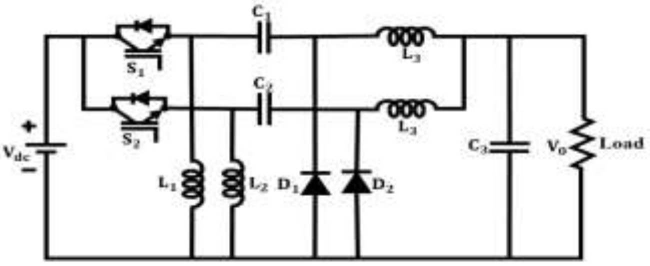

Figure 5. Circuit Diagram of Interleaved Zeta converter

Mode 1: Switch S_1 is activated during Mode 1, while S_2 is in off position concurrently. Energy from the DC source is stored in the inductor L_1, L_2 are charged during this phase. The capacitors C_1, C_2 supports in boosting voltage. The diode D_2 is in reverse biased and prevents current from flowing to load. The energy that has been stored by the inductor L_3 being released to the load via the output DC link capacitor C_o.

Mode 2: Switches S_1 and S_2 are both switched ON during this phase. The inductors L_1, L_2 are charged by the input voltage V_{dc}, storing energy. The inductor L_3, positioned on the output side, maintain continuous current to the load, but since diode D_2 is OFF, no energy is delivered to the load. Meantime, the capacitor C_1, C_2 also stores charge during this state.

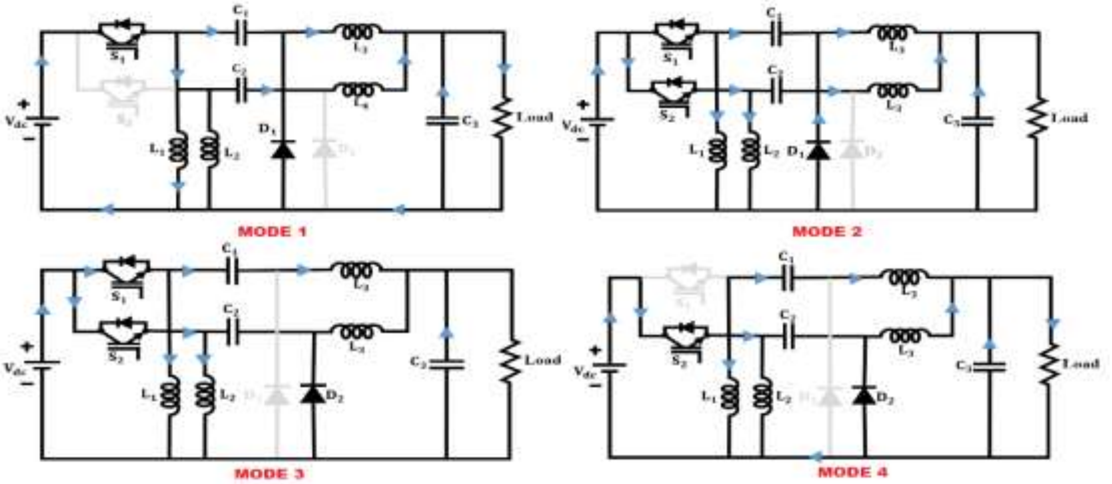

Figure 6. Modes of Operation of the Interleaved Zeta converter

Mode 3: S_1 is shut OFF and S_2 is on magnetized in this mode. The diode D_1 is in OFF state with inductors L_1, L_2 receiving no more further energy from input. However, the energy previously stored in inductors L_1 and L_2 remain in their magnetic fields. At the same time, L_3 continues to deliver power to load, ensuring continuous current flow to the output. The capacitors C_1, C_2 also maintain voltage balance supporting energy transfer.

Mode 4: In this mode, switch S_1 is OFF, switch S_2 is in ON state and diode D_1 is OFF, allowing inductors L_1 and L_2 to be charges by the input V_{dc}, storing energy. D_1 Remains reversed biased block energy transfer to the capacitors. Meanwhile inductor L_3 continue to provide current to the load ensuring uninterrupted power delivery. This mode stores energy in L_1 and L_2 while L_3 maintains stable output power.

Three Phase Voltage Source Inverter:

Rectifier fed inverter system has two stage converters. In this research inverter side control is described. Rectifier side control is used to find out duty cycle. Most inverter applications require a means of voltage control. This control may be required because of variations in the inverter source voltage and regulation within the inverter.

Three Phase BLDC Motor:

A three-phase brushless DC (BLDC) motor is a motor that operates on the principle of electromagnetic induction and is characterized by efficiency, reliability, and design. Unlike traditional brushed motors that operate with brushes and a commutator, BLDC motors rely on an electric motor to control the current level of the motor.

Fuel Cell Boost Converter:

In the field of renewable energy, fuel cell boost converters are crucial, particularly for applications that use fuel cells to produce power. This device is crucial in regulating the fuel's output power, which typically results in low voltage and could not be appropriate for direct power supply or battery charging. By raising the low level to a higher level, the boost converter makes it possible to use the fuel's energy effectively. The fuel cell boost converter goes through several crucial phases of operation. First, the fuel cell sends a modest power output to the converter. The voltage is then raised by using an inductor to store energy when the switch is closed and release it when the switch is open.

Bidirectional DC-DC Converter:

One kind of power electronics equipment that permits electrical energy to be transferred between two DC voltage levels and permits power flow in both directions is a bidirectional DC-DC converter. This feature is especially helpful in applications where controlling the energy flow between batteries, supercapacitors, and loads is crucial for optimum performance, such as energy storage systems, electric cars, and renewable energy systems

V. RESULTS AND DISCUSSIONS

The simulation results were analyzed using the program called MATLAB/SIMULINK. MATLAB is a language that can be used to calculate, visualize and compute in the user environment, where the problem and its solution are expressed using the information method. MATLAB is the best tool for signal analysis. The proposed work is implemented in MATLAB simulation are shown in figure 7.

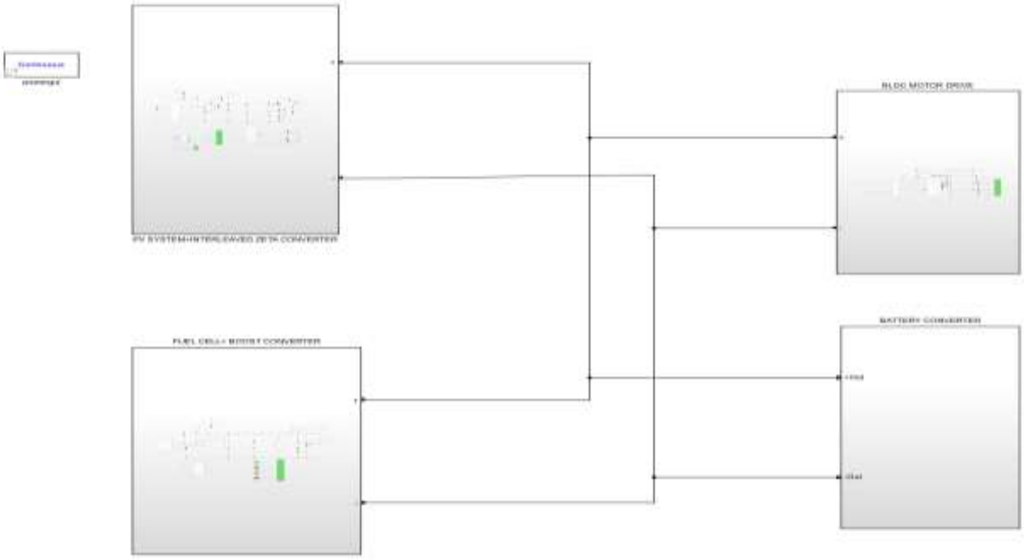

Figure 7. Over All Simulation Diagram

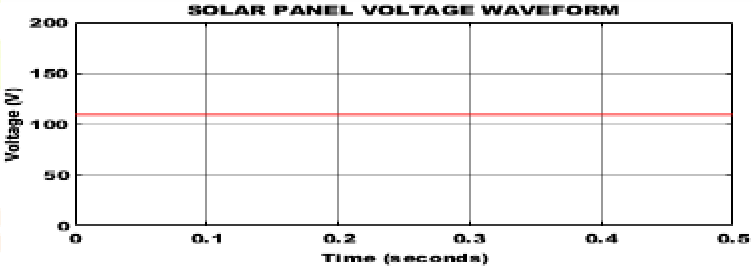

Figure 8. Solar Panel Voltage Waveform

Figure 8 represent as Solar Panel Voltage Waveform graph illustrates the voltage output of the solar panel over a 0.5-second interval. The voltage remains steady at 100 V, indicating consistent performance and reliable energy generation. This stability suggests that the panel is effectively converting solar energy into electrical energy without significant fluctuations, ensuring optimal operation during the measured timeframe.

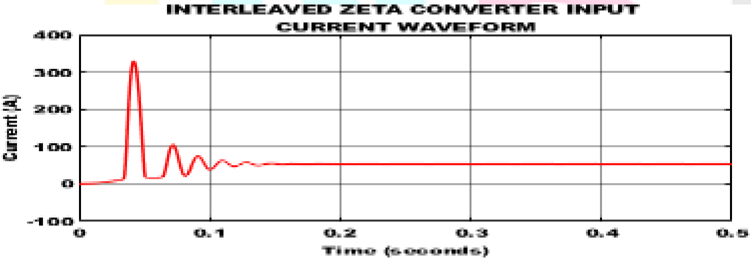

Figure 9. Interleaved Zeta Converter Input Current Waveform

Figure 9 represent as Interleaved Zeta Converter Input Current Waveform" graph displays the input current over a 0.5-second period. Initially, there is a sharp spike reaching approximately 300 A, followed by a gradual decay to a stable level. This pattern indicates a transient response characteristic of the converter, showcasing its ability to handle sudden changes in input while stabilizing effectively afterward.

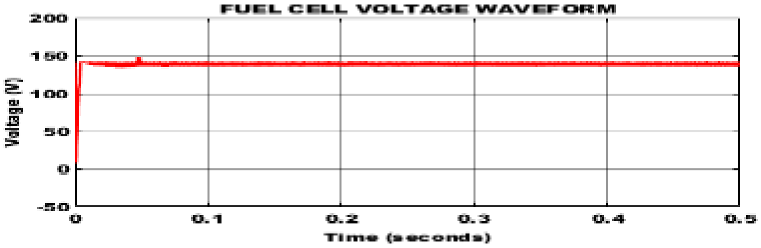

Figure 10. Fuel Cell Voltage Waveform

Figure 10 represent as Fuel Cell Voltage Waveform graph illustrates the voltage output of a fuel cell over a 0.5-second period. The voltage initially fluctuates slightly before stabilizing around 150 V. This consistent output indicates the fuel cell's reliable performance, demonstrating its ability to maintain voltage under steady operating conditions while providing a stable energy source for various applications.

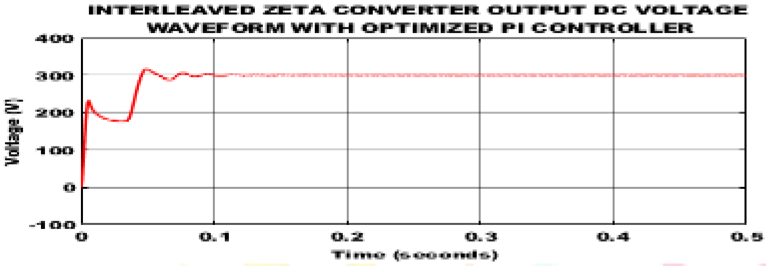

Figure 11. Interleaved Zeta Converter Output Dc Voltage Waveform with Optimized PI Controller

Figure 11 represent as Interleaved Zeta Converter Output DC Voltage Waveform with Optimized PI Controller graph illustrates the output voltage over a 0.5-second interval. The voltage initially fluctuates but quickly stabilizes around 300 V. This behavior demonstrates the effectiveness of the optimized PI controller in maintaining consistent voltage output, ensuring reliable performance and minimal deviation despite transient conditions during the conversion process.

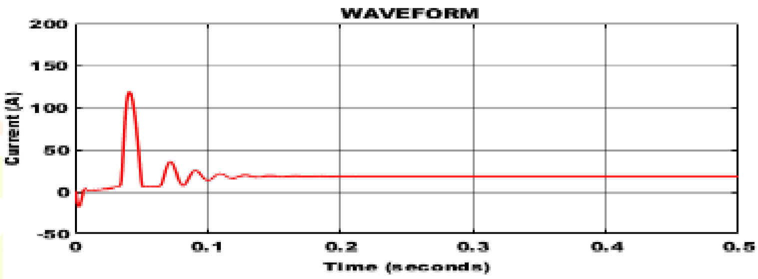

Figure 12. Interleaved Zeta Converter Output Current Waveform

Figure 12 represent as Interleaved Zeta Converter Output Current Waveform graph depicts the output current over a 0.5-second period. Initially, there is a sharp spike reaching approximately 100 A, followed by a rapid decline and eventual stabilization near zero. This waveform illustrates the dynamic response of the converter to load changes, highlighting its ability to manage output current effectively during operation.

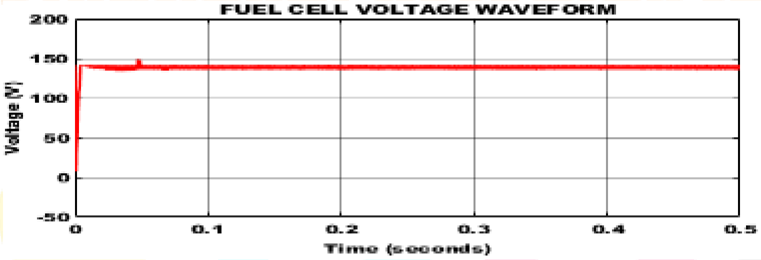

Figure 13. Fuel Cell Voltage Waveform

Figure 13 represent as Fuel Cell Voltage Waveform graph illustrates the voltage output of a fuel cell over a 0.5-second period. The voltage initially fluctuates slightly before stabilizing around 150 V. This consistent output indicates the fuel cell's reliable performance, demonstrating its ability to maintain voltage under steady operating conditions while providing a stable energy source for various applications.

Figure 14 represent as the State of Charge (SOC) of a battery over time, shown as a constant 80% SOC. This indicates that the battery maintains a steady charge level throughout the observed time frame (0 to 0.5 seconds). The stable SOC suggests that either the battery is in an idle state with no significant charging or discharging, or the system is actively regulating the charge to remain constant for optimized performance.

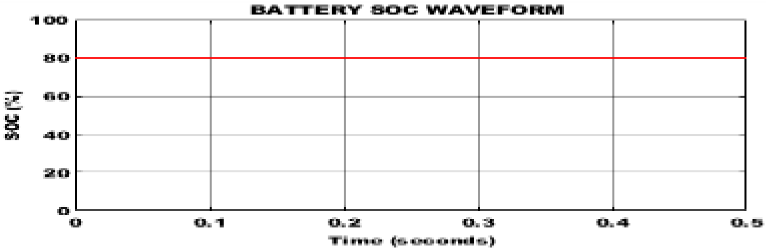

Figure 14. Battery SOC Waveform

VI. CONCLUSION

This paper introduces a sophisticated hybrid energy management system aimed at improving the performance and efficiency of electric vehicles through the incorporation of renewable energy sources, particularly photovoltaic panels and fuel cells. The high-gain interleaved Zeta converter plays a crucial role in optimizing energy conversion by effectively increasing low voltage outputs for enhanced power distribution. Utilizing an advanced control strategy that integrates a Flying Squirrel Search optimized Proportional-Integral (PI) controller, the system maintains stable voltage output across varying load conditions, thereby bolstering its reliability. The addition of a bidirectional DC-DC converter further enhances the system's adaptability by facilitating efficient energy transfer between the battery and the DC bus, enabling swift responses to energy demands. Simulation results demonstrate that the proposed hybrid energy management system not only achieves greater efficiency and dynamic performance but also exhibits robustness and reliability, positioning it as a promising solution for future electric vehicle applications.

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