ZETA Converter and Intelligent Controller Application for a PV-Powered EV Charging Station

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Abstract: ***The transportation industry is quickly changing due to the fast adoption of electric vehicles. Strong and eco-friendly electrical charging facilities is necessary for the changeover process, nevertheless. Conventional battery-powered automobile charging stations are usually dependent on the conventional electrical grid, which is highly dependent on non-renewable energy sources and is subject to fluctuations. This article presents a revolutionary method that overcomes inefficiency and unreliability in electric automobiles charging devices by integrating renewable energy sources. In order to work in both step-up and step-down configurations that enable appropriate power transfer with optimal efficiency, a zeta converter has been used to the regulation system for the variation of PV output voltage. In order to ascertain the solar irradiance and loading criteria, an intelligent robust regulation system is built for the uncertainties and nonlinearities of the proposed system. Simulation findings verify that the system can achieve MPPT and maintain consistent EV charging outcomes while operating significantly. The ANN-based MPPT reduces transient, rapidly tracking pv voltage and pv current.***

Index Term: Zeta Converter, SMC controller, ANN MPPT algorithm, photovoltaic energy system, electric vehicle (EV) and charging station.

I. INTRODUCTION

Electric vehicles (EVs) represent prospects as a remedy for the issues that fossil fuel-powered automobiles generate. However, the infrastructure for charging EVs determines how flexible they can actually be considered. A significant quantity of electrical energy, primarily from coal and gas-based power plants, is needed for EV charging. Therefore, when the electrical energy needed for EV charging comes from renewable energy sources like solar, wind, etc., EVs can really be a green and clean alternative to the current transportation system [1].

In addition to their intermittent and low voltage power sources, photovoltaic systems, DC microgrid interconnection, electric vehicle charging/discharging, and energy storage devices, power converters have experienced an incredible growth in recent years [2]. In this article, the non-isolated Zeta converter received significant attention. Zeta converters are the subject of several research studies recently because of their various benefits, including high power, high voltage quality and small size. As a result of connecting to a Zeta converter for effective power management, a Sliding Mode Controller (SMC) acts as the center of attraction for controlling the operation of a PV-powered EV charging station. As a result, it provides efficient PV voltage management leading to in consistent energy output across fluctuating solar irradiation levels, the Zeta converter is the stipulated option. For maintaining the charging station operation amid a variety of uncertainties, such as fluctuations in solar power and dynamic loading circumstances, the SMC improves the station dependability. Maximum Power Point Tracking (MPPT) artificial neural network (ANN) integration allows the PV system to dynamically adapt to changes in the environment, resulting in maximum power extraction. The MATLAB/Simulink platform is used to run extensive simulations that are used in the system performance evaluation. In concentrating on PV arrays coupled with storage units and charging infrastructure, the modeling method enables comprehensive evaluation of each system component. When analyzing the system power production and voltage stability under various solar irradiation levels and load conditions, the system simulations reveal the system performance.

This study reveals that to combine solar energy with SMC control and Zeta converter technology to provide an improved sustainable EV charging solution. Three significant advantages will result from the proposed integration of these parts: reduced energy waste, enhanced operating efficiency, and dependable charging power delivery. The combined approach promotes the growth of a sustainable, clean transportation infrastructure. According to research outcome, renewable energy technology is a significant potential to alter EV charging networks while reducing dependence for electricity from the conventional utility.

II. SYSTEM UNDER STUDY

An extensive review of solar-powered EV charging stations with Sliding Mode Controllers (SMC), Zeta Converters, and Maximum Power Point Tracking (MPPT) artificial neural network (ANN) is presented in this study. Conventional EV charging infrastructure is powered by the electrical grid, which is unreliable and dependent on fossil fuels. It is now necessary to do innovative research on renewable energy exploration, smart charger deployment and advanced control techniques that improve efficiency and sustainability. According to [1], user-focused strategies that integrate cost-saving and demand-based charging techniques are necessary for the optimization of electric vehicle (EV) charging.

This article observed the most effective methods for developing EV charging networks by concentrating on monetary advantages and policy support for the infrastructure and city planning strategies needed to facilitate the widespread adoption of charging stations [2]. By evaluating potential storage improvements and managing electric equipment and EV service platforms, it [3] explained advancements in electric vehicle technology. The article examined control strategies that employ hierarchical structures for EV charging stations linked to smart grids in order to demonstrate how smart energy management increases system stability while enhancing station effectiveness. The optimum positioning of charging stations is important for the development of EV network of chargers [4]. In order to attain effective energy distribution, decrease voltage fluctuations, and lower power losses, this article [5] focused on multi-objective optimization approaches. [6] In order to predict consumption patterns and enhance station accessibility, this study investigated prediction models for charging station occupancy using a hybrid Long Short-Term Memory (LSTM) neural network.

The incorporation of renewable energy, especially solar electricity, is becoming more widely acknowledged as a sustainable option for EV charging.[7] evaluated the viability of solar-powered EV charging stations, emphasizing their capacity to lessen reliance on traditional energy sources. This [8] examined the efficiency, energy storage and power management of a stand-alone photovoltaic (PV)-based charging station. The importance of energy storage devices in maintaining a steady power supply even in the face of varying solar irradiation is emphasized by their research. [9] Developed a PV-based off-grid EV charging station while tackling issues with energy storage, charge control, and financial viability.

Studied the advantages and working principles of solar cells, presenting their increased efficiency and expanding role in EV charging infrastructure [10, 11]. carried out a thorough analysis of energy management approaches used in microgrid systems, recognizing cutting-edge control methods that improve power stability and efficiency in PV-integrated EV charging stations.

A further essential field of study is improving the efficiency of solar energy conversion. examined [12] a number of variables influencing solar cell performance and suggested optimization strategies to boost energy production for EV charging applications. Their research revealed MPPT fuzzy logic algorithms and semiconductor novel materials as significant components that improve the power generation potential of PV-powered charging stations. Gaining optimal efficiency levels in renewable energy-powered EV charging systems requires effective power conversion and control technology. Because of its capacity to manage system uncertainties resulting from fluctuating solar power output and dynamic EV charging specifications, SMC is going through substantial study in [13,14]. As a result of generating consistent voltage outputs that lead to successful power delivery inside solar-powered charging environments, employees working in power converter research groups are proving the efficacy of SMC with Zeta converters. According to studies on charging stations for electric vehicles, the development of sustainable charging solutions requires the integration of smart control systems, optimal charging station deployment, and the utilization of renewable power sources [16,17]. An efficient way to meet the expanding needs for EV charging is to use solar energy in conjunction with cutting-edge converter systems and energy optimization techniques.

In order to maximize the efficiency and dependability of charging networks, research [15] efforts should focus on building integrated renewable energy systems and achieving quick energy optimization using artificial intelligence-enhanced predictive analysis. Architecture for PV-powered charging presents certain difficulties for this power system. The strategic placement of charging facilities and their adaptation to suit the demands of electric vehicles should be guided by the energy generation output from PV systems in [18,19]. Power flow control and dual operation as a distinct systems and linked units with the main power grid are necessary for the concurrently grid integration of these stations. Energy consumption should be strategically managed in order to maintain a balance between power generation and storage capacity. The schematic diagram configurations of a PV-powered EV charging system are shown in Fig.1.

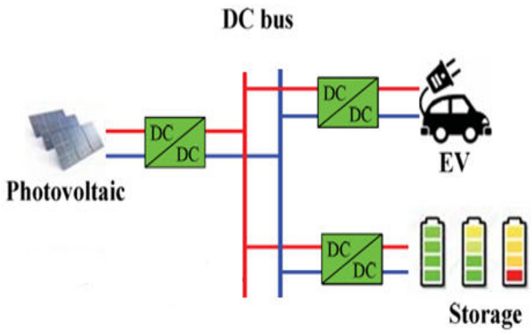


Fig.1. The block diagram depicts PV-powered electric vehicle charging with the use of Zeta converter technology.

III. Description of the studied EV

When converting solar energy into electrical power, the photovoltaic array is considered the main source of electricity. Due to variations in solar radiation and temperature rates, the power produced by the PV system varies. A crucial Maximum Power Point Tracking (MPPT) method must be performed by the system in order to maximize power. In this system, traditional implementation via P&O and incremental conductance techniques is replaced with an artificial neural network (ANN)-based MPPT algorithm.

The ANN-based MPPT algorithm operates as a rule-based technique that automatically manages boost converter duty cycle operations in response to fluctuations in PV voltage and current. It operates in three basic stages: neuron, rule evaluation, and weight function. During the weighted function, the input parameters (ΔV and ΔP) from PV voltage fluctuation and power variation are transformed into neuron variables (input layer, hidden layer and output layer). In order to provide quick maximum power point monitoring in situations of rapid irradiance fluctuations, the duty cycle change adheres to a pre-established ANN during the assessment stage. After the weighted function step, a modified duty cycle represents a crisp control signal. By optimizing performance and efficiency, the ANN MPPT algorithm improves charging outcomes and reduces power waste, thereby increasing PV system reliability.

A Sliding Mode Controller (SMC) is used by the boost converter to regulate the process of raising PV array voltage until it reaches the necessary DC bus level. SMC is a powerful nonlinear control technique that offers quick response times, excellent system stability and robust resistance to changes in system parameters. When it comes to reacting quickly to PV fluctuations ignited on the climate change, SMC performs better than standard PI controllers.

The PV voltage and current error signals serve as the foundation for defining the sliding surface function. The SMC sends control signals to the boost converter switch, which maximizes power transfer from the PV source and stabilizes the output DC voltage.

As a consequence of this technique, power supply is still consistent. Minimize the effects of overshoot and voltage ripple. The central DC bus serves as the primary distribution station for stabilize the distribution of electricity across all PV power generation or variations in load. In addition, the bidirectional converter stable operating limits are provided by the boost converter for the DC bus, providing continuous power to the extra loads and an EV charger.

For the safe charging and draining of lead-acid battery banks, the Zeta converter functions within the bidirectional converter to regulate energy flow between the ESS and DC bus. The Zeta converter exhibits high-gain functionality, non-inverting DC-DC operation, and greater voltage control while lowering switching losses, in contrast to buck-boost converters. For safe lead-acid battery charging from the DC bus, the Zeta converter operates as a step-down converter in charging mode. When solar power is insufficient, the Zeta converter seen in Fig. 2 uses step-up conversion to increase battery voltage and fulfil power demands. An energy storage system serves as a stability stabilizer by storing surplus energy from the PV system during the day, which then powers the EV charging at night or in low light. A Zeta converter within the bidirectional system enhances voltage regulation efficiency and current control while reducing system energy losses.

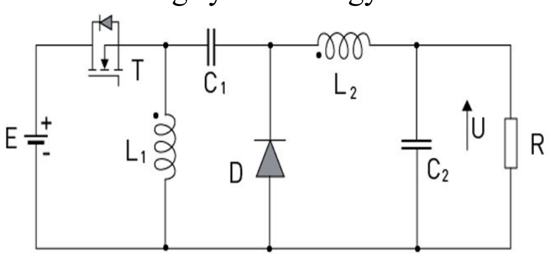


Fig.2. Zeta Converter

IV. Control Techniques

In order to achieve steady power conditions, a PV-powered EV charging station with a Zeta converter uses its regulatory system to function in a regulated process. The boost converter Sliding Mode Controller (SMC) regulates the DC bus voltage while managing variations in solar input. An ANN MPPT Controller maximizes PV power extraction by intelligently modifying the duty cycle. To achieve power balance, the bi-directional Zeta converter regulates both energy storage and discharging processes. In order to prevent both deep battery depletion and overcharge situations, the PI controller provides sure that the battery charge currents are appropriate. For safe EV charging procedures, the buck converter reduces voltage while adhering to a CC/CV charging strategy. Both voltage and current sensors for adaptive control systems are necessary for the real-time feedback system. EVs can operate efficiently and charge continuously and steadily attributable to the sophisticated control system that is currently put in position.

ANN-based MPPT Control

Fig.3 demonstrates that the ANN-based MPPT Control Algorithm optimizes harvesting by modifying the duty cycle of the converter to increase PV output. The system starts with a neuron, moves on to rule evaluation, and ends with a weight function. Neurons are used to convert the input variables PV voltage and power variations into weighted function values. Which control action will work best is determined by the preset input layer in the hidden layer assessment procedure. In order to translate the soft input into an exact adjustment value that regulates the duty cycle of the converter, the hidden layer requires a set of weight values. This technique improves system performance under various sunlight circumstances and speeds up system function with reduced oscillation. Artificial neural networks

(ANNs) outperform conventional MPPT approaches because to their superior efficiency in adapting to nonlinear PV characteristics. In addition to improving adaptability in PV systems, the solution boosts energy harvesting efficiency and stability. The ANN-based MPPT tracks PV voltage and PV current quickly and minimizes transient.

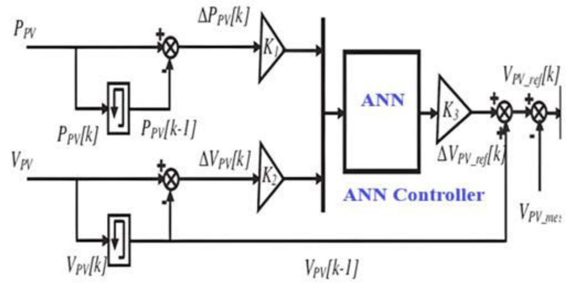


Fig.3. ANN-based MPPT controller.

SMC Controller

Sliding Mode controllers (SMC) provides robust and consistent voltage management in PV boost converter applications despite changeable solar conditions. A sliding threshold which directs system states toward the desired operational condition is established by the control. The control strategy adds disturbance-blocking switching controls while maintaining stable functioning comparable control components. Duty cycle change under SMC enables to maintain a steady DC bus voltage, which improves system efficiency. Along with lower steady-state errors and strong tolerance to parameter changes, it possesses quick dynamic reaction capabilities. SMC controllers can quickly adapt to variations in PV output; thus, devices are not affected by these fluctuations. By using this method, power stability is maintained while power conversion efficiency increases. The block diagram of the PI controller is depicted in Fig. 4.

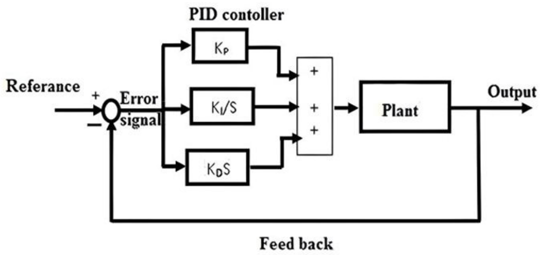


Fig.4. PI controller

BUCK Converter

The DC bus voltage is reduced by an EV charging system buck converter to the level required by the EV battery. To securely and effectively charge the battery, it uses a CC/CV (Constant Current/Constant Voltage) control system. The PI controller circuit modifies the converter duty cycle according to the necessary output voltage and currents. While the integral part increases accuracy by resolving the steady state error, the proportional part reacts to process faults. In constant current mode, the battery receives a set charging current from the converter prior to its voltage attained its predetermined value. When the voltage reaches the predetermined level, it switches to constant voltage mode, which keeps the voltage steady while the current gradually drops to avoid overcharging. Voltage and current sensors provide real-time signals for precise control. The technology maximizes energy efficiency, avoids battery overheating or deterioration and guarantees seamless charging transitions. This method improves EV charging dependability and battery longevity.

V. Simulation Results and Discussion

A PV-powered EV charging station is simulated using a few waveforms that replicate the functioning of different system components. These waveforms display the battery power transmission, voltage control, current characteristics, and charging capabilities. A detailed explanation of each waveform, together with its simulation settings and implications, is provided below. The simulation diagram depicted in fig.5.

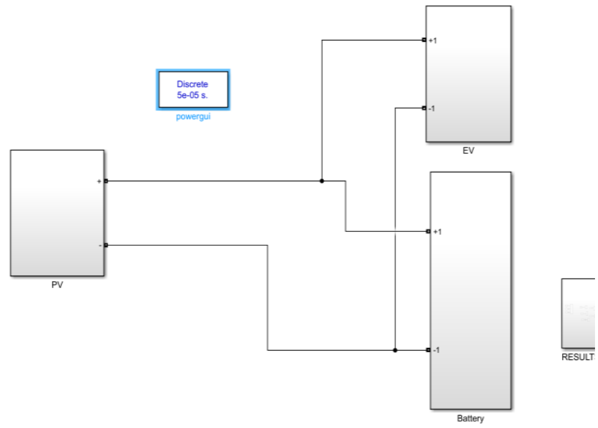
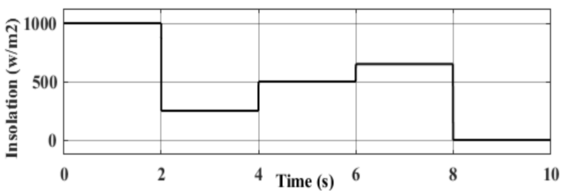
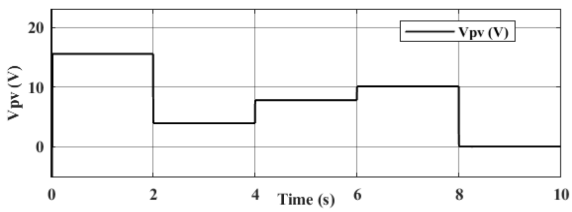


Fig.5. Simulation diagram.

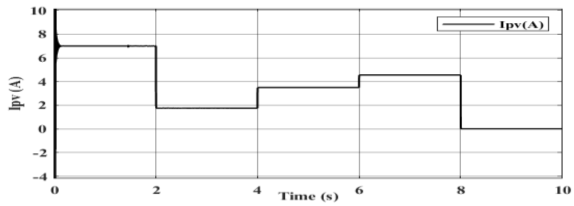
In Fig.6 (a), the irradiance level begins at zero in the morning, progressively rises to a peak at midday, and then falls until evening. The simulation takes into account standard test conditions (STC) with a peak irradiation of 1000 W/m² in order to assess system performance in practical settings. The ANN-based MPPT controller stabilizes the voltage in spite of varying solar irradiation, as seen by the PV voltage waveform in Fig.6(b). In order to maximize energy extraction, the simulation makes sure the PV voltage stays close to the MPP, which is normally 22V for a 126W panel.



(a)



(b)



(c)

Fig.6. (a)PV irradiance level, (b)PV Voltage, (c)PV current.

The boost converter duty cycle is continuously changed by the ANN-based MPPT algorithm to preserve voltage stability. Fig.6 (c) displays the PV current waveform, which is exactly proportional to irradiance and reaches its greatest values during the maximum level of sunshine. Depending on variations in sun irradiation the current varies between 0A and 7.5A. In order to ensure effective power transfer to the DC bus, the boost converter modifies the current flow under the direction of the MPPT algorithm. the DC bus stability, which powers the energy storage system (ESS) and EV battery. The boost converter Sliding Mode Controller (SMC) makes sure that the DC bus voltage is set steady at 25V even when the solar input varies. The charging and discharging cycles of the lead-acid battery utilized in the ESS are shown by the SOC waveform. The battery charges during times of strong PV generation, raising its SOC. The battery drains when solar power is low, providing energy to the EV or maintaining DC bus stability. To prevent deep discharge or overcharging, the modeling maintains the SOC between safe operating limits of 30% and 90%. The state of charge (SOC) and cycles of charging and draining affect the lead-acid battery voltage. According to the simulation, the battery voltage varies between 12 and 15 volts, depending on the level of charged it remains. To prevent overcharging, the bidirectional Zeta converter charging voltage is managed by a PI controller.

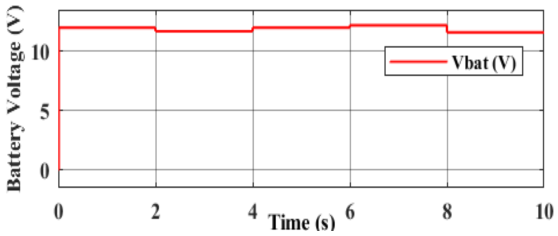


Fig.7. Battery voltage.

The lead-acid battery charging and discharging current is represented in Fig.7. The battery charges with a positive current when it detects an excess of PV power, while it discharges during periods of low solar radiation, producing negative current values. This procedure is managed by the bidirectional Zeta converter, which ensures effective energy storage and release.

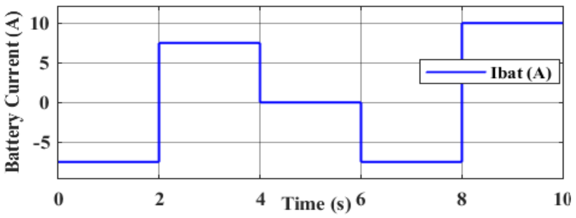


Fig.8. Battery Current.

Fig.8 illustrates the EV battery charging process over time. In order demonstrate ongoing charging, the SOC begins at a lower level and progressively rises. In order to prevent excessive current draw, the buck converter makes sure the battery charges according to a constant current/constant voltage (CC/CV) specification.

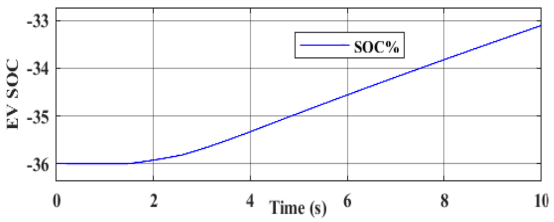


Fig.9. SOC of EV.

The buck converter and PI controller maintain a constant EV battery current depicted in Fig 9. The battery charges at a constant charging current of around 10A during the constant current phase. As the battery gets closer to full charge, the current progressively drops in accordance with the CC/CV process.

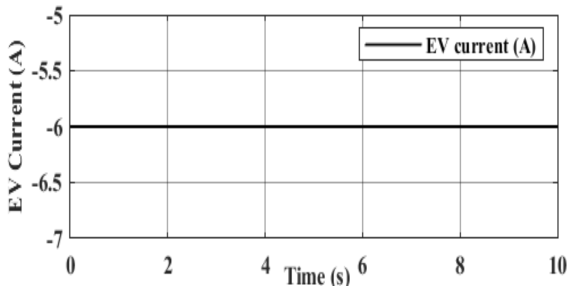


Fig.10. EV current.

Fig.10 depicts the voltage between the EV battery terminals while charging. The simulation remains the nominal voltage at 16V and progressively raises it as the SOC increases. A PI controller controls voltage variations to provide seamless charging.

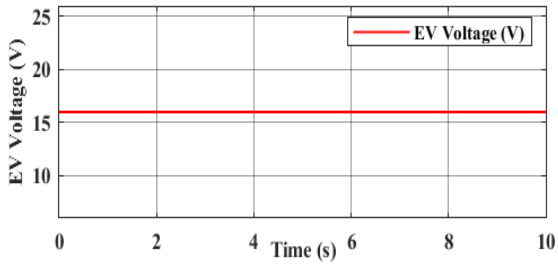


Fig.11. EV Voltage.

Fig.11 illustrates which both voltage and current outputs affect PV power. The solar irradiance pattern is followed by this waveform, which peaks around noon when sunlight is at its strongest. Power extraction is maximized using the ANN-based MPPT Controller, which maintains a peak value of 126W under optimal circumstances. the electricity delivered to the EV battery. Because of the buck converter control, the charging rate stays constant. The PI controller delivers steady power. The battery power waveform displays the ESS cycles of charging and draining. Negative signs indicate discharging when PV power is low, while positive signs suggest charging when PV power is high. The bidirectional Zeta converter effectively completes the process of switching to optimize power consumption.

V. CONCLUSION

Power control, stability and energy use optimization can be all successfully verified by an SMC-regulated PV-powered EV charging station with a Zeta converter. During variations in solar irradiation and load demand, the SMC effectively regulates the DC bus voltage to deliver a steady power supply. The bidirectional Zeta converter effectively controls the energy storage system (ESS) charging and discharging, supplying a steady source of power for EV charging.

Additionally, the ANN-based MPPT algorithm provides optimal system efficiency and optimizes solar power harvesting. The simulation output confirms that the system minimizes power loss, provides continuous EV charging and distributes energy across PV, ESS and load in an appropriate manner. The ANN-based MPPT tracks PV voltage and PV current quickly and minimizes transient.

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