iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 **Issue:** III **Month of publication:** March 2026

DOI: https://doi.org/10.22214/ijraset.2026.78319

Solar EV Charging with Zeta Topology

Anandhu E[1], Asim Ali[2], Jeslyn Sara Sam[3], Niranjan Rajeev[4], Prof. Jessy Thomas[5], Dr. Sija Gopinathan[6]
Department of Electrical and Electronics Engineering Mar Athanasius College of Engineering, Kothamangalam, Kerala

Abstract: Electric vehicles are rapidly emerging as a sustainable transportation solution; however, conventional grid-based charging systems increase electricity demand and contribute to carbon emissions. Solar photovoltaic energy offers a clean and renewable alternative for EV charging. The output of photovoltaic systems is highly dependent on solar irradiance and temperature, which leads to fluctuations in voltage and power generation. In order to improve energy extraction efficiency, a solar photovoltaic charging system using a ZETA DC–DC converter integrated with a Maximum Power Point Tracking algorithm is presented.

The ZETA converter operates in both buck and boost modes while maintaining a non-inverted output voltage suitable for battery charging. A PIC microcontroller implements the MPPT control algorithm and monitors battery parameters such as state of charge, state of health, and charging duration. Real-time system parameters are displayed through an LCD and transmitted to the ThingSpeak cloud platform using an ESP8266 Wi-Fi module for remote monitoring. The proposed system is modeled and simulated using MATLAB/Simulink to evaluate voltage regulation, output ripple, and charging performance. Simulation results demonstrate efficient power extraction, improved voltage stability, and enhanced charging performance under varying solar conditions. The system promotes environmentally friendly transportation while reducing dependence on conventional grid power.

Keywords: Solar photovoltaic system, ZETA converter, Maximum Power Point Tracking, EV charging, IoT monitoring

I. INTRODUCTION

The increasing demand for sustainable energy and the rapid growth of electric vehicles have intensified the need for efficient renewable energy based charging systems. Solar photovoltaic (PV) technology has emerged as one of the most promising renewable energy solutions due to its ability to directly convert solar radiation into electrical energy. However, the electrical output produced by photovoltaic panels is highly dependent on environmental factors such as solar irradiance, temperature, and shading conditions. These variations lead to fluctuations in the output voltage and current of the PV system, which reduces the efficiency of energy utilization when directly connected to energy storage systems or loads.

To address this issue, Maximum Power Point Tracking (MPPT) techniques are widely employed in photovoltaic systems to ensure that the solar panel operates at its optimal power point under varying environmental conditions. MPPT algorithms continuously adjust the operating voltage and current of the PV panel to extract the maximum possible power. Among the commonly used MPPT techniques, the Perturb and Observe (P\&O) method is widely preferred due to its simplicity, reliability, and ease of implementation in embedded control systems.

DC–DC converters play an essential role in MPPT systems as they regulate the power flow between the solar panel and the energy storage unit. Various converter topologies such as buck, boost, buck–boost, SEPIC, and Cuk converters have been studied for renewable energy applications. However, these conventional converters often introduce limitations such as output voltage polarity inversion, discontinuous current, or higher ripple levels. The ZETA converter has gained significant attention in photovoltaic energy systems because it offers both step-up and step-down voltage conversion while maintaining a non-inverted output voltage and continuous current flow.

In addition to efficient power conversion, intelligent monitoring and control are essential for modern renewable energy systems. With the advancement of Internet of Things (IoT) technologies, solar energy systems can now be remotely monitored and analyzed in real time. By integrating Wi-Fi communication modules and cloud platforms, system parameters such as voltage, current, and battery status can be transmitted to online dashboards for visualization and performance analysis. A solar power based maximum power point tracking system using a ZETA converter can therefore provide an efficient and intelligent solution for renewable energy management. The system integrates photovoltaic energy harvesting, DC–DC power conversion, battery monitoring, and IoT based cloud connectivity. Such integration improves overall system efficiency, enhances battery performance, and enables remote supervision of system operation.

II. PROPOSED SYSTEM

The proposed system is designed to efficiently harvest solar energy and regulate it for battery charging applications using a Maximum Power Point Tracking (MPPT) technique combined with a ZETA DC–DC converter. The system integrates photovoltaic energy generation, power conditioning, embedded control, and IoT-based monitoring to improve energy efficiency and operational intelligence. The photovoltaic panel serves as the primary renewable energy source, while the ZETA converter regulates the output voltage to match the battery charging requirements.

A PIC microcontroller implements the MPPT algorithm and generates pulse width modulation (PWM) signals to control the switching element of the converter. In addition, an IoT communication module enables real-time monitoring of system parameters through a cloud platform.

A. System Architecture

The architecture of the proposed solar MPPT system consists of several functional blocks including the photovoltaic panel, voltage sensing circuits, ZETA converter, PIC microcontroller, battery storage unit, LCD display, and IoT communication module. The overall block diagram of the system is illustrated in Fig.1. The solar panel generates a variable DC voltage depending on environmental conditions such as solar irradiance and temperature.

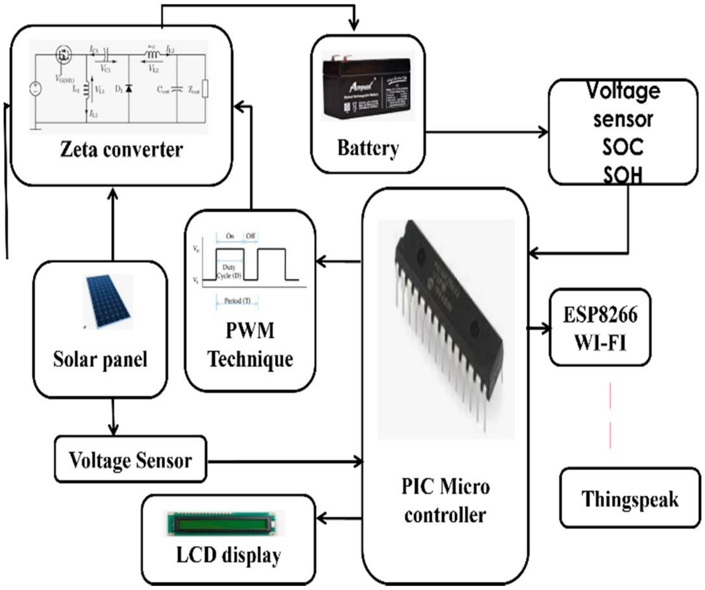


Fig. 1 Block Diagram of Solar MPPT System using ZETA Converter

The generated solar voltage is supplied to the ZETA converter, which regulates the output voltage to provide a stable supply for charging the battery. The PIC microcontroller continuously monitors the solar panel voltage and battery voltage using voltage sensing circuits. Based on these measurements, the controller executes the MPPT algorithm and adjusts the duty cycle of the PWM signal controlling the converter switch. The regulated power is then delivered to the rechargeable battery for energy storage. System parameters such as solar voltage, battery voltage, and charging status are displayed locally through an LCD display. At the same time, the measured data is transmitted to a cloud platform through the IoT communication module for remote monitoring and analysis.

B. Solar PV Module and ZETA Converter

The solar photovoltaic module converts sunlight into electrical energy using the photovoltaic effect. The output voltage of the PV panel varies depending on solar irradiance, temperature, and environmental conditions. Since the PV output is not constant, it cannot directly supply a stable voltage for battery charging applications. Therefore, a DC–DC power converter is required to regulate the PV output voltage. In the proposed system, a ZETA DC–DC converter is employed to regulate the photovoltaic output voltage. The ZETA converter is a non-inverting converter capable of operating in both step-up and step-down modes. This capability allows the converter to either increase or decrease the input voltage depending on the battery charging requirements. The circuit configuration of the ZETA converter is shown in Fig. 2.

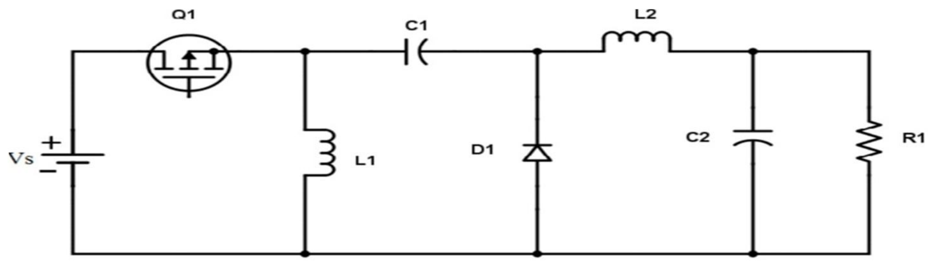


Fig. 2 Circuit Diagram of ZETA Converter

The ZETA converter consists of two inductors, two capacitors, a diode, and a switching element such as a MOSFET. The switching device is controlled using a PWM signal generated by the microcontroller. One of the main advantages of the ZETA converter is that it provides a non-inverted output voltage while maintaining continuous current flow through the load. This characteristic improves the efficiency of power transfer and reduces output voltage ripple. By adjusting the duty cycle of the switching signal, the converter maintains a regulated output voltage even when the input voltage from the solar panel fluctuates. This ensures stable battery charging and improved energy utilization.

C. Conveyor Belt and Sorting Mechanism

The PIC16F72 microcontroller acts as the central control unit of the system and is responsible for implementing the Maximum Power Point Tracking algorithm. The microcontroller continuously measures the voltage generated by the solar panel through voltage sensing circuits connected to its analog-to-digital converter inputs. These measured values are processed by the MPPT algorithm to determine the optimal operating point of the photovoltaic panel. In this system, the Perturb and Observe (P\&O) technique is used to track the maximum power point. The algorithm slightly perturbs the operating voltage of the PV system and observes the resulting change in output power.

If the power increases, the algorithm continues to adjust the duty cycle in the same direction. Otherwise, the perturbation direction is reversed. Through this iterative process, the controller continuously adjusts the duty cycle of the PWM signal controlling the MOSFET switch in the ZETA converter. This ensures that the photovoltaic system operates close to its maximum power point under varying environmental conditions. The microcontroller also monitors battery parameters such as charging voltage and calculates battery performance indicators including State of Charge (SOC) and State of Health (SOH). These parameters are important for maintaining safe battery operation and preventing overcharging or deep discharge.

D. IoT-based Monitoring System

To enhance system intelligence and accessibility, an IoT-based monitoring system is integrated using the ESP8266 Wi-Fi module. The ESP8266 enables wireless communication between the solar MPPT system and the internet, allowing real-time monitoring of system performance. The PIC microcontroller transmits system data such as solar voltage, battery voltage, charging current, and battery status to the ESP8266 module through serial communication. The Wi-Fi module uploads this data to the ThingSpeak cloud platform, where it is stored and visualized in the form of graphs and charts.

Through the cloud platform, users can remotely access system information using a smartphone or computer. Real-time monitoring enables users to track system performance, analyze energy generation trends, and detect potential faults. The integration of IoT technology therefore transforms the conventional solar power system into an intelligent energy management platform capable of remote supervision and performance analysis.

III.SIMULATION AND RESULTS

In order to evaluate the performance of the proposed solar MPPT system using the ZETA converter, a detailed simulation study was carried out using MATLAB/Simulink. The simulation model represents the behavior of the photovoltaic source, the ZETA DC–DC converter, the MPPT control algorithm, and the battery load. The main objective of the simulation is to analyze the dynamic behavior of the converter, verify the effectiveness of the MPPT algorithm, and observe the charging characteristics of the battery under varying operating conditions. Simulation allows the performance of the proposed system to be analyzed before practical hardware implementation. Parameters such as voltage regulation, output current response, and power extraction efficiency can be evaluated to verify the capability of the system to operate efficiently under different solar conditions..

A. Simulation Model of the Sorting System

The complete MATLAB/Simulink model of the proposed photovoltaic charging system is shown in Fig. 3. The model consists of a solar PV source, ZETA converter, MPPT control block, and rechargeable battery load. The photovoltaic module generates a variable DC voltage depending on solar irradiance conditions. Since the PV output voltage fluctuates continuously, it is regulated using the ZETA converter. The switching element of the converter is controlled through a PWM signal generated by the MPPT controller.

The relationship between input and output voltage of the ZETA converter is given by: $V_o = \frac{D}{1-D} V_{in}$

Where V_o= Output voltage

V_{in} = Input voltage from PV panel

D = Duty cycle of PWM signal

By adjusting the duty cycle, the converter regulates the output voltage and ensures efficient battery charging.

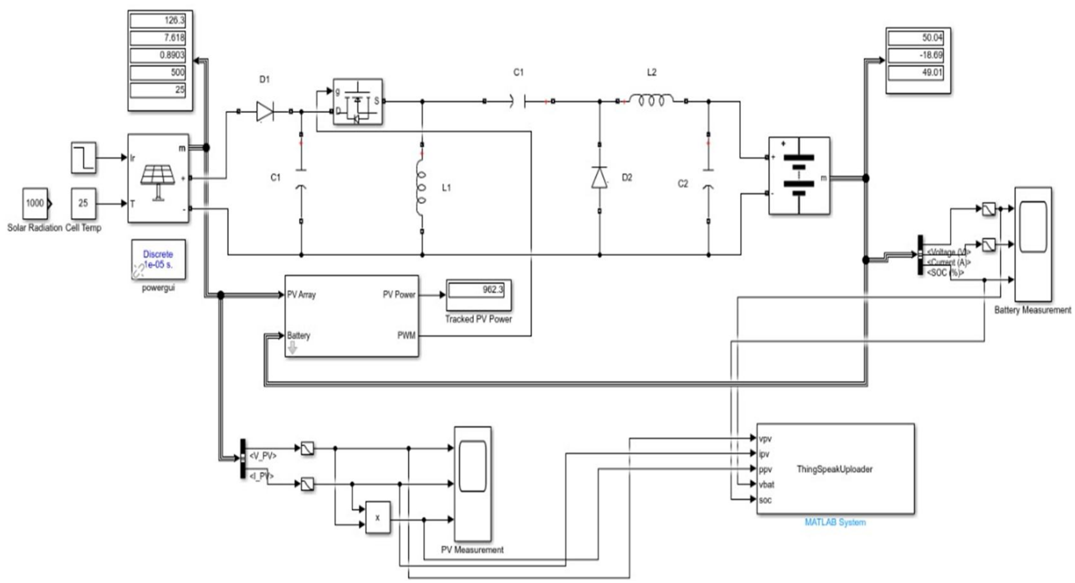


Fig. 3 Simulation Model of ZETA Converter with Battery

B. MPPT Control Performance

The MPPT controller ensures that the photovoltaic panel operates at its maximum power point under varying environmental conditions. The Perturb and Observe (P\&O) algorithm is implemented to track the optimal operating point of the PV system. The controller periodically perturbs the operating voltage of the PV panel and observes the change in output power. If the power increases, the perturbation continues in the same direction; otherwise, the perturbation direction is reversed. This iterative process allows the system to continuously track the maximum power point. The MPPT algorithm generates a PWM control signal that drives the MOSFET switch in the ZETA converter. As environmental conditions change, the duty cycle is adjusted automatically to maintain maximum power extraction from the solar panel.

C. Battery Charging Characteristics

The charging behavior of the battery was analyzed to evaluate the effectiveness of the proposed solar energy management system. Fig. 4 shows the variation of battery voltage, charging current, and state of charge during the charging process. Initially, the charging current is high when the battery voltage is low. As the battery becomes charged, the voltage gradually increases while the current decreases. This behavior is typical in controlled battery charging systems. The state of charge increases steadily as the battery receives energy from the solar panel through the ZETA converter, demonstrating efficient power transfer.

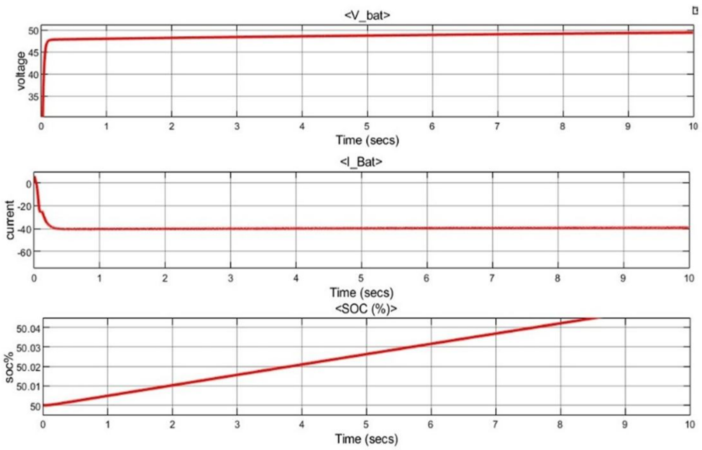


Fig. 4 Graph showing Battery Voltage, Current and State of Charge

D. PV Output Characteristics

The electrical characteristics of the photovoltaic panel were also analyzed during the simulation process. Fig. 5 shows the output voltage, current, and power generated by the PV panel when the MPPT controller is active.

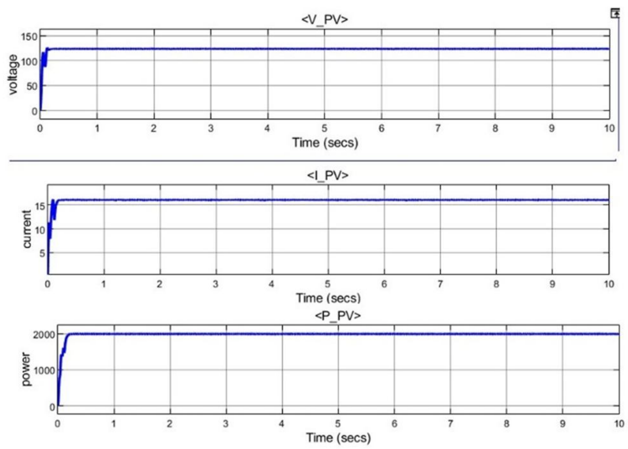


Fig. 5 Graph showing output voltage, current and power of pv panel

The results show that the MPPT controller maintains the PV output power close to its maximum value. When solar conditions vary, the duty cycle of the converter is adjusted dynamically to maintain efficient energy extraction.
Overall, the simulation results confirm that the ZETA converter combined with the MPPT controller effectively regulates the PV output voltage and ensures efficient battery charging.

IV. HARDWARE IMPLEMENTATION

A hardware prototype of the proposed solar MPPT system was developed in order to validate the practical feasibility of the system. The hardware implementation integrates a photovoltaic panel, ZETA DC–DC converter circuit, PIC microcontroller based MPPT controller, voltage sensing circuits, rechargeable battery, LCD display, and ESP8266 Wi-Fi module for IoT connectivity.
The hardware system performs real-time solar energy harvesting, voltage regulation, battery charging, and remote monitoring of system parameters.

A. Hardware Architecture

The overall hardware architecture of the proposed system is illustrated in Fig. 6. The photovoltaic panel converts solar energy into electrical power and supplies it to the ZETA converter.

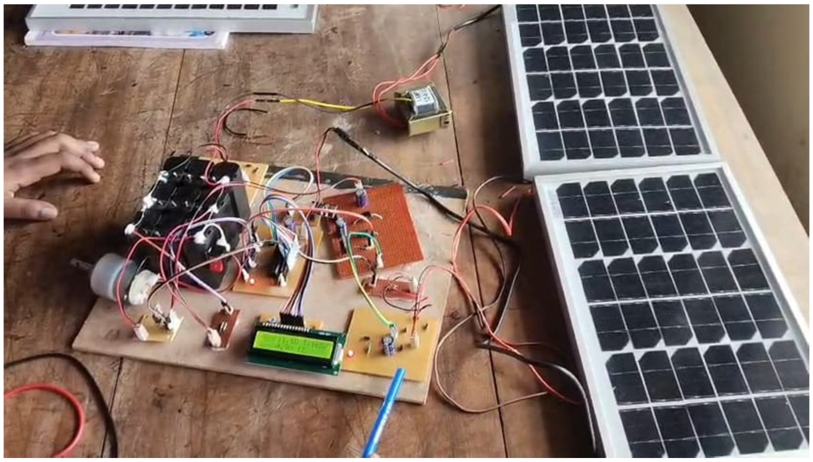


Fig. 6 Hardware Prototype of Solar MPPT System

The ZETA converter regulates the voltage level and provides a stable output suitable for charging the battery. The PIC microcontroller monitors system parameters and generates PWM control signals for the converter.

B. PIC Microcontroller Control Unit

The PIC16F72 microcontroller acts as the central controller of the system. It performs several important functions including voltage measurement, MPPT algorithm execution, PWM signal generation, and communication with peripheral devices.

The microcontroller reads the solar panel voltage through analog input channels using its internal analog-to-digital converter. Based on the measured voltage values, the MPPT algorithm determines the optimal duty cycle for the converter. The PWM module of the PIC microcontroller generates switching pulses that control the MOSFET switch in the ZETA converter.

C. Power Conversion Stage

The ZETA converter forms the power conversion stage of the system. It is responsible for regulating the fluctuating output voltage from the solar panel and providing a stable output voltage to charge the battery. The converter contains two inductors, two capacitors, a diode, and a MOSFET switch. The switching operation is controlled through PWM signals generated by the microcontroller. By adjusting the duty cycle of the PWM signal, the converter operates either in buck mode or boost mode depending on the input voltage level. The non-inverting nature of the ZETA converter ensures that the output voltage polarity remains the same as the input voltage, making it suitable for battery charging applications.

D. IoT Monitoring System

To enable remote monitoring of system parameters, an ESP8266 Wi-Fi module is integrated into the system. The ESP8266 establishes a wireless connection with the internet and allows system data to be transmitted to a cloud platform. Measured parameters such as solar voltage, battery voltage, and charging status are sent from the PIC microcontroller to the ESP8266 module. The Wi-Fi module uploads the data to the ThingSpeak cloud platform, where it can be visualized in the form of graphs and charts. This IoT integration allows users to monitor system performance remotely using a smartphone or computer. Real-time monitoring also helps in detecting faults and analyzing system performance under different environmental conditions.

V. CONCLUSIONS

A solar power based maximum power point tracking system using a ZETA converter provides an efficient solution for renewable energy based battery charging applications. The integration of the ZETA converter enables both step-up and step-down voltage conversion while maintaining a non-inverted output voltage suitable for stable battery charging. Implementation of the MPPT algorithm through a PIC microcontroller ensures that the photovoltaic system continuously operates at its maximum power point under varying environmental conditions. The incorporation of IoT technology using an ESP8266 Wi-Fi module enables real-time monitoring and visualization of system parameters through the ThingSpeak cloud platform.

Simulation and hardware implementation demonstrate that the proposed system improves energy extraction efficiency, enhances battery performance, and enables intelligent monitoring of renewable energy systems. The combination of photovoltaic energy conversion, efficient power regulation, and cloud-based supervision makes the system suitable for modern smart renewable energy applications and sustainable energy management systems.

REFERENCES

[1] H. Parthasarathy, L. Udayakumar, and G. Balasubramanian, "Modeling and Simulation of PV Module and Zeta Converter," Proc. Int. Conf. on Circuit, Power and Computing Technologies (ICCPCT), Nagercoil, India, pp. 1–6, 2016.

[2] E. Vuthchhay, C. Bunlaksananusorn, and H. Hirata, "Dynamic Modeling and Control of a Zeta Converter," Proc. Int. Symp. on Communications and Information Technologies (ISCIT), Vientiane, Laos, pp. 498–503, 2008.

[3] Y. M. Chen, A. Q. Huang, and Q. Yu, "A High Step-Up Three-Port DC–DC Converter for Stand-Alone PV/Battery Power Systems," IEEE Transactions on Power Electronics, vol. 28, no. 11, pp. 5049–5062, Nov. 2013.

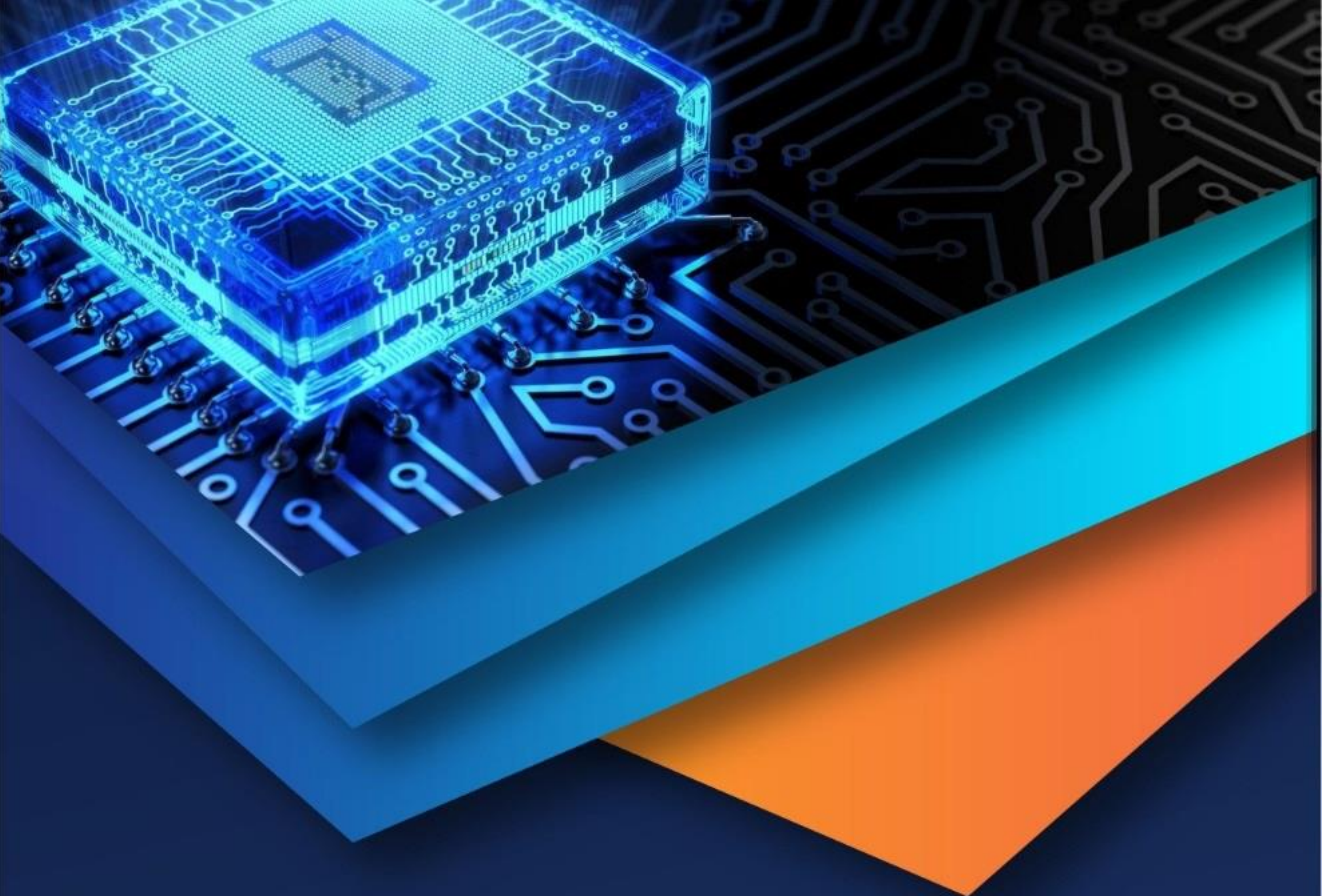
[4] A. M. S. S. Andrade, J. R. Dreher, and M. L. S. Martins, "High Step-Up Integrated DC–DC Converters: Methodology of Synthesis and Analysis," Proc. Brazilian Power Electronics Conference (COBEP), Gramado, Brazil, pp. 1–6, 2013.

[5] S. Kumar and P. Singh, "Photo-Voltaic (PV) Based Electric Vehicle (EV) Charging Using Zeta Converter," Proc. IEEE 9th Int. Conf. on Electrical Energy Systems (ICEES), pp. 1–5, 2023.

[6] R. Mehta, T. Das, and N. Bansal, "IoT-Based Smart Solar Energy Monitoring System for Electric Vehicle Charging," International Journal of Emerging Technology and Research, vol. 9, no. 3, pp. 112–118, 2022.

[7] A. Mishra and R. Gupta, "IoT-Enabled Solar Powered EV Charging Station with Remote Monitoring," International Journal of Smart Grid Applications, vol. 5, no. 4, pp. 45–52, 2023.

[8] M. Patel and A. Joshi, "Performance Analysis of Zeta Converter for Renewable Energy Applications," IEEE Transactions on Power Electronics, vol. 36, no. 7, pp. 1205–1212, 2021.



10.22214/IJRASET

45.98

IMPACT FACTOR:
7.129

IMPACT FACTOR:
7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY