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Design and Analysis of Bidirectional Battery Charger for Electric vehicle

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Abstract: Electric Vehicles (EVs) are experiencing rapid adoption across the United States and globally due to advancements in sustainable transportation technologies. However, large-scale EV charging imposes significant demand on electrical distribution systems, which can result in increased line losses and voltage drops within feeder networks. Additionally, uncontrolled charging may disrupt the normal functioning of household motor-driven appliances.

This research focuses on addressing these challenges by proposing an effective solution that minimizes the negative impact of EV charging while enhancing the utility of EV systems for end users. The study explores the implementation of a bidirectional charging mechanism using AC–DC–AC power conversion techniques, enabling both charging and discharging operations.

Such bidirectional capability allows EV batteries to act as auxiliary power sources, supporting external loads during situations such as outdoor activities or power outages. Furthermore, this functionality contributes to grid stability by enabling vehicles to supply stored energy back to the grid during peak demand or emergency conditions, thereby improving overall energy management and reliability.

Keywords: ATmega328P, Inverter, Relay

I. INTRODUCTION

A. Background

The accelerated adoption of electric vehicles (EVs) is significantly influencing both transportation and power system infrastructures. Traditional EV charging architectures predominantly operate in a unidirectional manner, where electrical energy is transferred solely from the utility grid to the vehicle battery. Although this method fulfills basic charging requirements, it does not fully utilize the energy storage capability of EV batteries within a broader energy ecosystem.

To overcome this limitation, bidirectional charging technology has emerged as a promising solution, enabling energy exchange in two directions: Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G). Through this approach, EVs can function not only as energy consumers but also as distributed storage resources, actively participating in grid operations and energy balancing.

The implementation of bidirectional charging systems relies on advanced power electronic converters, typically configured using AC–DC and DC–AC stages. These converters employ high-speed switching devices such as Insulated Gate Bipolar Transistors (IGBTs) or Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs) to achieve efficient and controlled power flow. Additionally, sophisticated control algorithms are incorporated to regulate charging and discharging processes while ensuring synchronization with grid parameters and maintaining power quality standards.

The Vehicle-to-Grid (V2G) paradigm plays a vital role in the development of smart grid frameworks. During periods of peak electricity demand, EVs can supply stored energy back to the grid, thereby alleviating network stress and enhancing system reliability. Conversely, during off-peak intervals, vehicles can be charged at lower demand and cost, promoting efficient load management. This bidirectional interaction also facilitates better integration of renewable energy sources, such as solar and wind, by storing surplus generation for later use.

Beyond V2G functionality, bidirectional charging supports additional applications, including Vehicle-to-Home (V2H) and Vehicle-to-Load (V2L). These modes enable EVs to deliver backup power to residential systems or external loads during grid outages or emergency situations, thereby improving energy security and resilience.

Despite its numerous benefits, bidirectional charging technology presents several challenges, including concerns related to battery lifespan, increased system cost, complexity in control design, and the requirement for supportive regulatory frameworks and infrastructure. Nevertheless, continuous research and technological progress are addressing these limitations, positioning bidirectional EV charging as a critical element in future sustainable and intelligent energy systems.

The following block diagram showing the all components we have used in this system

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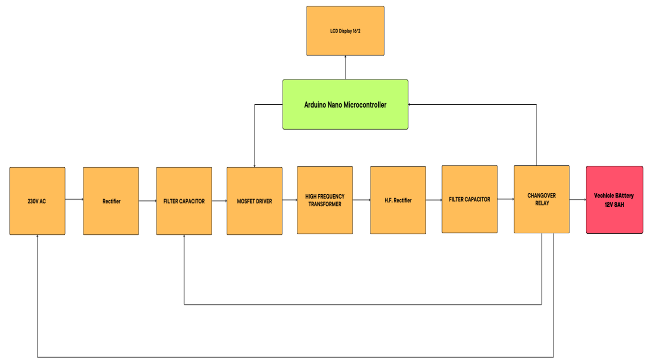


Fig. Block diagram of the system

B. Necessity

The importance of bidirectional electric vehicle (EV) chargers is primarily driven by their capability to support advanced functionalities within modern smart grid systems. With the growing integration of renewable energy sources such as solar and wind, power generation has become increasingly intermittent and less predictable. In this context, bidirectional chargers enable EV batteries to operate as decentralized energy storage units, helping to balance supply–demand variations through demand response mechanisms.

During periods of high electricity demand, these systems allow stored energy in EV batteries to be delivered back to the grid, thereby reducing the load burden on existing power infrastructure and improving overall grid stability. This functionality is especially critical in urban areas and developing regions where maintaining reliable power supply remains a significant challenge.

Beyond technical benefits, bidirectional charging also offers notable economic advantages for both utility providers and EV users. Vehicle owners can engage in energy exchange programs by supplying stored power to the grid during peak demand intervals. This approach not only helps in lowering individual electricity expenses but also creates opportunities for additional income, thereby enhancing the economic feasibility of EV adoption.

Moreover, bidirectional charging systems contribute to improved energy reliability through Vehicle-to-Home (V2H) applications, where EVs can function as backup power sources during grid outages. Such capability is particularly valuable in areas that experience frequent power disruptions.

From an environmental standpoint, bidirectional charging supports efficient utilization of renewable energy resources. By storing surplus energy generated during periods of high renewable output and redistributing it when required, these systems help decrease dependence on conventional fossil fuel-based generation. Consequently, they play a significant role in reducing greenhouse gas emissions and advancing sustainable energy objectives.

C. Objectives

1) To develop a bidirectional charging system capable of facilitating two-way power flow, enabling both charging and discharging operations between the electric vehicle and the grid.
2) To implement Vehicle-to-Grid (V2G) functionality, allowing energy stored in the EV battery to be supplied back to the utility grid when required.
3) To enhance grid support and enable effective demand response by utilizing EVs as distributed energy resources.
4) To promote the integration of renewable energy sources by storing excess generation and supplying it during periods of demand.
5) To provide emergency backup power through Vehicle-to-Home (V2H) and Vehicle-to-Load (V2L) applications.
6) To improve overall energy management and maintain power quality within the electrical system.

II. LITERATURE SURVEY

1. Kang Miao Tan, Vigna K. Ramachandaramurthy and Jia Ying Yong Power Quality Research Group, Department of Electrical Power Engineering Universiti Tenaga Nasional Kajang, Malaysia,. “Bidirectional Battery Charger for Electric Vehicle”:

The increasing adoption of electric vehicles has accelerated the development of Vehicle-to-Grid (V2G) technology, which facilitates bidirectional power exchange between EV batteries and the utility grid. This capability supports various grid services such as peak load reduction, load balancing, voltage regulation, and enhanced system stability.

In this work, a bidirectional battery charger with an advanced control strategy is proposed. The controller is designed to operate under multiple modes, including fast and slow charging as well as discharging conditions. The effectiveness of the proposed system is validated through simulation using PSCAD/EMTDC software. Results demonstrate that the control strategy maintains stable and efficient performance across all operating modes, confirming its suitability for practical V2G applications.

2. Travon Dent Report for CPP McNair Research Program, Summer 2016 “Developing Bi-directional Charging Functions for Electric Vehicles”:

The rapid growth in electric vehicle usage has introduced significant challenges to power distribution systems, particularly due to increased load demand during charging. This can lead to higher line losses, voltage drops, and interference with residential electrical equipment.

To address these issues, the study proposes a bidirectional charging system based on AC–DC–AC converter topology. The system enables both charging and discharging operations, thereby enhancing the functionality of EVs. In addition to reducing the negative impact on the grid, the approach allows EV batteries to be utilized as auxiliary power sources for external loads. Furthermore, during emergency or peak demand conditions, stored energy can be supplied back to the grid, improving overall system reliability and efficiency.

3. N. Sujitha, S. Krithiga , School of Electrical Engineering, Vellore Institute of Technology, Chennai Campus, Chennai, Tamil Nadu, India “Grid tied PV- Electric Vehicle Battery Charger using Bidirectional Converter.”

Recent advancements in renewable energy integration have led to the development of hybrid EV charging systems that combine photovoltaic (PV) sources with grid connectivity. Due to the intermittent nature of solar energy, grid-assisted charging becomes essential for maintaining continuous operation.

This study presents a grid-connected PV-based EV charging system incorporating a bidirectional converter. A SEPIC converter is utilized for DC–DC conversion, while a bidirectional AC–DC converter enables energy exchange with the grid. During periods of sufficient solar irradiation, the PV array supplies power for charging the EV battery, and any excess energy is delivered to the utility grid. Conversely, during low or no solar conditions, the grid supports the charging process through the bidirectional converter.The system is modeled and analyzed using MATLAB/Simulink, and simulation results confirm its effective dynamic performance and reliability under varying operating conditions.

III. METHODOLOGY

A. Basic Idea

Electric vehicles (EVs) have emerged as a competitive alternative to conventional internal combustion engine vehicles due to their lower carbon emissions and the rising cost of fossil fuels. Despite these advantages, large-scale adoption of EVs is still constrained by several factors, including high initial cost, inadequate charging infrastructure, and limited driving range on a single charge.

Furthermore, the increasing integration of EVs into the power system introduces additional challenges for the electrical grid. A high penetration of EV charging can significantly increase load demand, leading to stress on existing grid infrastructure. However, instead of considering EVs solely as electrical loads, their batteries can be effectively utilized as distributed energy storage systems. This concept has led to the development of Vehicle-to-Grid (V2G) technology.

The V2G framework enables bidirectional interaction between electric vehicles and the utility grid, allowing not only battery charging but also controlled energy transfer from the vehicle back to the grid based on predefined schedules and power requirements. This interaction provides multiple advantages. From the utility perspective, it contributes to load balancing, peak demand reduction, voltage and frequency regulation, enhanced system stability, and mitigation of power quality issues such as harmonics. From the consumer’s standpoint, V2G technology offers economic benefits by enabling EV owners to supply stored energy to the grid and generate additional revenue. However, most commercially available EV chargers are currently designed for unidirectional operation, supporting only charging functions under either slow or fast modes.

To realize the full potential of V2G systems, specialized bidirectional chargers are required to enable controlled two-way power flow between the grid and the EV battery. In this work, a bidirectional EV battery charger incorporating an advanced control strategy is proposed. The system is designed to operate in four distinct modes: fast charging, slow charging, fast discharging, and slow discharging, ensuring flexibility and efficient energy management under varying conditions.

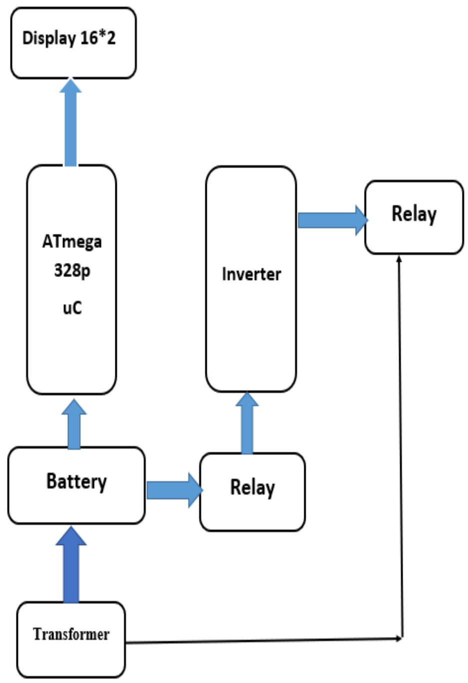


Fig. Block diagram of the system

B. *Working of the System*

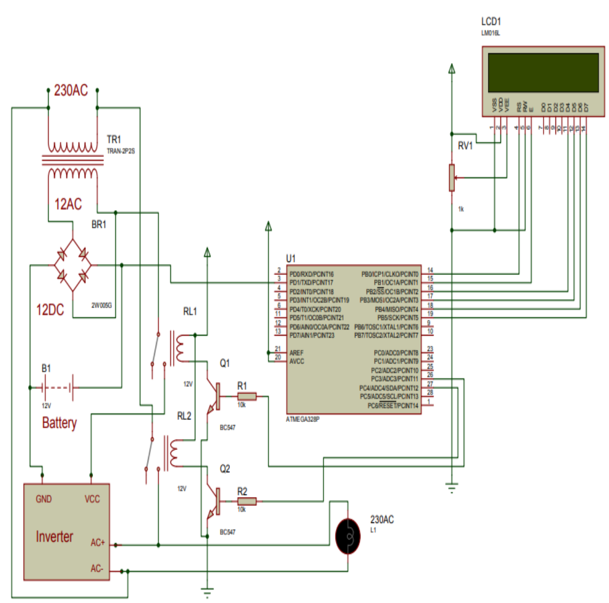


Fig. Bi-Directional EV Charger

In charging mode, the primary objective is to convert single-phase AC supply from the grid into DC power suitable for battery charging. To meet grid standards and ensure power quality, the system requires a mains filter along with an active rectification stage. Additionally, a DC–DC converter is employed to regulate and match the rectified output voltage according to battery requirements.

In AC charging configurations, the charger is typically integrated within the vehicle (on-board), whereas in DC charging systems, the charging unit is located externally within the charging station. Both configurations are widely used; however, they introduce additional cost either for vehicle manufacturers or utility providers. To address this, an optimized approach involves utilizing existing onboard components for charging functions.

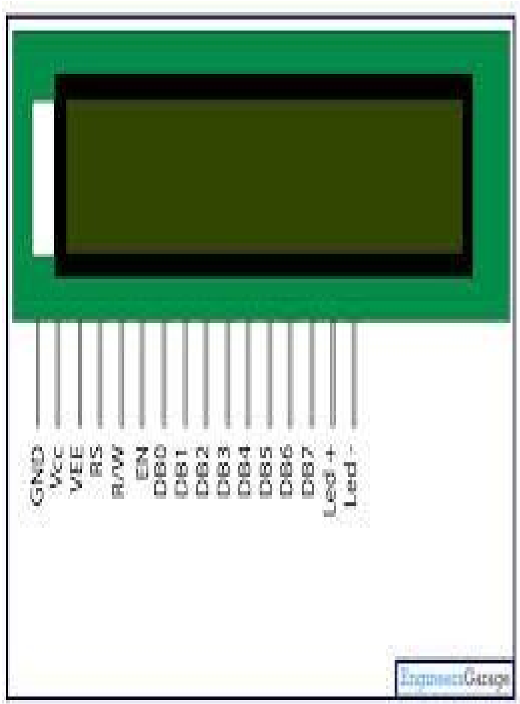
In the proposed system, key charging functionalities are achieved by reusing components already present in the vehicle. The electric machine (E-machine) stator operates as an input filter, the inverter functions as a rectifier for single-phase or three-phase AC supply, and the DC–DC boost converter regulates the DC-link voltage to match the battery voltage. This integrated configuration reduces overall system cost while maintaining performance efficiency. Furthermore, with appropriate filtering, the system can support high-power AC charging, potentially up to the rated traction power of the vehicle. The system operation can be broadly divided into driving and charging modes. During traction (driving mode), energy is supplied from the battery through the battery link. The DC–DC converter adjusts the voltage to the DC-link level, which typically ranges up to 800 V. The inverter then converts this DC power into AC to drive the electric machine. In regenerative braking mode, the direction of power flow is reversed, allowing energy to be recovered and stored back in the battery. The battery voltage varies significantly depending on its state of charge (SOC), typically ranging between approximately 270 V and 450 V. This wide variation is effectively managed by the DC–DC converter, eliminating the need for additional voltage margins in the inverter design.

AC charging operation is further categorized into single-phase and multi-phase modes. Single-phase charging utilizes standard household supply (e.g., 230 V or 110 V), but the charging power is limited to a few kilowatts based on regulatory constraints. In this mode, AC power from the grid is passed through the electric machine windings, which provide inductive filtering. The inverter performs AC-to-DC conversion, and the DC–DC converter adjusts the voltage to safely charge the battery.

In DC fast charging mode, the charging station supplies DC power directly to the vehicle's DC-link. The DC–DC converter then regulates this voltage to suit the battery. This approach offers significant advantages, including compatibility with different charging station voltage levels (such as 400 V and 800 V) without requiring modifications. Moreover, it enables faster charging since higher voltage levels reduce current requirements, thereby minimizing losses and improving efficiency.

C. Related Components

1) Liquid Crystal Display (LCD): It is one kind of electronic display module used in an extensive range of applications like various circuits & devices like mobile phones, calculators, computers, TV sets, etc. These displays are mainly preferred for multi-segment light-emitting diodes and seven segments. The main benefits of using this module are inexpensive; simply programmable, animations, and there are no limitations for displaying custom characters, special and even animations, etc.



2) MICROCONTROLLER: Various functions of the microcontroller are as follows:
. To read the data from ADC which is the data received from the LDR sensor.
. To turn on LED light if the signal is sense by the sensor.
. To turn Off LED light if the object does not sense by the sensor.

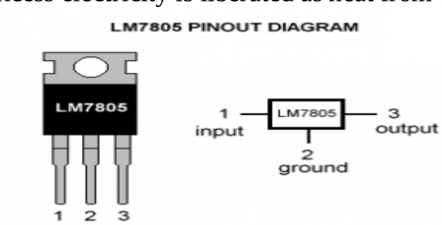
3) Inverter: The basic role of an inverter is to change DC power into AC power. The AC power can be supplied to homes, and industries using the public utility otherwise power grid, the alternating-power systems of the batteries can store only DC power. In addition, almost all the household appliances, as well as other electrical equipment can be functioned by depending on AC power.

4) Battery: A battery is a device that converts chemical energy contained within its active materials directly into electric energy by means of an electrochemical oxidation-reduction (redox) reaction. Batteries are the most common electrical energy storage devices in electrical vehicles. The performance of a battery when it is connected to a load or a source is based on the chemical reactions inside the battery. The chemical degrade with time and usage that reflect the gradual reduction in the energy storage capacity of the battery. The battery depreciation process needs to be reduced by conditioning the battery in a suitable manner by controlling it's charging and discharging profile, even various load conditions.

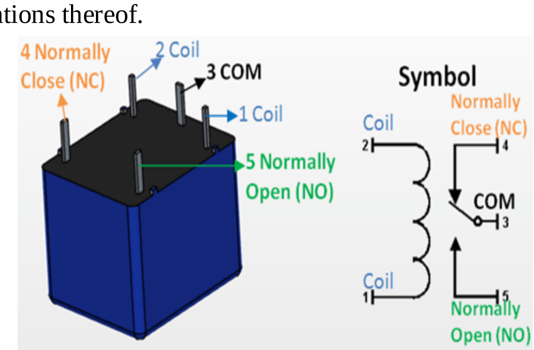
5) LM 7805Voltage Regulator

Voltage regulators ICs are the ICs that are used to regulate the voltage. IC 7805 is 5V Voltage regulators that restrict the voltage output to 5 volt and draws 5V regulated power supply. It comes with provision to add heat sink.

The maximum value for the input to the voltage regulator is 35V. It can provide a constant steady voltage flow of 5V for higher voltage input till the threshold limit of 35V. If the voltage is near to 7.5V then it does not produced any heat and hence no need for heat sink. If the voltage input is more, then excess electricity is liberated as heat from 7805.



6) Relay: A relay is an electrically operated switch. It consists of a set of input terminals for a single or multiple control signals, and a set of operating contact terminals. The switch may have any number of contacts in multiple contact forms, such as make contacts, break contacts, or combinations thereof.



D. System Components Specification

Components	Rating
Microcontroller	ATmega328
Input voltage	5V
Input voltage (recommended)	7-12V
Digital I/O pin	14(Of which 6 provide PWM output)
Analog Input pin	6
DC Current per I/O pin	40mA
DC Current for 3.3V pin	50mA
Flash Memory	32Kb of which 0.5Kb used by boot loader
EEPROM	1Kb
Clock Speed	16MHz

IV. CONCLUSION

The proposed system demonstrates a flexible and reliable approach for uninterrupted charging of electric vehicle (EV) batteries using a constant voltage charging method, irrespective of variations in solar irradiation. The integration of a bidirectional converter enables efficient energy management by allowing the EV battery to be charged using solar power during high irradiation conditions, while also supporting power injection into the grid during peak generation periods.

Furthermore, during low or no solar availability, the system ensures continuous battery charging by drawing power from the utility grid. This dual-mode operation enhances system reliability, optimizes energy utilization, and supports grid stability. The proposed work offers significant scope for future enhancement. Further improvements can focus on increasing system efficiency through the optimization of passive components to accommodate a wider range of EV battery voltages. Additionally, the development of a user-friendly control interface is envisioned, which would enable real-time monitoring, control, and management of power flow operations. Such advancements would contribute to the practical implementation and scalability of bidirectional EV charging systems.

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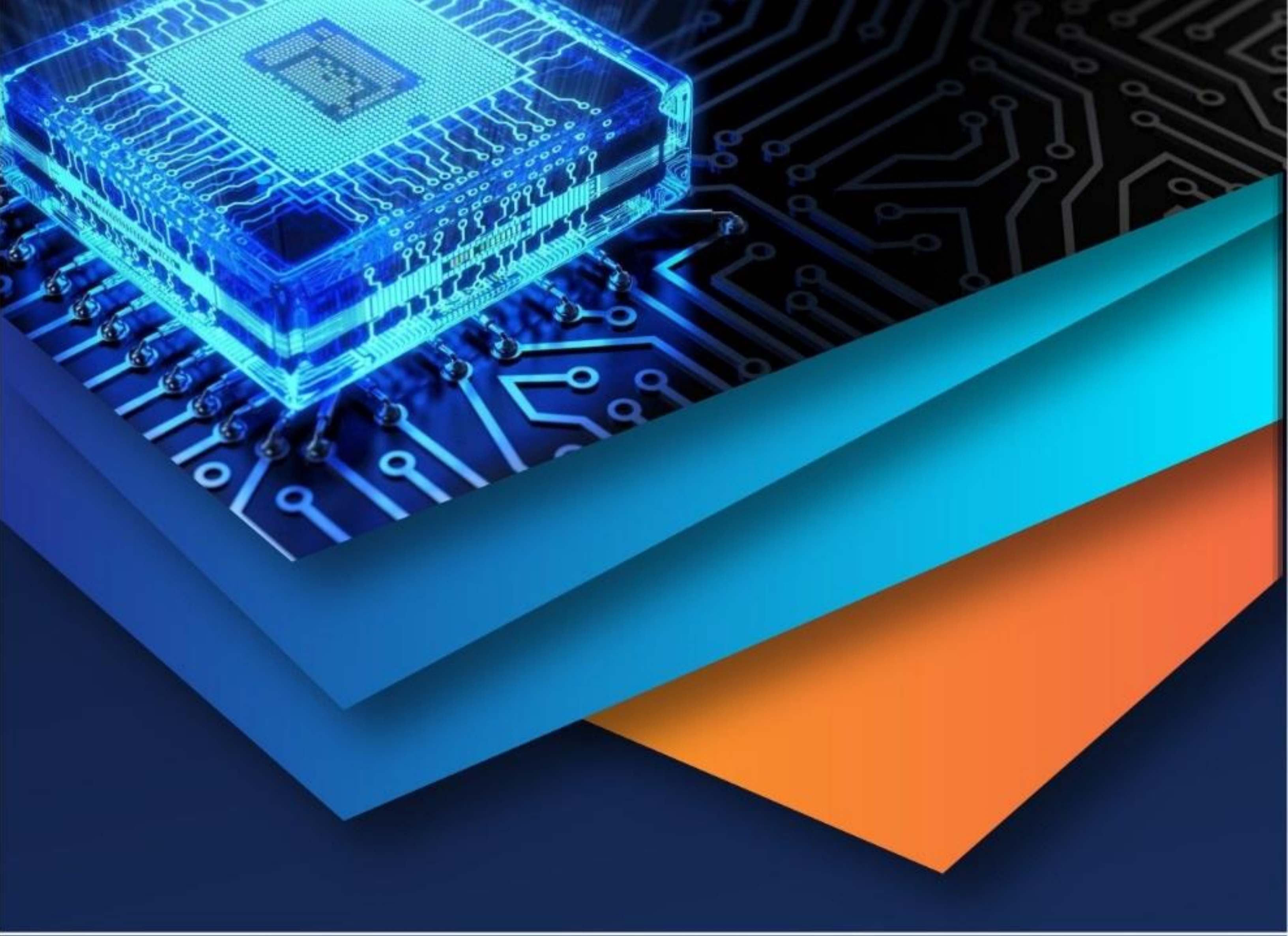

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