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IoT Connected Smart Energy Meter

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Abstract: Dawn of household electricity has revolutionized the world making life much easier and improving standard of living but still 940 million (13% of the world) do not have access to electricity. It is therefore the responsibility of those with stable power supply to keep their use of electricity in check as the less power we waste the more there will be for the ones who need it. Our goal is to design and implement a system to accurately measure the power consumption of a household in kWh using PZEM-004T module and, using IoT principles, wirelessly transmit the data to the ThingSpeak cloud server where it could be visually displayed This could help individual real time energy consumption data so they can take action accordingly. We also aim to collect data from multiple households and use data analysis techniques to find out valuable information and make accurate predictions regarding the future power consumption and consequential actions to be taken.
Index Terms: Energy meter, PZEM-004T, Internet of Things, ThingSpeak, Arduino.

I. INTRODUCTION

The issue of electricity wastage is a pressing global concern, as there are still significant populations without access to electricity, and the predominant reliance on depleting fossil fuels for power generation exacerbates environmental challenges. To combat these issues effectively, there is an imperative need for solutions that optimize energy consumption and enable data-driven decisions. This research work focuses on addressing these concerns by introducing the concept of smart energy meters, which have become an integral part of the rapidly evolving smart grid infrastructure.

Traditional offline energy meters have relied on manual readings, a process that is inconvenient and often leads to delays in data collection. Smart energy meters, on the other hand, offer real-time monitoring, data analytics capabilities, and the potential for two-way communication between utilities and consumers. These meters capture, store, and transmit detailed energy consumption data, enabling a comprehensive understanding of energy usage patterns at both the household and appliance levels.

The significance of real-time monitoring cannot be overstated. Traditional energy meters lack the ability to provide instantaneous insights into energy usage, whereas smart energy meters, as explored in this research, offer continuous and automated monitoring. This capability empowers households and utility providers to respond promptly to fluctuations in energy demand, identify inefficiencies, and potentially reduce peak load demands. Precision in energy consumption measurement is another fundamental attribute of smart energy meters. Conventional meters may lack the accuracy required for capturing subtle variations in energy usage, which can be critical for detecting abnormalities or inefficiencies. Smart energy meters employ advanced measurement technologies and sensors, ensuring high accuracy and reliability in energy consumption data. This precision is crucial for determining whether electric devices conform to modern energy efficiency standards or if they are consuming more power than expected. The heart of this research project is an IoT-based energy meter that combines the PZEM-004T energy meter and the NodeMCU Wi-Fi module. The PZEM-004T offers accurate measurement of voltage, current, power, and energy consumption, while the NodeMCU provides the means to collect, process, and transmit this data to a centralized platform for analysis. By leveraging IoT technology, this smart energy meter ensures data accessibility and real-time insights into electricity consumption.

In the subsequent sections of this paper, we will delve into the technical intricacies of the smart energy meter's design and implementation. This will encompass detailed discussions on the hardware components, data communication protocols, and data analysis techniques employed. Demonstrating how such a system aids in energy conservation and contributes to a more sustainable and efficient electricity grid, we will highlight the significance of integrating real-time data and IoT technology in optimizing energy usage, reducing wastage, and enhancing the quality of life for people worldwide.

II. RELATED WORK

A brief literature survey by summarizing the key findings of five research papers related to smart energy meters.

1) Dr. John Smith's paper, published in 2020, explores the latest advancements in smart energy metering technologies. It emphasizes improved accuracy and data granularity, which enable real-time data collection and more efficient grid management.
   However, Dr. Smith also highlights disadvantages, such as concerns about data security and privacy, as well as the costs associated with deploying smart meters. Applications of these technologies are explored in demand response, load forecasting, and enhanced billing accuracy.
2) The paper delves into consumer perspectives regarding smart energy meters in her 2019 paper. Advantages identified include their potential to encourage energy conservation and empower users with actionable data. Disadvantages primarily revolve around privacy concerns, data ownership issues, and potential health effects of radio frequency emissions. The paper also discusses applications in home energy management, personalized recommendations, and demand-side management, considering the consumer viewpoint.
3) Dr. David Williams' research, published in 2021, focuses on the integration of renewable energy sources into the grid using smart meters. The advantages highlighted center on real-time monitoring of distributed generation, which is essential for the efficient incorporation of renewables. However, the paper does not shy away from discussing potential disadvantages, such as cybersecurity vulnerabilities and the need for robust security measures. The applications explored encompass micro-grid control, net metering, and grid stability with intermittent renewables.
4) The next paper offers a comprehensive cost-benefit analysis of deploying smart meters, published in 2018. The advantages showcased include potential savings for utilities and consumers through more efficient operations and reduced energy wastage. On the flip side, the paper acknowledges substantial upfront costs and potential consumer backlash due to privacy concerns. Applications of smart meters in optimizing grid infrastructure, reducing distribution losses, and enhancing electricity reliability are underscored, demonstrating their tangible benefits.
5) Dr. Michael Brown's research, published in 2022, investigates the use of IoT-enabled smart meters in industrial contexts. The advantages lie in their role in real-time monitoring and control of energy consumption, ultimately contributing to energy efficiency. The paper recognizes the complexity of integrating these meters into existing industrial systems and emphasizes the need for specialized expertise, constituting potential disadvantages. Applications are explored in the realm of industrial automation, predictive maintenance, and optimizing energy use in manufacturing processes, showcasing their potential to enhance industrial efficiency.

III. OBJECTIVES

The objective of this paper is to utilize Internet of Things technology to create a Smart Energy Meter that can monitor household usage and communicate the consumption data to a cloud storage platform. This leads to an innovative solution for monitoring energy usage that can provide further insight into electricity consumption.

IV. METHODOLOGY

A. AC Power

The polarity of AC voltage and current is constantly changing, alternating between positive and negative. The AC power wave available at mains is a sine wave with a frequency of 50 Hz.

1) Power

Electric power is the rate at which electric energy is required to do work in an electrical circuit. It is measured in Watts or Horsepower.

Apparent power (VA)

$$S = V \times I$$

Active Power (W)

$$P = V \times I \times \cos \varphi$$

Reactive Power (VAR)

$$Q = V \times I \times \sin \varphi$$

The angle **φ** being the power factor.

B. Power Factor

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Power factor is the measure of how efficiently the load is using the power. A power factor of 0 means that none of the power is being used actively, while a power factor 1 means all the power is being used actively.

Power Factor = Active power (P) / Apparent Power(S)

C. Components

1) *PZEM-004Tv3.0:* PZEM-004T is an AC multifunctional Electric Energy Metering Power Monitor module which we will be using to measure the parameters.

- Working voltage: 80 – 260V AC
- Test Voltage: 80 – 260V AC
- Rated Power: 100A/ 22000W
- Operating frequency: 45 – 65Hz
- Measurement accuracy: 1.0

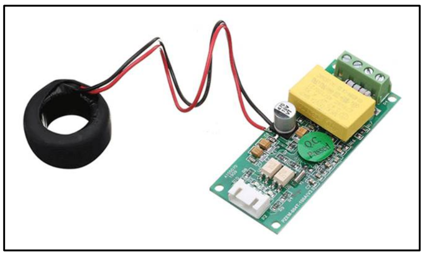

Fig1. PZEM004Tv3.0

2) *NodeMCU ESP8266:* NodeMCU is a microcontroller with an on-board Wi-Fi module that provides an easy and reliable way to connect any system to the internet to seamlessly transfer the gathered data in real time.

- Based on ESP8266, 32 – bit microcontroller with clock speed 80MHz
- Integrated Wi-Fi
- Supports 802.11 b/g/n protocols
- Max data rate – 150Mbps

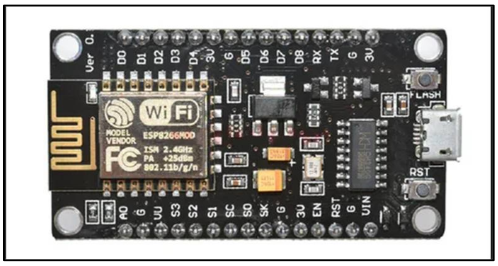

Fig2. NodeMCU ESP8266

D. Method

1) *Hardware Setup:*

- Connect the PZEM-004T energy meter module to the NodeMCU board as per the pin configuration.
- Ensure proper power supply to both the NodeMCU and the PZEM-004T module.
- Load to be connected between the PZEM module and mains.

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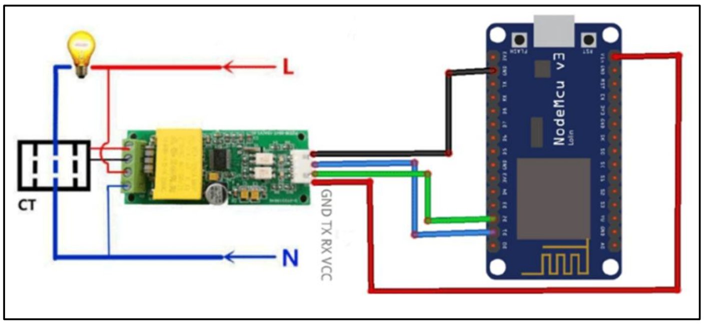


Fig3. Circuit Connections of PZEM004tv3.0 with NodeMCU

Any load/ appliance can be connected to the device to measure its characteristics.

2) Software Setup:

- Arduino IDE is used for programming the device, and testing the values.
- NodeMCU is programmed with the logic for implementing the device features, fetching current, voltage, power factor, and power.
- Along with the Wi-Fi credentials and ThingSpeak Write API key, this enables the device to post the recorded values on the ThingSpeak cloud.

3) Software Design Flowchart:

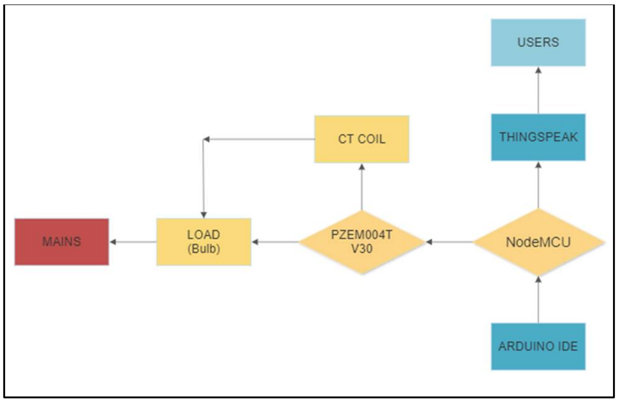


Fig4. Flowchart depicting Smart Energy Meter logic

4) Program for plotting energy consumption values:

- A python program was developed to monitor energy consumption over time.
- The program connects to ThingSpeak, a cloud-based data analytics platform, and retrieves data on power and current.
- The program then plots the energy consumption over time. This information can be used to track energy usage and identify areas where energy savings can be made.
- The plot is attached in Results and Discussions Energy field.

5) Running a simulation circuit in Falstad:

For better understanding of characteristics of circuit before hardware implementation of PZEM004Tv3.0, we simulate the 6W and 0.5W lamp circuit in Falstad.

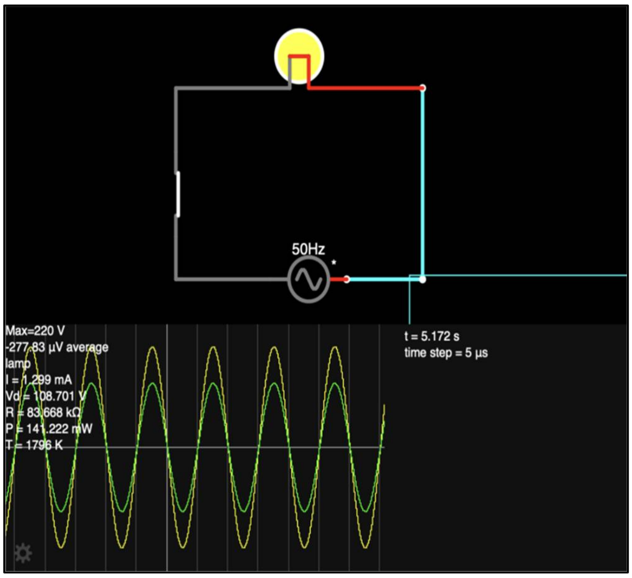


Fig5. Voltage & Current characteristics of a 0.5W Lamp simulation circuit

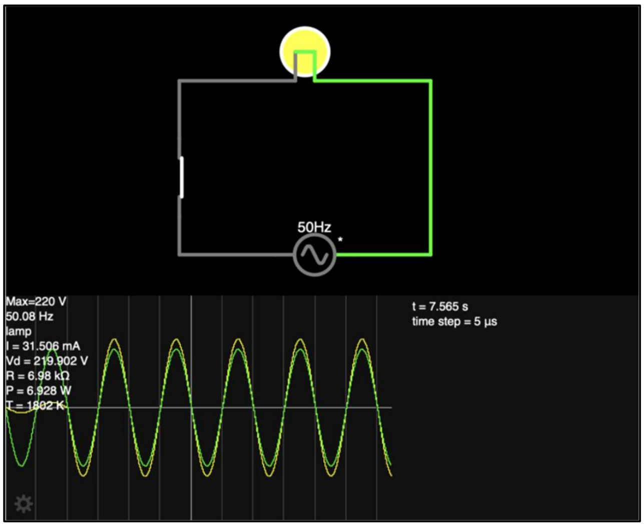


Fig6. Voltage & Current characteristics of a 6W Lamp simulation circuit

Similarly, power consumption of the lamp can also be simulated and plotted, providing visualization of the power requirement.

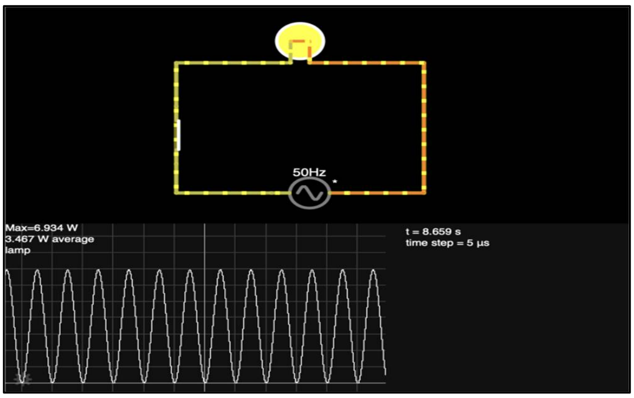


Fig7. Power consumption graph of 6W Lamp

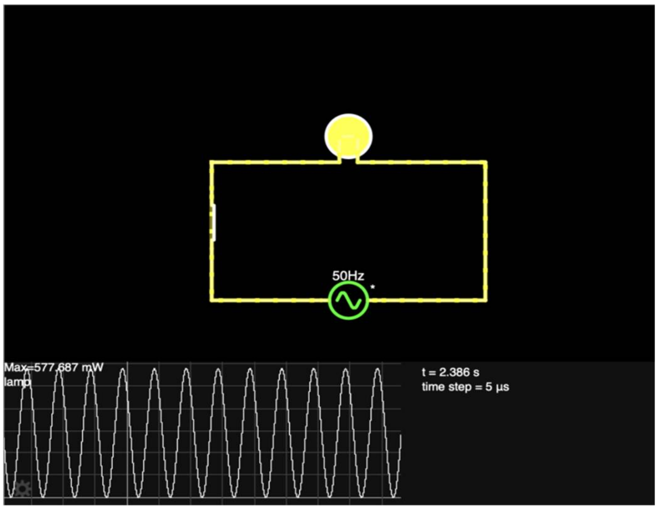


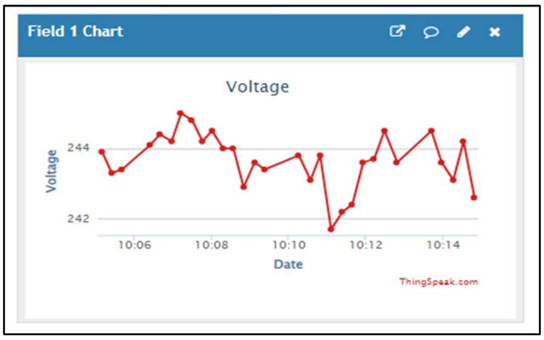
Fig8. Power Consumption graph of 0.5W Lamp

Simulation circuits aid in visualization of the characteristics of the load that will be tested with the data collected from the PZEM004Tv3.0. This data can be then compared to find accuracy of our complete Smart Energy Meter.

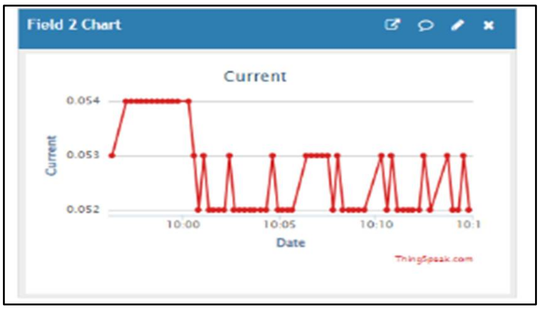
V. RESULTS AND DISCUSSIONS

After assembly and configuration, the energy meter provides data in four data fields:
The Smart Energy meter device was tested with two bulbs of wattage 0.5W and 6W respectively. This was done to test whether the readings returned by the device are accurate across different loads.
In the following field graphs, we can see that obvious difference between the characteristics of the 0.5W bulb and 6W bulb.

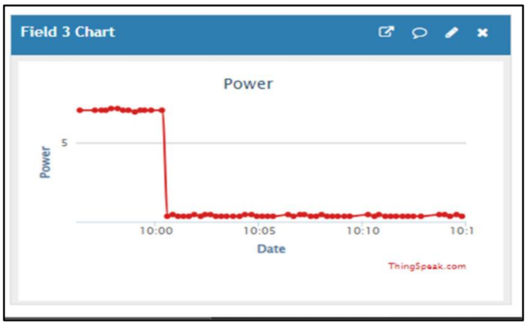
1) Voltage



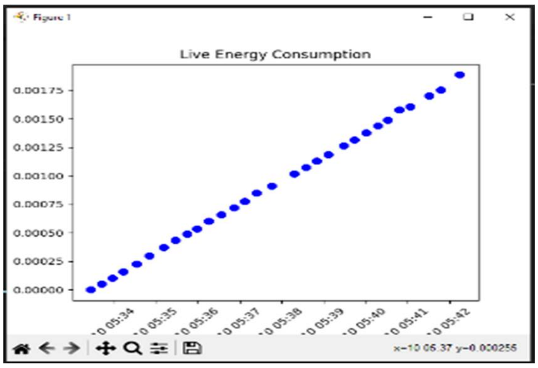
2) Current



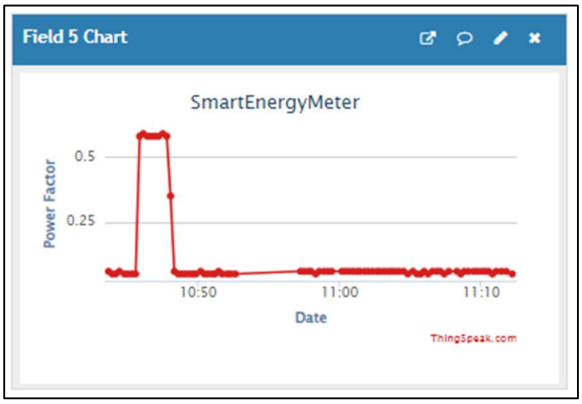
3) Power



4) Energy



5) Power Factor



6) Power Factor Observations:

CHARACTERISTICS	LOAD	
	0.5 W BULB*	6 W BULB*
Voltage	~240 V	~240 V
Power	~0.7 W	~6.8 W
Power Factor	~0.06	~0.58

Fig. Table comparing power factor of both test loads (0.5W and 6W)

This test helps us determine appliances with higher power factor, and utilize power given more effectively.

VI. FUTURE SCOPE

For added functionality to the IoT Connected Smart Energy meter, it could be used to monitor other aspects of energy consumption, such as cost of energy or emissions associated with usage.

The device can be made more accurate, Hall Effect sensors could be used to measure the current.

VII. DISCUSSION

In this paper we have designed and constructed a Smart Energy Meter which can monitor characteristics of any household appliance and store them on a cloud platform (ThingSpeak). The cloud storage platform enables visualization of data, enabling observation of appliance behavior keeping watch for any anomalies.

Users can also map their appliance usage thereby helping them in planning an efficient way of using them.

To ensure accuracy and to validate the data acquired from the Smart Energy Meter, simulation models of the load circuits were run on Falstad. This ensures that the Smart Energy Meter is a reliable and practical device.

VIII. CONCLUSION

The IoT smart energy meter mode using PZEM-004T and NodeMCU ESP8266 Wi-Fi module gives accurate energy consumption data along with other parameters like the voltage, current and power. It thus provides us with useful data that if gathered on a large scale could be used to make insightful predictions.

The more convenient data monitoring system with ThingSpeak and data being transferred using Wi-Fi over the internet makes it easier and more intuitive to keep track of individual power consumption.

If proper energy monitoring and management is implemented on a large scale, we can all pave a path to an energy abundant future where everyone has access to clean and sufficient electricity.

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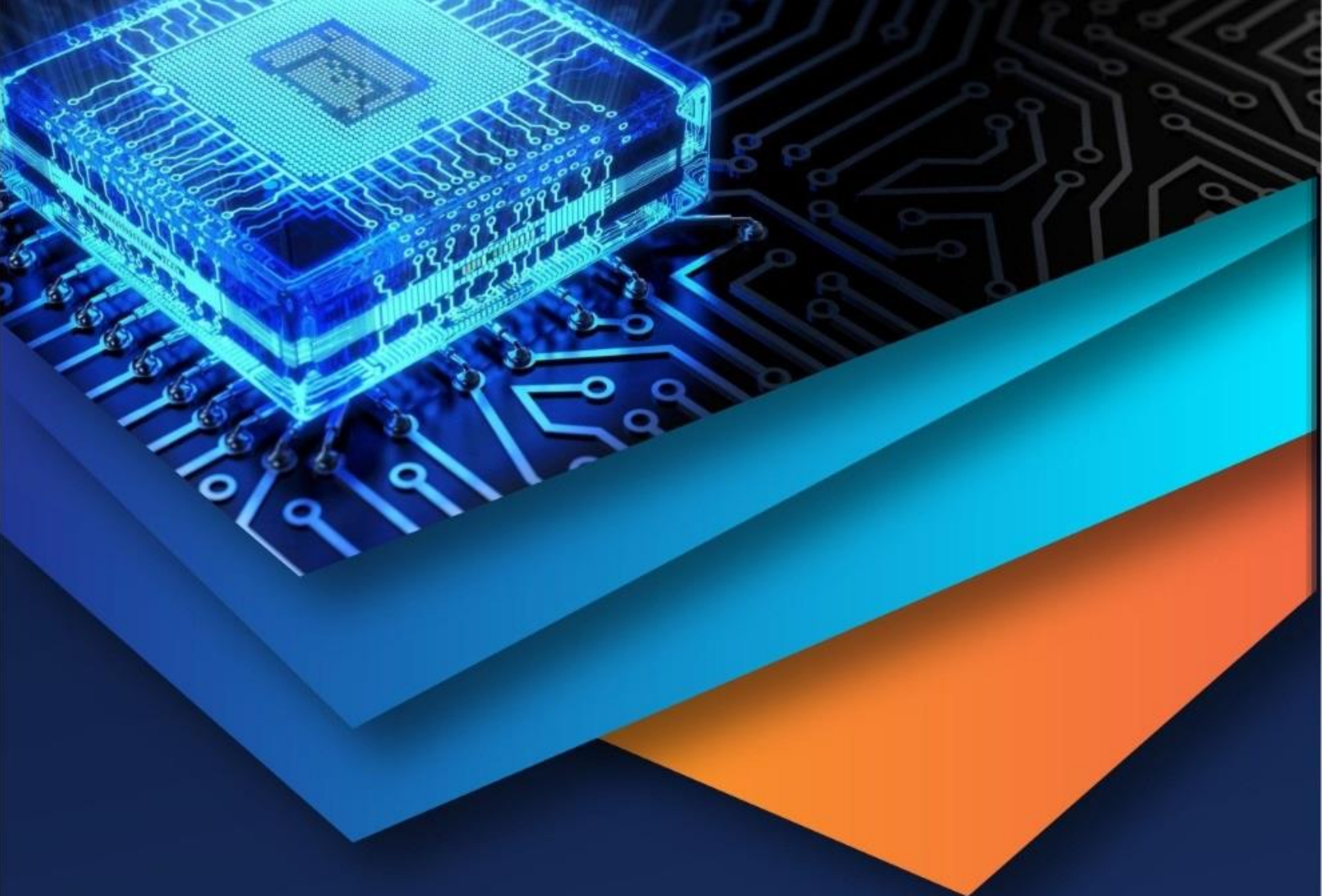

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