iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 11 Issue: X Month of publication: October 2023

DOI: https://doi.org/10.22214/ijraset.2023.56381

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue X Oct 2023- Available at www.ijraset.com

Design of an Economical Intelligent Frequency Meter

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Abstract: Vigilantly monitoring the energy consumption of electrical appliances is a crucial aspect of effectively controlling energy usage and expenditures, hence optimizing financial and temporal resources. The utilization of electrical devices can result in various modifications to the characteristics of an electrical power source. Various aspects of an electrical power source undergo modifications when employed for the purpose of powering devices. There have been alterations in the items that necessitate documentation beside the cumulative measurement of meters. This paper discusses the design and implementation of an Arduino-based frequency meter specifically tailored for the measurement of frequency in a three-phase synchronous generator. Additionally, this method was employed to identify instances of malfunction in a three-phase alternating current generator, encompassing both low and high frequencies. The frequency meter that was suggested displayed the measured parameters and the protection condition of each data point directly on the liquid crystal display (LCD) screen. Additionally, a USB cable was employed to facilitate the printing of the Arduino software program in serial mode on a personal computer. A smart monitoring system was developed for various working circumstances using a Bluetooth module. The ZMPT101b AC voltage sensor has been utilized in conjunction with the frequency meter. The frequency was determined by analyzing the signal obtained from the AC voltage sensor, without the need for additional equipment such as a zero crossing detector.
Keywords: Monitoring system, Cost-efficient, Frequency,Arduino, and Sensors.

I. INTRODUCTION

The synchronous generators are widely regarded as the principal component of the power generation system, responsible for supplying the requisite electrical energy to customers. The voltage, current, and frequency of the generator may experience fluctuations over the established safety thresholds as a result of various abnormal grid conditions, including failures, unbalanced loads, and insufficient power supply to meet the minimum power requirements. The power system's efficacy, efficiency, and dependability will have substantial impacts as a result of this undesired activity.

Presently, the field of digital electronics energy measurement is progressively supplanting the conventional technology employed by electro-mechanical meters. The utilization of a wireless digital power meter is expected to provide enhanced convenience in performing the activity of meter-reading . PLC and Arduino are increasingly garnering attention within the realm of measurement equipment and monitoring systems owing to their versatile capabilities and extensive library functionalities. The system exhibits robustness, efficiency, and user-friendliness simultaneously. Various methodologies have been employed to assess, observe, and identify malfunctions in electrical systems that rely on microcontrollers. The training system developed by Khan et al. incorporates a combination of electro-mechanical and microcontroller-based (Arduino) relays, allowing for the seamless switching between the two setups within the electrical system. Additionally, this system provides information regarding the present magnitude of the fault and the duration it takes for the relay to eliminate the fault . In the eighth reference, a research investigation was conducted to observe and quantify electrical amounts utilizing Arduino. The system developed by the authors in reference [9] utilizes an Atmega328P microcontroller to accurately gauge the voltage of a certain phase. If the measured voltage exceeds or falls below the predetermined value which spans from 160 to 220 volts, the system seamlessly transitions to an alternate phase. The implementation of a power system protection system based on Arduino-GSM technology has been carried out as an educational experiment to evaluate various electrical parameters . In their study, Shivkumar et al. developed a frequency protection relay and power factor correction system utilizing Arduino as the underlying platform. The researchers in reference employed the Arduino Uno microcontroller board to effectively demonstrate the implementation of over- and under-current protection mechanisms for a renewable energy system.

The practical implementation of a monitoring and protection system for distribution transformers has been accomplished by utilizing Arduino, GSM, and GPS technologies. This system effectively captures and logs crucial parameters such as current, voltage, oil pressure, and ambient temperature for the purpose of safeguarding the transformers.

According to previous research , it has been observed that... This study presents the design and actual implementation of a protection and smart monitoring system for a single phase of a synchronous generator. The study identified factors of both low and high frequencies. Three distinct methods of data monitoring were employed in this study: the utilization of a serial monitor within the Arduino software integrated development environment (IDE), the implementation of a 16*2 LCD display, and the utilization of an Android application that received the data over a Bluetooth module.

II. AN INTENDED MONITORING AND SAFEGUARDING SYSTEM

The proposed Arduino-based system is depicted in Figure 1. There are three primary components to the system: sensors, a controller (Arduino), and a monitoring component. The voltage sensor is the only type of sensor employed. Mega 2560, similar to Arduino, but with an embedded ATMega328 microcontroller. There are 54 digital I/O, 16 analog I/O, and 4 hardware serial UARTs.

ports), a crystal oscillator running at 16 MHz, and a 10-bit Analog to Digital Converter (ADC). Everything necessary for the microcontroller's operation is included within; programming is as easy as connecting a USB cable and running the Arduino IDE program . There are three distinct kinds of monitoring setups used in this investigation.

The first option requires constant connectivity between the Arduino and the computer, as data is monitored using the serial monitor feature of the PC. The second method employs an I^2C interface model and a 2*16 LCD for immediate data presentation. The third approach employs a Bluetooth module to transmit data to a mobile device, where it may be seen via a dedicated app (serial monitor).

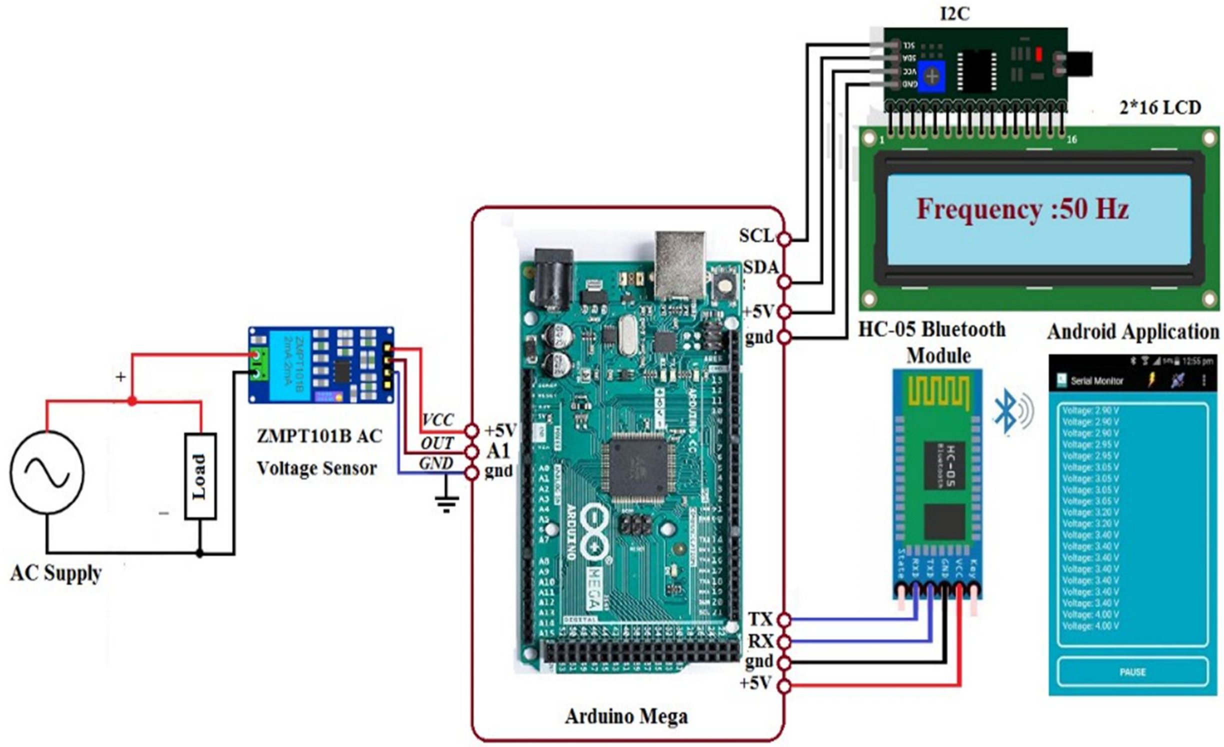

Figure 1. An Intended Monitoring And Safeguarding System

III. SENSOR FOR VOLTAGE

The ZMPT101B sensor module incorporates a voltage transformer for use as an alternating current (AC) voltage sensor. Wide measuring range (voltage input of 0-250 AC), great accuracy, and reliability are its distinguishing features . It's simple to set up and use, and the ADC output may be fine-tuned with a trim potentiometer that has many turns. With a peak value of 311 V , the module read the signal to be measured (220 V phase voltage). The 2.5 V (peak) is achieved by an internal voltage transformer. In order for the Arduino ADC to pick up the signal, a 2.5 V offset was introduced, as illustrated in Figure 2.

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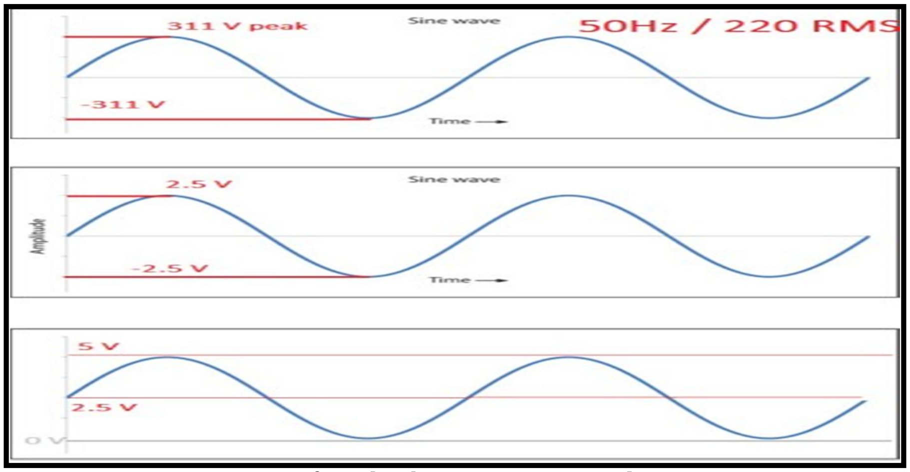
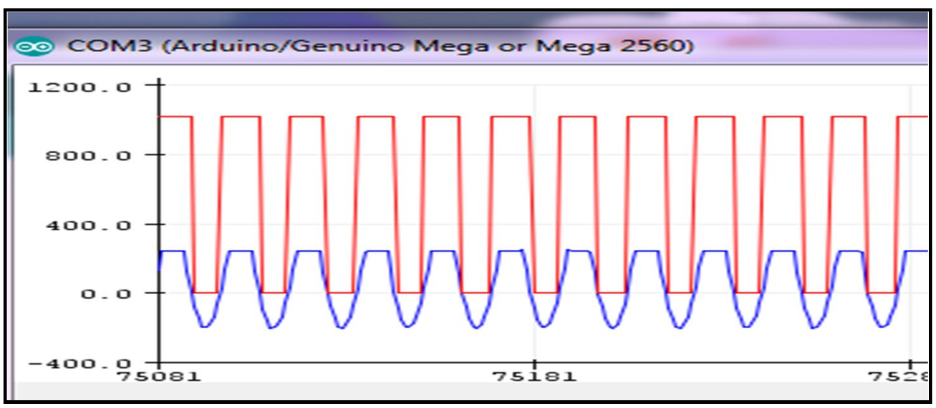


Figure 2. Operation of single-phase ZMPT101B voltage sensor.

IV. FREQUENCY MEASUREMENT

The frequency is monitored using the zmpt101B sensor's alternating current voltage signal (or the load current sensor's alternating current signal). As indicated in Figure 3 (a), the AC voltage signal is compared to the zero-reference value to convert the sine wave signal to a square wave (if the AC voltage signal is greater than zero, the square wave signal equals one, if the AC voltage signal is less than zero, the square wave signal equals zero). The square wave's duration will be measured between each of its rising edges. As illustrated in Figure 3 (b), the frequency is equal to the inverse of the time duration value.



(a): Frequency measurement

```
//----------------Frequency Measurment----------------//
   for(int f=0;f<25000;f++)
{ float sensor_voltage = analogRead (A1);
if ((sensor_voltage -512) > 0){
   digitalWrite(7,HIGH);}        //digital pin 7 is high
if ((sensor_voltage -512) < 0){
   digitalWrite(7,LOW);}        //digital pin 7 is LOW
 currentstate = digitalRead(2); // read squre wave form pin 7
if( prevstate != currentstate) // If there is change in input
  { if( currentstate == HIGH ) // If input only changes from LOW to HIGH
      { duration = ( micros() - prevmicros ); // Time difference in microsecond
        freq = (1000000/duration); // Frequency = (1/ time millis)*1000*1000;
        prevmicros = micros(); }}// store time for nect revolution calculation
 prevstate = currentstate; // store this scan (prev scan) data for next scan
 if( ( millis()-lcdrefresh ) >= 1000 )
     {Serial.print("Frequency (Hz) = ");  Serial.println(freq);
     lcdrefresh = millis(); }}
```

(b): Frequency measurement code process
Figure 3. Frequency measurement.

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V. THE PROTECTION METHOD

The values of these parameters will be shown on the (serial monitor on PC, mobile application via Bluetooth, and 2x16 characters LCD) following the measurement of the synchronous generator's frequency. The system is then monitored and safeguarded by comparing the measured and threshold values as follows:

There are two main acceptable frequency limit levels in general. The first is called the "Operational limit" and it is equal to ± 0.2 Hz (i.e., 49.8 Hz to 50.2 Hz). The second level is called the "Statutory limit" and it is equal to ± 0.5 Hz (i.e., 49.5 Hz and 50.5 Hz) as Figure 4 illustrates.

The statutory limit, or second frequency criteria limit, has been taken into consideration in the current work. A "High Frequency" message and a "HF" message will show up on the LCD and serial monitor on PC and mobile application via Bluetooth, respectively, if the frequency value is higher than 50.5 Hz. Furthermore, if the frequency falls below 49.5 Hz, Figure 5 illustrates the appearance of a "LF" message on the LCD and a "Low Frequency" message on the PC's serial monitor and mobile application using Bluetooth.

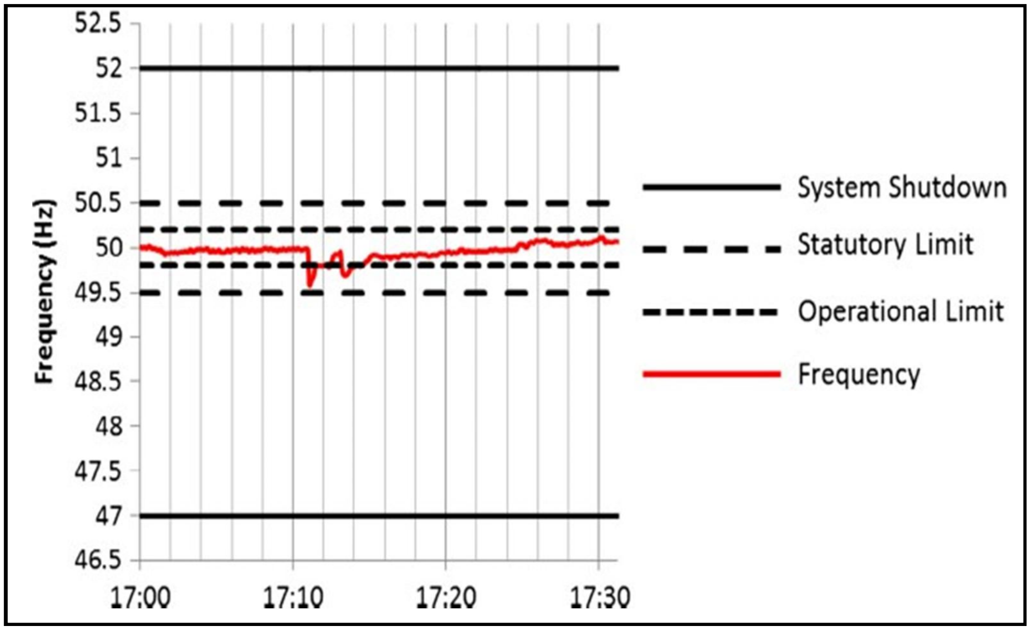

Figure 4. The legal and operational frequency restrictions

```
if(freq <= 49.500){Serial.println("Low Frquency");
                    blue.println("Low Frquency");
                    lcd.setCursor(14,0);lcd.print("LF");}
if(freq >= 50.500){Serial.println("High Frquency");
                    blue.println("High Frquency");
                    lcd.setCursor(14,0);lcd.print("HF");}
```

Figure 5. Message code for extremely high or low frequencies.

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VI. RESULTS AND DISCUSSION FROM THE EXPERIMENTS

Figure 6 depicts the experimental configuration of the proposed monitoring and protection system for one phase of a three-phase alternator that is based on Arduino. The system is designed to monitor and protect the phase.

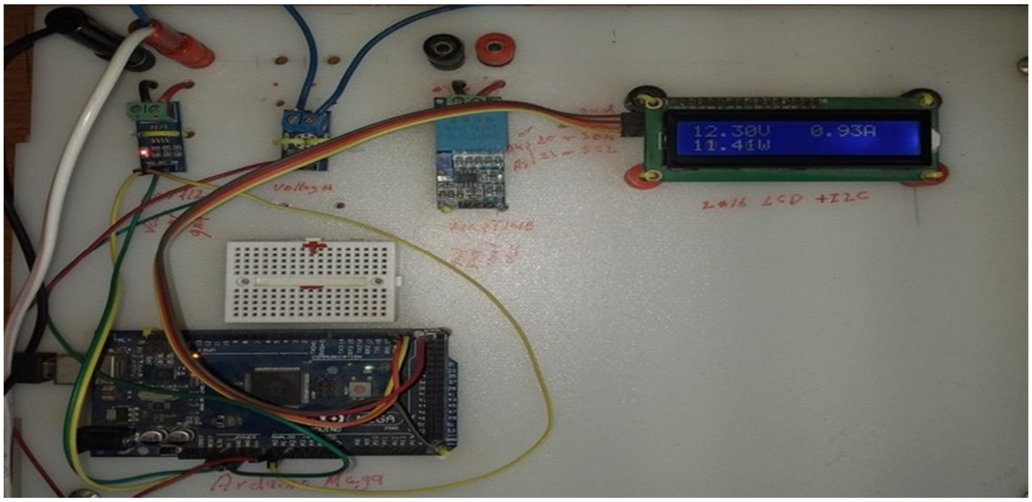
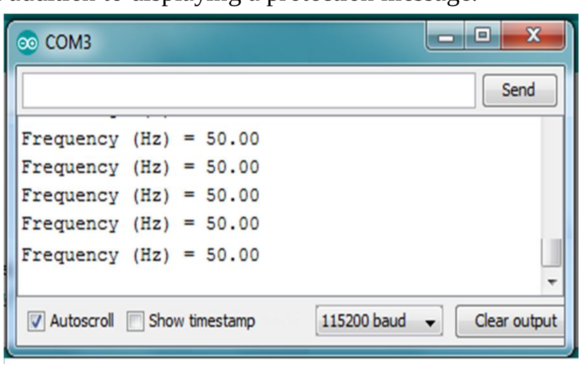


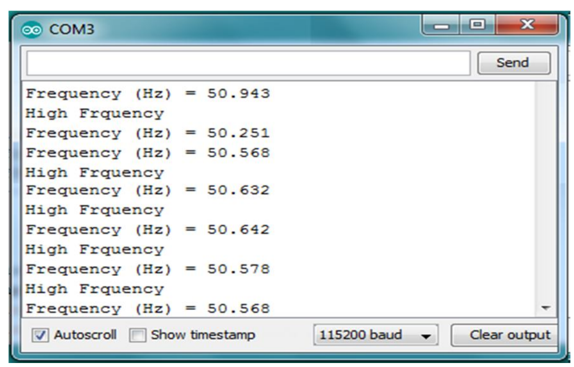
Figure 6. Arduino board with sensors.

The functionality of the system has been evaluated under a variety of settings, and the frequency that has been measured is directly displayed on the serial monitor that is located on the personal computer. Seventh figure shown. Figures 7.a, 7.b, and 7.c, respectively, represent normal operation, high-frequency cases, and low-frequency cases, respectively.

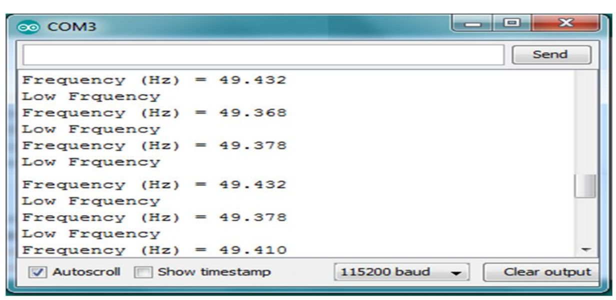
At the same time, a Bluetooth module has been used to transfer the same data to be displayed on the Android app, as shown in Figure 8. This has been done in the same sequence as the serial monitor displaying; this property offers flexibility to the process of monitoring the system. At the same time, 2 by 16 LCD characters were utilized for the purpose of immediately mentoring these facts in addition to displaying a protection message.



(a) Normal operation



(b) High Frequency



(c) Low Frequency

Figure 7. A screen capture from a serial monitor, showing measuring data from a variety of typical and abnormal scenarios.

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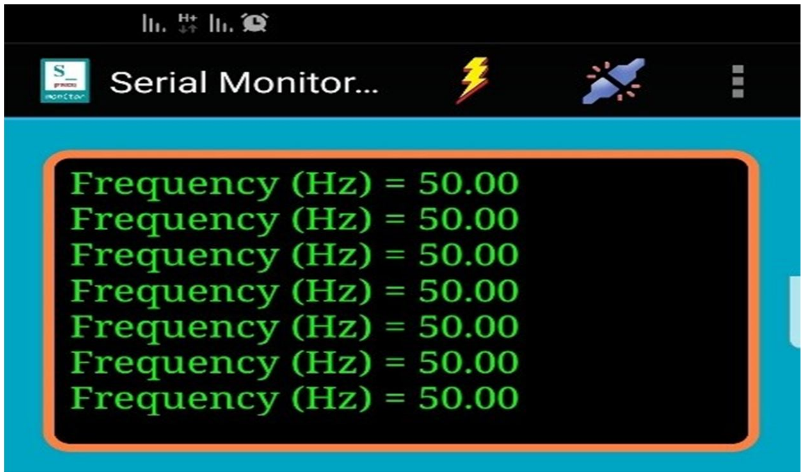

(a) Normal operation

(b) High Frequency

(c) Low Frequency

Figure 8. Serial Monitor (Mobile application) screen –shoot of measuring data at various normal and abnormal cases.

VII. CONCLUSIONS

The suggested Arduino-based system is capable of accurately tracking frequency over time and identifying any anomalous synchronous generator behavior. The proposed software included a threshold value that, if surpassed, would trip the load and trigger an alarm message regarding the anomalous operation in addition to a protective method. Because of the Arduino Mega's low cost and straightforward circuitry in comparison to other controllers, as well as its dependability and versatility, it finds extensive use in the control of power systems. In this study, frequency is measured without the usage of an external circuit (zero crossing detectors), as only one sensor (voltage) is utilized. Future research can develop anomalous situations (such unbalanced load and phase failure) as well as power factor, power consumption, and energy measurement for the suggested system (i.e., with only two employed sensors).

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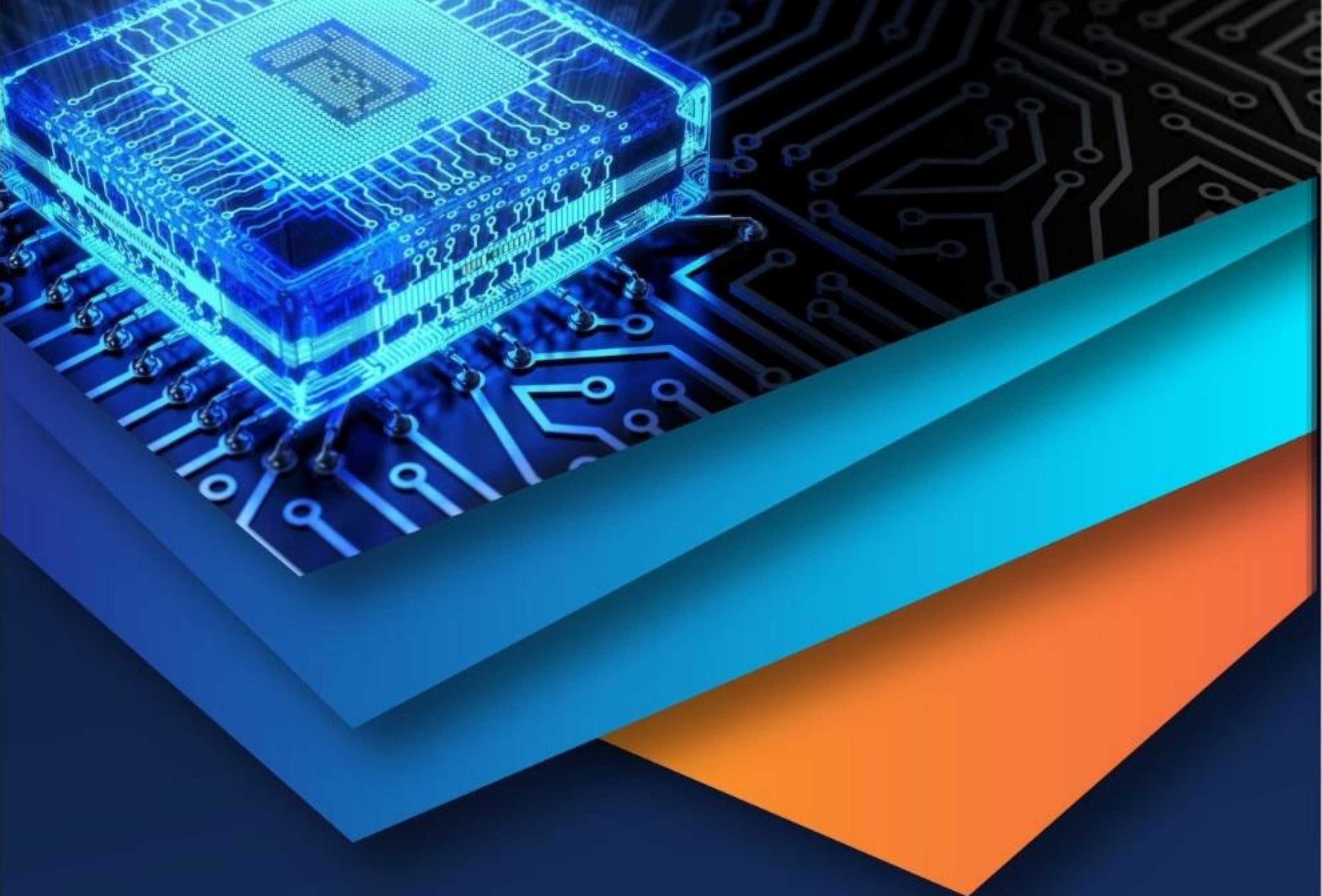

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