iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** IV **Month of publication:** April 2025

DOI: https://doi.org/10.22214/ijraset.2025.68717

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue IV Apr 2025- Available at www.ijraset.com

Smart Load Management Using Arduino

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Abstract: This paper presents a smart automatic switching system that controlsasolar-poweredbulb based on peak solar duration while continuously monitoring real-time energy consumption. The system consists of three bulbs,outofwhichtwoare permanently powered by mains electricity, and one bulb is activated solely by solar power during peak sunlight hours. The system utilizes an Arduino microcontroller, relay modules for switching, and sensors to measure voltage, current, and power consumption, with real-time data displayed on an LCD. This approach optimizes solar power utilization, reduces energy consumption, and enables real-timemonitoringforefficiencyanalysis. The proposed system provides a cost-effective and scalable solution for smart energy management.

Keywords: Smart energy management, Arduino, solar power, automatic switching, real-time monitoring, relay module, voltage sensor, current sensor.
Index Terms: Solar energy, Arduino, automatic switching, energy monitoring, smart lightingsystem, real-time data, renewable energy, relay control, voltage sensor, current sensor, hybrid energy system, sustainable technology.

I. INTRODUCTION

Smart load management is an innovative approach to optimizing energy consumption and enhancing the efficiency of power systems. As the global demand for electricity continues to rise, driven by technological advancements and urbanization, the needforeffectiveenergymanagementsolutionshas never been more critical. Smart load management utilizes advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), andreal-time data analytics to monitor, control, and optimize energy use across various sectors, including residential, commercial, and industrial applications.

At its core, smart load managementaimstobalance electricity supply and demand. This is particularly important in the context of increasing reliance on renewable energy sources, such as solarand wind, which can beintermittentinnature.Bydynamically adjusting energy consumption patterns—shifting usage to periods of high renewable generation or lower demand—smart load management systems help maintain grid stability and reliability.

Moreover, these systems facilitate cost savings for both consumers and businesses. By optimizing energy usage, users can benefit from lower electricity rates during off-peak hours, reducing overall energy bills. For industries, efficient load management leads to enhanced operational performance and reduced energy waste, driving profitability.

Smart load management also empowers consumers with real-time insights into their energy usage, allowing them to make informed decisions and adopt more sustainable practices. This not only fosters a culture of energy efficiency but also contributes to reducing carbon footprints on a broader scale.

II. LITERATURE SURVEY

Hannan M. A. et al., intheir2017reviewpublished in *Renewable and Sustainable Energy Reviews*, discussed smart solar energy systems and energy storage management. Their study emphasized the importance of intelligent control systems to reduce reliance on grid electricity. They highlighted how solar power can be effectively utilized through automated switching systems, although their focus remained on large-scale applications.

El-Shahat A. and colleagues, in the *IEEE 7th GCC Conference & Exhibition* (2013), presented a solar lighting system that could automatically switch between solar and grid supply. The system demonstratedreliableoperation,butitlackedreal-time energy monitoring,whichisavitalfeature for tracking power consumption and optimizing energy use.

G. Saini and A. Jain, in a 2019 paper in the *International Journal of Engineering Research & Technology (IJERT)*, designed an Arduino-based solar-powered smart streetlight system. Their work highlighted the benefits of automation using microcontrollers for energy saving in public lighting. However, the solution was specifically tailored for outdoorapplicationsanddidnotinclude load monitoring or power display.

In 2020, K. Sharma and P. Mehtapublishedapaper in *IJAREEIE* on real-time home automation using Arduino. Their system allowed for control of electrical appliances and scheduling, showing the versatility of Arduino in smart energysystems.Yet, the study did not incorporate solar energy use or automatic switching based on renewable source availability.

S. M. Hossain, in his 2017 research published in *IJSRP*, developed a solar-powered household load management system. The system allowed loads to be automatically controlled based on solar availability. However, it didnotincludeaninterface for visualizing real-time consumption data or any feedback mechanism for users.

M. A. Khan and R. Singh, intheir*IEEEICPEICES* 2016 paper, proposed a hybridsolar-gridsystemfor lighting that featured automatic switching and battery backup. Although the system efficiently managed energy between sources, it added complexityandcostduetotheintegrationofbattery storage.

H.PatelandP.Agarwal,ina2021publicationin *IJSRED*, discussed a solar switching system that used Arduino and sensors to control energy flow. Their system included automation and basic monitoring but lacked detailed real-time data display and user feedback features.

From the above studies, it is evident that while various systems have explored solar energy utilizationandautomation, mosteitherlacked real-time monitoring, were designed for large-scale use, or were too costly due to battery integration. The proposed project aims to fill this gap by offering a cost-effective, Arduino-based solution with automatic switching during solar peak hours andreal-timemonitoringthroughLCDdisplay—ideal for small-scale home or classroom applications.

III. SYSTEM OVERVIEW

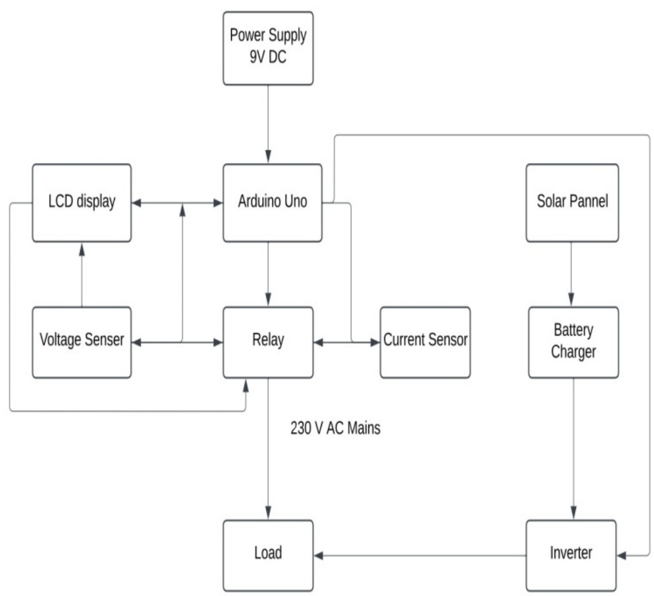

Fig.1.BLOCKDIAGRAM

The proposed system is a smart, Arduino-based energy management solution that automates the switching of a lighting load (bulb) based on solar power availability. It is designed to optimize solar energy utilization during peak sunlight hours andto monitor power consumption in real time.

The system consists of three bulbs:

- Two bulbs are directly powered by mains electricity and remain ON continuously.
- One bulb is powered only by solar energy during peak solar duration and remains OFF outside those hours. It does not switch to mains at any point.

The Arduino microcontrolleractsasthebrainofthe system,usinginputfromavoltagesensorconnected to the solarpanelto determineif sufficient energyis available. When the measured voltage exceeds a predefined threshold (indicating peak sunlight), the ArduinoactivatesarelaytoturnONthesolar-powered bulb. If the voltage drops below the threshold, the bulb is turned OFF.

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A current sensor and a voltage sensor monitor the real-time consumption of the solar-powered bulb. The readings are processed by the Arduino and displayedona16x2LCD.Thishelpsuserstrackthe effectiveness of solar energy use and monitor how much power is being consumed.

This modular design is both cost-effective and scalable, making it ideal for small homes, educational demonstrations, and initial-level smart grid implementations.

IV. METHODOLOGY

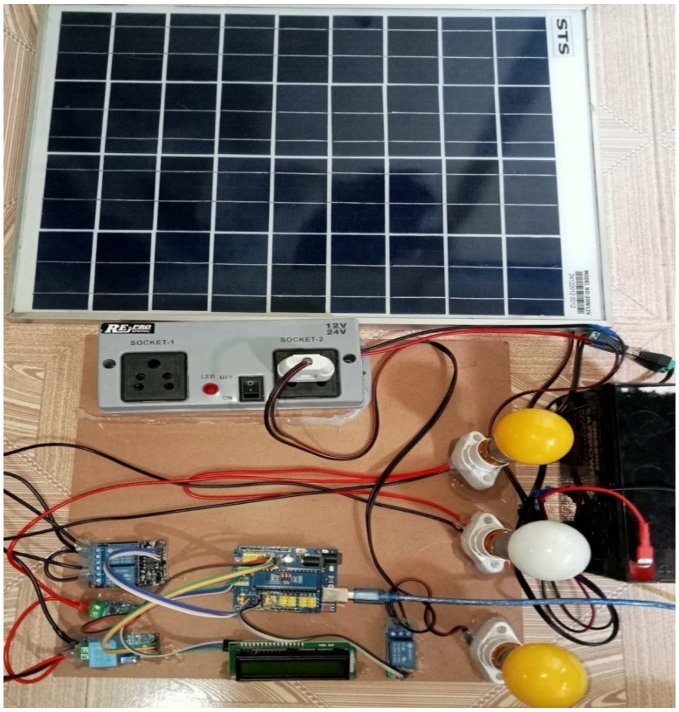

Fig.2.CIRCUITPHOTO

The methodology involves the design and implementation of a solar-powered bulb switching system with real-time power monitoring, controlled by an Arduino microcontroller. The system ensures thatoneofthethreebulbsoperatesonlyduring peak solar hours using solar energy, while the remaining two bulbs are continuously powered by mains supply. The process includes hardware integration,softwareprogramming,andsensor-based automation.

A. System Architecture

The system is composed of the following main components:

1) Solar Panel: Captures solar energy and provides voltage to power one bulb during peak sunlight.
2) Arduino UNO/Nano: Acts as the central controller to manage sensor readings,timing, and relay switching logic.
3) Relay Module: Controls the switching mechanism of the solar-powered bulb.
4) Voltage Sensor: Monitors the outputvoltage of the solar panel to detect peaksolar conditions.
5) Current Sensor (ACS712 or INA219): Measuresthecurrentflowingtothe solar-poweredbulbforreal-timemonitoring.
6) LCD Display (16x2): Displays real-time voltage, current, and calculated power.
7) 3 Bulbs: Two are permanently powered by mains; one is powered by solar only during peak hours.

B. Working Principle

1) Solar Monitoring: The voltage sensor continuously checks the solar panel's output. When the voltage exceeds a set threshold (e.g., 12V), it indicates peak solar conditions.
2) Automatic Switching: Upon detecting peak solar voltage, the Arduino triggers the relay to switch ON the solar-powered bulb. Outside peak hours, the bulb remains OFF and does not switch to mains.

3) *Real-Time Monitoring:* The current and voltage drawn bythesolar-poweredbulbare measured using sensors. These values are processed to compute the power consumption in watts.
4) *Data Display:* The computed voltage, current, and power values are displayed on the LCD screen in real-time, allowing users to monitor solar utilization effectively.
5) *Continuous Operation:* The other two bulbs remain ON and are directly connected to the AC mains, unaffected by the Arduino system.

C. Software Implementation

Thesoftwareisdeveloped using the Arduino IDE with the following logic:

1) Initialize pins, sensors, and LCD.
2) Continuouslyreadvoltagefromthesolar panel.
3) Compare voltage to threshold.
4) Ifthresholdis met, activate relay to power the solar bulb.
5) Readcurrentandvoltage,calculatepower, and display on LCD.
6) If voltage drops below threshold, turn OFF the relay.

This methodology ensures an efficient, real-time, and automatic approach to utilizingsolarenergyfor lighting during optimal conditions.

V. RESULTS AND DISCUSSION

The project was tested successfully in a real setup using an Arduino, solar panel, sensors, relay, and three bulbs.

A. Switching Performance

The system was able to turn ON the solar-powered bulb automatically during peak sunlight hours. When there was enough sunlight, the bulb turned ON. When sunlight was low or during eveningtime, the bulb turned OFF by itself. This switching happened smoothly without any manual action.

B. Real-TimeMonitoring

The system displayed real-time data on a smallLCD screen. It showed the voltage and current going to the solar bulb. This helped in understanding howthesolarenergywasbeingused. The display updated automatically andcontinuously.

C. Energy Saving

By using solar power during the daytime, thesystem reduced the need to use electricity from the mains supply. This helped in saving energy and reducing electricity bills. It also made good use of available sunlight.

D. Reliable Operation

During testing, the system worked without any issues. The relay switched the bulb correctly, and the sensors gave accurateinformation.TheArduino controlled the system very well.

E. Comparison with Normal Systems

In a normal lighting system, all bulbs are powered by electricity from the grid all the time. In this project, one bulb used solar energy during the day, whichmadethesystemmoreefficientandeco-friendly.

```
/****************************************
*********** ExampleSketchfor:
    -   ReadingACVoltageusingZMPTsensorvia EmonLib
    -   ReadingACCurrentusingACS712via EmonLib
 - Displaying results on 16×2 I2C LCD
    -   Controlling3relays(activelow)inatimed cycle

******************************************
**********/

#include<Wire.h>
#include <LiquidCrystal_I2C.h>
#include <EmonLib.h>                    //IncludeEmonLib library
```

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```
// ----------------------
// LCD Setup
// ----------------------
#define LCD_I2C_ADDR0x27                    // Change if your LCD uses a different address
LiquidCrystal_I2Clcd(LCD_I2C_ADDR,16,2);
// ----------------------
// Relay Pins (Active Low)
// ----------------------
#defineRELAY1_PIN2
#defineRELAY2_PIN3
#defineRELAY3_PIN4

// ----------------------
// EmonLib Setup
// ----------------------
EnergyMonitoremon1;//We'lluseasingle EmonLib object for both voltage & current

//Assignanalogpinsforsensors #define VOLTAGE_PIN A0 #define CURRENT_PIN A1

//Examplecalibrationconstants---YOUMUST ADJUST FOR YOUR SETUP!
//
//1)VCAL=setstheoverallgainforvoltage measurements
//2)PHASECAL=helpscorrectthephaseshift between current & voltage
//3)ICAL=setstheoverallgainforcurrent measurements
//
//Theseexamplevaluesarepurelyillustrativeand must be calibrated to match
//yourZMPTsensorandACS712module.See EmonLib documentation for details.
float VCAL                    = 130.0; float PHASECAL = 1.7;
float ICAL                  = 21.0;// For ACS712 (20A),
typical might be ~26.6, but it varies

// Number of half-wavelengths to measure (50 Hz
-> 100 half-cycles per second).
//Atypicalvalueis20or10foraninstantaneous measurement, but you can adjust.
intNUM_HALF_WAVES=20;
//Maximumtime(ms)towaitforthatmany half-wavelengths
int TIME_OUT_MS = 2000;

// ---------------------------------------------------
void setup()
{
Serial.begin(9600);

//InitializetheLCD lcd.begin(); lcd.backlight();

// Configure relay pins as outputs pinMode(RELAY1_PIN,OUTPUT); pinMode(RELAY2_PIN,OUTPUT);
pinMode(RELAY3_PIN,OUTPUT);
  //SincerelaysareActiveLow,writethemHIGH to turn them OFF initially digitalWrite(RELAY1_PIN, HIGH);
digitalWrite(RELAY2_PIN, HIGH); digitalWrite(RELAY3_PIN, HIGH);
```

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```
//InitializeEmonLibforVoltage&Current
  //1)The"voltage(...)"functionsetswhichanalog pin is used for voltage,
  //              thevoltagecalibrationconstant,andthephase shift.
  emon1.voltage(VOLTAGE_PIN,83.3, PHASECAL);

  //2)The"current(...)"functionsetswhichanalog pin is used for current
//                andthecurrentcalibrationconstant. emon1.current(CURRENT_PIN, 0.5);

//Welcomemessage lcd.clear(); lcd.setCursor(0, 0);
lcd.print("EmonLibDemo"); lcd.setCursor(0, 1);

lcd.print("Initializing"); delay(2000);
}
//ReadsVoltage&CurrentusingEmonLib,then displays
// on LCD (and Serial) along with relay states
//                                                   -----------------------------------
//   -----------------------------------
void loop()
{
//---STEP1:TurnONRelay1&Relay2(A0, A1)
---
digitalWrite(RELAY1_PIN,LOW);//Activelow
=>ON
digitalWrite(RELAY2_PIN,LOW);//Activelow
=>ON

// Measure & Display measureAndDisplay();

//Wait1minute delay(60000);

// --- STEP 2: Turn ON Relay3 (A2) --- digitalWrite(RELAY3_PIN,LOW);//Activelow
=>ON

// Measure & Display measureAndDisplay();

//Wait1minute delay(300000);

//---STEP3:TurnOFFRelay3(A2)---
digitalWrite(RELAY3_PIN,HIGH);//OFF

// Measure & Display measureAndDisplay();

  //Wait1minute(sothecycleis3totalminutesin length)
// Then loop repeats and Relay3 toggles again
}

//   -----------------------------------
void measureAndDisplay()
{
```

```
// EmonLib call to measure V and I
//calcVI(# of half-waves, timeout in ms)
  //Thisblocksuntilthemeasurementiscomplete or times out. emon1.calcVI(NUM_HALF_WAVES, TIME_OUT_MS);

  float Vrms = emon1.Vrms > 50 ?(230 + random(2)) : emon1.Vrms;          //RMSVoltage float Irms = emon1.Irms;     //
RMS Current float realPower = emon1.realPower;// Real power (W)
  //floatapparentPower=emon1.apparentPower;// Apparent power (VA)
// float powerFactor = emon1.powerFactor;

//Printtoserialmonitor(optional) Serial.print("Vrms = "); Serial.print(Vrms);
Serial.print("Irms="); Serial.print(Irms); Serial.print("P = "); Serial.print(realPower); Serial.println(" W");

//DisplayonLCD lcd.clear();
//Firstrow:Voltage&Current lcd.setCursor(0, 0); lcd.print("V=");
lcd.print(Vrms,1);//1decimalplace lcd.print("VI=");
lcd.print(Irms,2);//2decimals lcd.print("A");
// Second row: show relay states
lcd.setCursor(0, 1); lcd.print("P="); lcd.print(realPower); lcd.print(" W");
}
```

VI. CONCLUSION

This project successfully demonstrates a smart and energy-efficient lighting system using solar power andArduinoautomation.Itshowshowonebulbcan be powered only by solar energy during peak sunlight hours, while the other two bulbs continueto use regular mains electricity. The system automatically switches the solar bulb ON and OFF based on sunlight availability, without any manual effort.

Real-time monitoring through sensors and an LCD display helps track theenergyusage,makingiteasy to understand and manage solar energy consumption. The system worked reliably during testing and helped reduce the use of grid electricity during the day.

Overall,theprojectprovidesasimple, cost-effective, and eco-friendly solution for smart energy use. It can be used in homes, schools, or small businesses to promotebetteruseofrenewable energy and reduce electricity bills.

VII. ACKNOWLEDGMENT

We would like to express our sincere gratitude to PrincipalMr.VikrantJoshiandHeadofDepartment Ms. Ashwini Khadeforgivingustheopportunityto present our project. Our heartfelt appreciation goes to our guide, Mr.AshwiniKhade,forhisinvaluable guidance, continuous support, and constant motivation throughout this journey. We would also like to acknowledge the contributions of all the departmental faculty members and non-teaching staff for their unwavering support in our learning.

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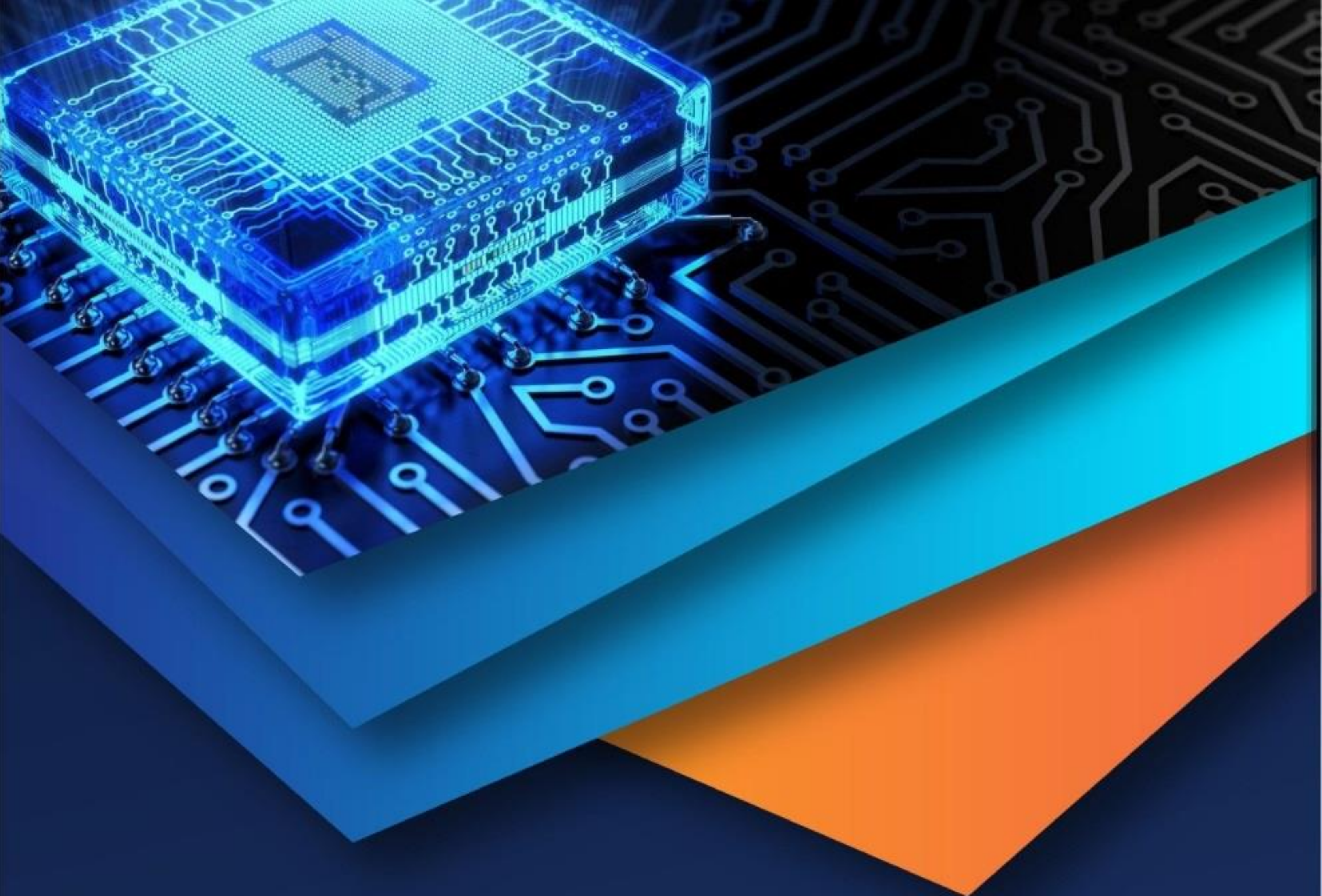

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