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A Hybrid Solar Tracking System with Photovoltaic Cells and Thermoelectric Module

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Abstract—Conventional sources like fossil fuels were used in early stages to satisfy the energy demands. Nowadays these are slowly replaced by renewable sources like photovoltaic sources. Solar PV is starting to play a substantial role in electricity generation in some countries as rapidly falling costs have made unsubsidised solar PV-generated electricity cost-competitive with fossil fuels in an increasing number of locations around the world.Solar cells, also called photovoltaic (PV) cells, convert sunlight directly into electricity. PV gets its name from the process of converting light (photons) to electricity (voltage), which is called the*PV effect. *Today, thousands of people power their homes and businesses with individual solar PV systems. Utility companies are also using PV technology for large power stations. Solar panels used to power homes and businesses are typically made from solar cells combined into modules that hold about 40 cells. So this paper describes the design of a hybrid solar tracking system made with photovoltaic cells and thermoelectric modules which is the need of the hour. Assolar energy is a renewable heat source freely and widely available everywhere, outdoor performance of photovoltaic (PV) modules suffers from elevated temperatures. Conversion efficiency losses of up to about25% can result, depending on the type of integration of modules in the roof. Cooling of modules would therefore enhance global performance. Instead of module cooling we propose to use the thermal waste by attaching thermoelectric modulesat the backof PVmodules, to form a PV–TE hybrid module.
Keywords—Hybrid, Photovoltaic (PV) cells,Solar cells, TE module.

I. INTRODUCTION

In recent years, the fast development and the growingdemand of comfort have increased the energy consumption,and surging oil and gas consumption and increasingenvironmental awareness have prompted more and moresustainable development. Thedesires for new and renewable energy sources such as solarpowers have been growing in recent decades. In this method,photovoltaic effect is one of the ways to generate electricityfrom the sun in which solar energy is converted to electricity using an electronic device called solar panel bythe photovoltaic effect directly. Research onsolar cell has been carried out since 1960, and differenttechnologies have been proposed to reduce the material andto increase the production capacity.Currently, silicon modules represent the leadingPV technology because of both their capability to providehigh efficiency and the great availability of silicon materialon the earth. In particular, monocrystalline solar cells offerthe highest efficiency of more than 20%. Two alternativetypologies developed to reduce the cost in PV modulesproduction are: 1) the polycrystalline silicon that providesworse performance in terms of efficiency (13%–16%) and2) the amorphous silicon that offers low efficiency (6%–9%),but is less affected by high temperatures andshading. Despite PV is considered a commercially maturetechnology, the efficiency of the PV plants is still quitelow; therefore, in the best of cases, about 80% of thepotential energy available would be wasted. On the otherhand, this technology continuously reduces its cost andrequires technical advance and new research for efficiencyincrement. Therefore, many researchers have focusedon the reduction of the losses that affect solar panels suchas losses caused by the sunlight, the conditioning circuitrequired, the energy storage system, the Joule effect, and so on.To reduce these effects, researchers are focusing on twostrategies: 1) to develop new materials or 2) to try recoveringpart of the energy lost as heat by the Joule effect, Therefore, nowadays, panel's manufacturers have highinterest in combining thermoelectric (TE) and PV effects toobtain higher performance.

This paper presents the system layout of our work.Section II explains about the system design. Section III briefs out about photovoltaic module. Then section IV deals about thermo electric module. Section V deals about hybrid PVTE module and section VI gives the simulation results.

II. SYSTEM DESIGN

A schematic of the PVTE system is shown in Fig. 1where the blocks represent the PV and the TE modules;the thermal energy generated in the PV block is convertedto electricity by the TE block. These elementscan bereasonably considered separately, since

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the effects that leadto the generation of current can be considered independentof each other; indeed, even if the TE module is posteriorlyintegrated into the solar panel, and it exploits thetemperature of the rear of the panel itself, this phenomenonaffects the solar cell performance in a reasonablynegligibleway.The system operates at room temperature having the solar radiation as input andthe total electric power generatedby the system as output. At high solar irradiance, the PV moduletemperature (*T*max) can reach 50 °C–60 °C and differs fromroom temperature by about 30 °C–40 °C (_*T*). These values

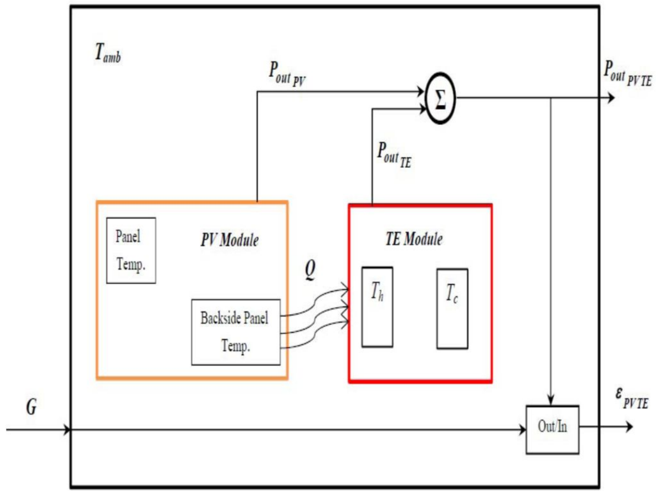

Fig:1: PVTE hybrid model

depends on the site, the type of the integration, and the periodof year considered. To calculate the PV panel temperature (*T*),which strongly depends on the incident light, the workingconditions, and the installationconditions, the followingrelation was used:

$T = T_{amb} + c \cdot G$ (1)

being *G* (W/m2) the irradiance and *c* (K ·m2/W) a coefficient,known as the Ross coefficient, which depends on theinstallation conditions of the PV panel. The valuesof *c* are 0.058 K·m2/W for roof PV panels integrated,0.036 K·m2/W for the top of the roof with small roof-moduledistance (<10 cm), 0.027 K·m2/W for the top of the roof withlarge roof-module distance (>10 cm), and 0.020 K·m2/Wfor free standing.The performance of the combined system should be givenin terms of both generated electric power and overallsystemefficiency by highlighting their dependence on environmentalconditions, such as temperature and radiation, and on physicalproperties of the used material. Then, the generatedelectrical power of the overall system will be the sum ofthe electric powers generated by both modules. Under thisassumption, the overall efficiency of the system can becalculated as the ratio between the sum of the generatedelectric powers by each module and the power of theinput system, i.e., the solar radiation available to thePV module. In this case, both the front face temperature (*T*)and operating temperature of TE (*Tm*) will determine thePV and the TE module performance, respectively. Precisely,the temperature of the cells within the PV module (*T*) willdepend on the ambient temperature (*T*amb) and on the incidentsolar radiation flux (*G*); the operating TE temperature (*Tm*)will depend on rear paneltemperature (*Th*) and on theambient temperature (*T*amb). It is useful to note that there is aheat flow (*Q*) going from the PV to the TE module, which isdissipated through the latter. Finally, to preserve the energybalance, the following losses should be considered:

Transformation losses due to conditioning circuits of the PV module (there are in fact inverter and other
circuitries), which are not included in the model;
Losses due to the Joule effect in the PV module;
Losses due to the Joule effect in the TE module;
Losses due to dispersion currents;
Convection losses.

Incident solar radiation is converted to electric power bythe PV module with efficiency ofηPV. The waste solar energyin heat form is assumed to be absorbed by TE module and is
converted to electric energy with efficiency of ηTE. Then, thetotal amount of generated power is:

$P_{PVTE} = P_{PV} + P_{TE} = \eta_{PV} G + (1-\eta_{PV}) G \eta_{TE}$ (2)

And the efficiency of hybrid PV-TE system is written as

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$$\eta PVTE = \eta PV + (1- \eta PV)\eta TE \quad (3)$$

III. PHOTOVOLTAIC MODULE

Photovoltaics (PV) or solar cells as they are often called, are semiconductor devices that convert sunlight into direct current (DC) electricity. Groups of PV cells are electrically configured into modules and arrays, which can be used to charge batteries, operate motors, and to power any number of electrical loads. With the appropriate power conversion equipment, PV systems can produce alternating current (AC) compatible with any conventional appliances, and can operate in parallel with, and interconnected to, the utility grid.A typical silicon PV cell is composed of a thin wafer consisting of an ultra-thin layer of phosphorus-doped (N-type) silicon on top of a thicker layer of boron-doped (P-type) silicon. An electrical field is created near the top surface of the cell where these two materials are in contact, called the P-N junction. When sunlight strikes the surface of a PV cell, this electrical field provides momentum and direction to light-stimulated electrons, resulting in a flow of current when the solar cell is connected to an electrical load.

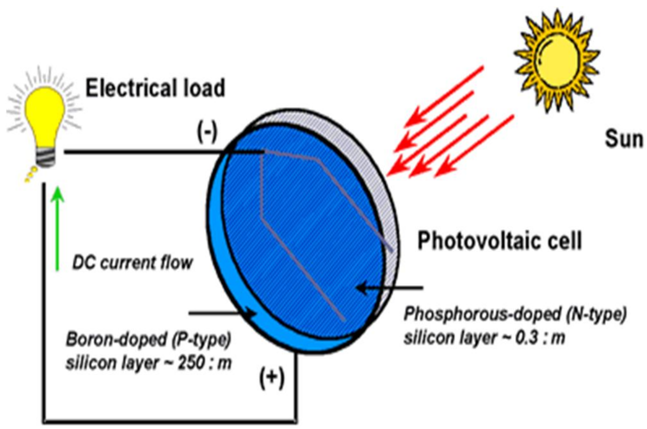

Fig: 2: Working of PV cell

Regardless of size, a typical silicon PV cell produces about 0.5 – 0.6 volt DC under open-circuit, no-load conditions. The current (and power) output of a PV cell depends on its efficiency and size (surface area), and is proportional to the intensity of sunlight striking the surface of the cell. For example, under peak sunlight conditions, a typical commercial PV cell with a surface area of 160 cm^2 (~25 in^2) will produce about 2 watts peak power. If the sunlight intensity were 40 percent of peak, this cell would produce about 0.8 watts. Photovoltaic cells are connected electrically in series and/or parallel circuits to produce higher voltages, currents and power levels. Photovoltaic modules consist of PV cell circuits sealed in an environmentally protective laminate, and are the fundamental building blocks of PV systems. Photovoltaic panels include one or more PV modules assembled as a pre-wired, field-installable unit. A photovoltaic array is the complete power-generating unit, consisting of any number of PV modules and panels.

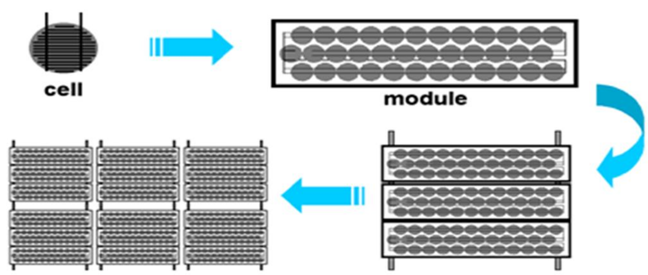

Fig: 3: Photovoltaic cells, modules, panels and arrays.

The performance of PV modules and arrays are generally rated according to their maximum DC power output (watts) under

Standard Test Conditions (STC). Standard Test Conditions are defined by a module (cell) operating temperature of 25o C (77o F), and incident solar irradiance level of 1000 W/m2 and under Air Mass 1.5 spectral distribution. Since these conditions are not always typical of how PV modules and arrays operate in the field, actual performance is usually 85 to 90 percent of the STC rating.Today's photovoltaic modules are extremely safe and reliable products, with minimal failure rates and projected service lifetimes of 20 to 30 years.

IV. THERMO ELECTRIC MODULE

The thermoelectric effect is the direct conversion of temperature differences to electric voltage and vice versa. A thermoelectric device creates voltage when there is a different temperature on each side. Conversely, when a voltage is applied to it, it creates a temperature difference. At the atomic scale, an applied temperature gradient causes charge carriers in the material to diffuse from the hot side to the cold side.This effect can be used to generate electricity, measure temperature or change the temperature of objects. Thermoelectric materials generate power directly from heat by converting temperature differences into electric voltage. These materials must have both high electrical conductivity (σ) and low thermal conductivity (κ) to be good thermoelectric materials. Having low thermal conductivity ensures that when one side is made hot, the other side stays cold, which helps to generate a largevoltage. Peltier module allows to turn heat into electricity. Becauseit can be placed in areas that are normally warm anyway, the electricity created is "free" in a sense, though it does work best when one side of the module is cold and the other is hot. The principle phenomenon that underpins thermoelectric generators (TEGs) is the generation of electrical energy by exploiting the temperature difference as heat flows between two materials. The larger the differential, the more energy can be generated.

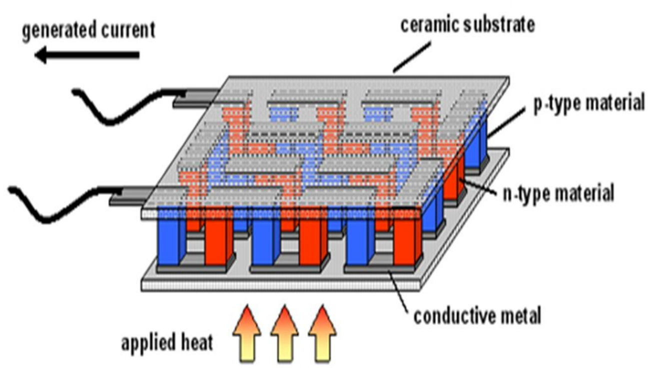

Fig: 4: *Structural* diagram of thermoelectric module using the Peltier effect to generate *energy from heatflow.*

By measuring the power output of the thermoelectric device through a load, the efficiency of the thermoelectric device can be calculated as follows:

$$\eta = \frac{Pout}{Qin} \quad (1)$$

Where, η = thermal efficiency Pout = measured power output of the device (watts) Qin = measured input heat to the device (watts)

In order to calculate efficiency using Equation (1), the input heat, Qin, and output power Pout, must be found. The input heat is found using the heater voltage and heater resistance as shown in Equation (2) below.

$$Qin = \frac{V^2_{heater}}{R_{heater}} \quad (2)$$

The heater voltage was measured by the data acquisition system and the heater resistance was measured as 9.00Ω prior to testing.

The power output was calculated using the load voltage and load current with equation (3) below. (3)

$$P_{out}=V_{load}.I_{load} \quad (3)$$

The load voltage (Vload) is measured directly with the data acquisition system by measuring the voltage drop across both the

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0.488Ω fixed resistor and the 0-25Ω rheostat. The load current (Iload) is found by measuring the voltage drop across only the 0.488Ω fixed resistor and calculating the current.

V. HYBRID PVTE MODULE

A. Solar Panel

A solar cell or photovoltaic cell is a device that converts solar energy into electricity by the photovoltaic effect. The collection of solar cells is called a solar panel or solar array. Solar panel is placed on top of the tracker board which absorbs the maximum sunlight which can also be stored in the battery for future use.

B. LDR

A light dependent resistor (LDR) is a resistor whose resistance decreases with increasing incident light intensity. The LDR consistsofadisc of semiconductor material with two electrodes on its surface. Three LDR's are used for tracking at different positions.

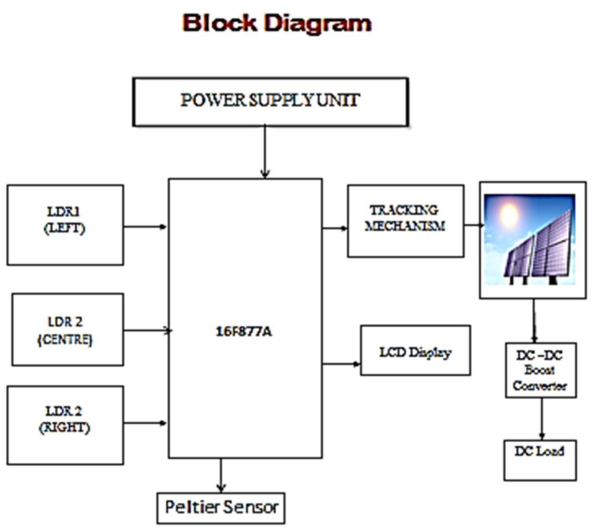

Fig:5 :Block Diagram

C. Peltier Sensor

The Peltier effect is based on the temperature difference created by applying a voltage between two electrodes connected to a sample of semiconductor material. Peltier sensors work on peltier effect.It measures the heat energy from sun's radiation and generates the output signal.

D. Microcontroller

Microcontroller type is PIC16F877A. One unit of PIC16F877A microcontroller can be programmed and erased so many times.PIC includes features for entire analog as well as digital form of operations. It plays a major role as the coordination between different components in the circuit.

E. Stepper Motor

A stepper motor is an electromechanical device which converts electrical pulses into discrete mechanical movements. The shaft or spindle of a stepper motor rotates in discrete step increments when electrical command pulses are applied to it in the proper sequence. This plays an important role in tracking mechanism.

F. LCD

A liquid-crystal display (LCD) is a flat-panel display or other electronic visual display that uses the light-modulating properties of liquid crystals. LCD displays utilize two sheets of polarizing material with a liquid crystal solution between them. Each crystal is like a shutter, either allowing light to pass through or blocking the light.The combined output voltage from the photovoltaic cell and thermoelectric module is displayed in the LCD.

G. Working

Fig:6: Working Prototype

In this project, we have used a combination of photovoltaic cell and peltier sensor (thermoelectric module) for efficient tracking of solar energy. The solar tracker has been used to utilize maximum energy. There are three LDR's attached to the solar panel at different positions. Thus the light dependent resistors will sense maximum solar power. The output from the LDR's is given to the microcontroller (PIC16F877A).The LDR's effectively function during the day by sensing the sunlight. During the night and under low light conditions, peltier sensor will be used to sense the heat energy produced due to different temperatures and produces the equivalent output signal. The microcontroller will compare the output from the three LDR's and the thermoelectric peltier sensor.The tracking mechanism consists of the stepper motor connected to the solar panel. Based on the controller output, the stepper motor will rotate the panel towards the direction in which the solar energy received is maximum. The output voltage is displayed in the LCD unit. The solar energy received from the panel is utilized by connecting a DC load.

VI. SIMULATION RESULTS

Proteus (*PROcessor for TExt Easy to USe*) is a fully functional, procedural programming language created in 1998 by Simone Zanella. Proteus incorporates many functions derived from several other languages: C, BASIC, Assembly, Clipper/dBase;it is especially versatile in dealing with strings, having hundreds of dedicated functions; this makes it one of the richest languages for text manipulation.We have used this Proteus 8.84 to build up the above microcontroller setup. Proteus8 is a best simulation software for various designs with microcontroller. It is mainly popular because of availability of almost all microcontrollers in it. So it is a handy tool to test programs and embedded designs.

MPLAB X IDE is a software program that runs on a PC to develop applications for Microchip microcontrollers and digital signal controllers. It is called an Integrated Development Environment (IDE), because it provides a single integrated "environment" to develop code for embedded microcontrollers.

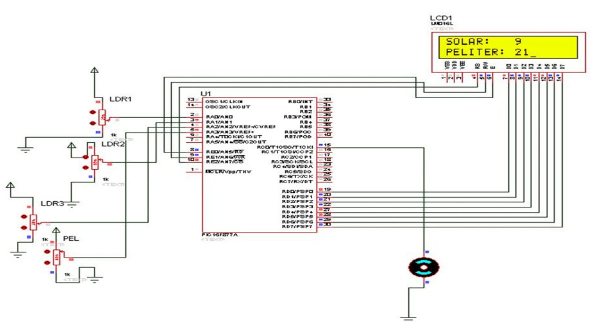

Fig:7 :Simulation result 1

The simulation in Fig 7 depicts that when the light intensity of three light dependent resistor's are low the stepper motor connected to the microcontroller will be in static position. Thus the solar tracking mechanism will not occur.

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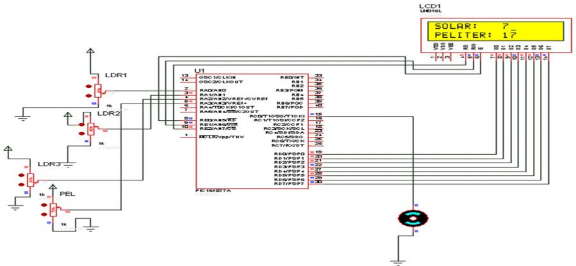

Fig:8: Simulation result 2

But in *Fig 8*as soon as the intensity of any two LDR's increases ,the motor connected to the PIC microcontroller will start to function and practically it directs the solar panel to the direction where the light intensity is high, in order to obtain higher efficiency.

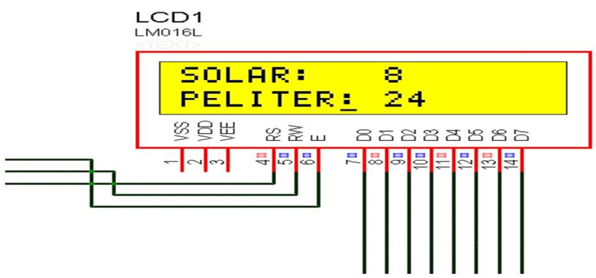

Fig:9 : Simulation result 3

So, the voltages from the solar panel are displayed with the help of an LCD interfaced with the PIC microcontroller. The LCD also displays the voltage produced by the peltier sensor.

IV. CONCLUSION

From the results it is observed that in order to obtain higher efficiency for a solar panel system the panels must align itself according to the varying intensity of sunlight, which can be possibly done with the help of tracking mechanism. But the heat losses in the system will reduce the efficiency. In such cases the proposed PVTE hybrid system combines the photovoltaic module with the thermoelectric module and this thermoelectric module transfers the heat obtained at the rear end of the photovoltaic panel into desirable voltage values. The simulation results shows the voltage values obtained by LDRs and the light intensity values of the peltier sensor. The total efficiency depends on type ofmodule integration, material type and the assumption that thebackside issufficiently cooled such that it is at ambienttemperature.

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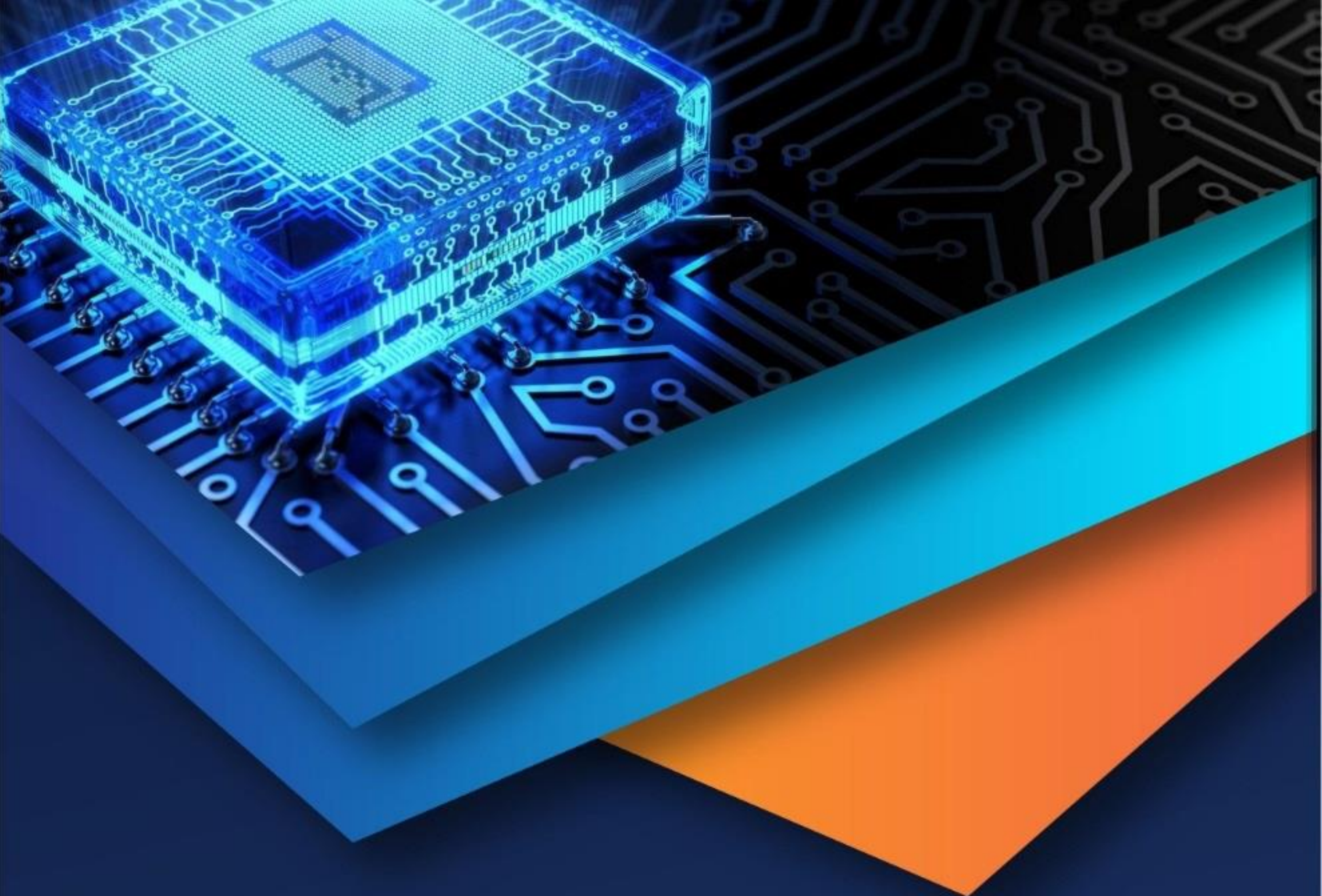

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