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Solar Powered Pump Controller for Agricultural Application: Design, Topology and Algorithm

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Abstract: This research paper presents the design and application of a solar pump controller specifically tailored for agricultural purposes. The controller is developed with the objective of harnessing solar energy efficiently to power irrigation systems in a sustainable manner. The design process involves careful selection and integration of key components, such as solar panels, inverters, and control circuitry, to ensure optimal performance. The controller typically includes a maximum power point tracking (MPPT) algorithm, which enables it to extract the maximum power from the solar panels, even under varying weather conditions. Safety mechanisms are also incorporated to safeguard the system against voltage fluctuations, overcharging, and other potential risks. The application of the solar pump controller in agriculture offers numerous advantages. By eliminating the reliance on grid electricity, it reduces operational costs and contributes to environmental sustainability. The controller enables precise control over water delivery, thereby enhancing irrigation efficiency and conserving valuable water resources. Moreover, it enhances system reliability and longevity by preventing damage caused by electrical irregularities and voltage fluctuations. Extensive field tests were conducted in agricultural settings to evaluate the performance of the controller under various conditions. The results demonstrate significant energy savings and improved crop yield, highlighting the optimized water management facilitated by the solar pump controller. Overall, this research contributes to the development of a reliable, cost-effective, and environmentally friendly solution for agricultural irrigation systems.
Keywords: Solar water pumping system, Solar VFD, farming & Irrigation system, MPPT

I. INTRODUCTION

Access to a reliable water supply is crucial for agricultural activities, especially in rural areas where grid electricity may be unreliable or completely inaccessible [16]. In such regions, solar pumping systems have emerged as an effective solution to fulfil the water requirements of farming communities. This discussion focuses on the design and functionality of a solar pump controller specifically tailored for agricultural applications in rural areas [1]-[9].

The solar pumping system plays a vital role in providing water for farming in regions with unreliable or absent grid electricity [17]-[20]. By harnessing solar energy through photovoltaic (PV) arrays, the system can generate direct current (DC) power from sunlight. At the heart of the system lies a microprocessor-based controller, which facilitates the conversion of this DC power to alternating current (AC), allowing for the operation of various types of pumps suitable for agricultural purposes Fig.1.

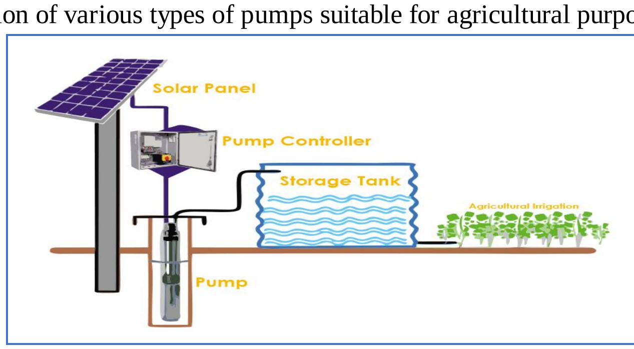

Fig. 1 working of solar pump

An exceptional feature of the solar pump controller is its ability to continuously pump water on sunny days. The primary function of the controller is to optimize the utilization of solar energy, ensuring a consistent water supply for agricultural operations. This is achieved by regulating the output of the solar panels and effectively controlling the speed of the pump, thereby maximizing the use of available solar resources [21]-[23].

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Unlike traditional solar pumping systems, this particular system does not rely on batteries or other energy storage devices. By eliminating the need for energy storage components, the system is simplified, resulting in reduced complexity and maintenance requirements. This absence of batteries streamlines the configuration, making it a cost-effective and reliable solution for agricultural water supply [14].

Solar pumping system mainly consists of three parts
- solar panel
- pump controller
- water pump

There are two main types of solar pump controllers:
1) *On-grid:* On-grid controllers are designed to work with grid-connected solar systems, while off-grid controllers are designed for standalone solar systems
2) *Off-grid:* Off-grid controllers are further divided into two categories: shunt controllers and MPPT (Maximum Power point Tracking) controllers. Shunt controllers are simple and inexpensive but less efficient than MPPT controllers. Which can extract more power from the solar panel array with its advanced MPPT algorithm [10]-[12].

II. WORKING OF SOLAR PUMP CONTROLLER

Solar pump controller consists of an array of solar panels connected in series and parallel configurations to generate the power and voltage requirements. In the proposed system, the output voltage from the solar panel gets boosted to dc-link voltage which acts as a voltage source for a three-phase inverter that runs a motor-pump set. Application of this system is gaining momentum, especially in the areas where the grid is not available. For the design of this system, the selection of the solar panel and its rating is important, as the efficiency of solar panels is major concern. To obtain maximum power from solar panels, MPPT algorithm is to be implemented. Block diagram of solar pump controller is illustrated in Fig. 2 and each blocks functioning is explicated as under.

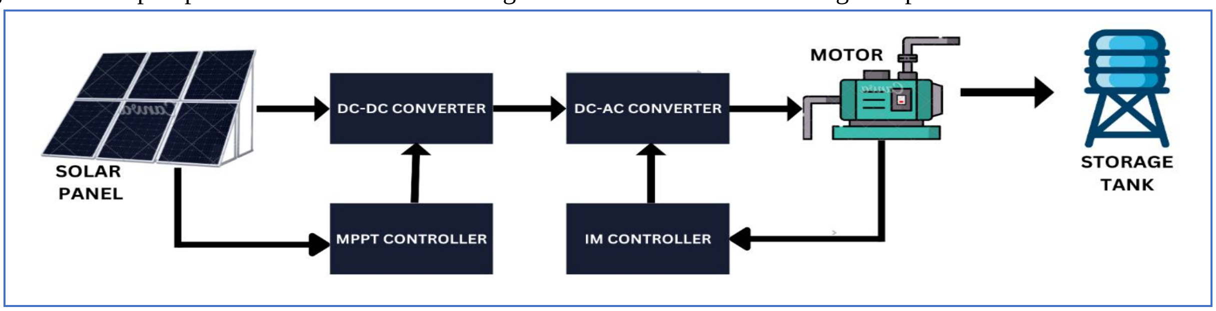

Fig. 2 Block diagram of solar pump controller

1) *Solar Panel*: The function of a Solar panel is to convert solar energy into electrical energy. It provides energy to the motor for water supply.
2) *Maximum Power Point Tracking (MPPT):* The MPPT algorithm optimizes the power output from the solar panel. It adjusts the solar panel through maximum power point tracker in such a manner that maximum voltage and current can be achieved.
3) *DC-DC Converter:* The DC-DC converter controlled by the MPPT controller converts the Input DC from the Solar panel to a regulated and required DC voltage level that requires by the motor and also protects the motor from overvoltage and under voltage.
4) *Motor Control:* The motor control is responsible for controlling the speed and direction of the motor. It receives feedback from the motor and adjusts the output voltage and current to the motor accordingly for smoother operation.
5) *DC-AC Converter:* The DC-AC converter, which is generally known as an inverter converts the input DC from the DC-DC converter to the AC source as per motor requirements.
6) *Pump:* A pump is an electrical machine that controls the flow of the water. It is driven by the motor and is responsible for pumping water from one source to another source or storage tank.

Justification for algorithm, flowchart for incremental conductance method and inverter for V/F control techniques are discussed subsequently.

A. Implementation of the MPPT Algorithm

There are two major drawbacks with the output of solar panels.

1) The output power generation by solar panels is very less, as the efficiency of the solar panel is 15% to 20%.

2) The output of solar panels is not always the same as it varies with changes in condition.

For instance, the output power generated by solar panels tends to be lower during cloudy weather, and its production fluctuates throughout the day. In the early mornings and evenings, the output is comparatively lower than afternoon, which is when the highest output is provided by the panels. Additionally, solar cells do not exhibit linear I-V and P-V characteristics. As a result, there exists a specific point on the graph where the solar panel's maximum power can be identified Fig. 3. This point is known as Maximum Power Point (MPP) and to determine this point, many methods are developed such as Perturb and observed, Fractional Short Circuit Current (FSCC), Fractional Open circuit Voltage (FOCV), Incremental conductance, etc. Among these, we have decided to use Incremental conductance due to its enhanced steady-state accuracy.

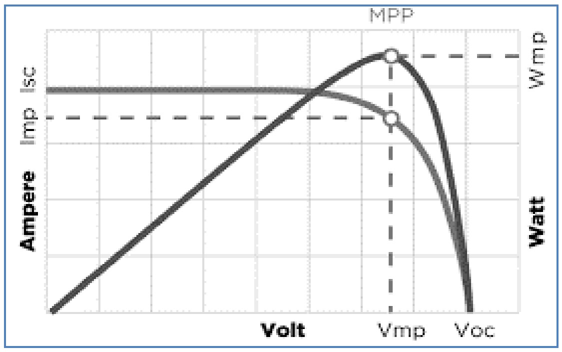

Fig. 3 MPPT Curve

The incremental conductance algorithm observes and detects the slope of the P–V curve, and the MPP is tracked by searching the peak of the P–V curve. This algorithm uses the incremental conductance dI/dV and the instantaneous conductance I/V for MPPT.

B. Flow Chart of the Incremental Conduction Method

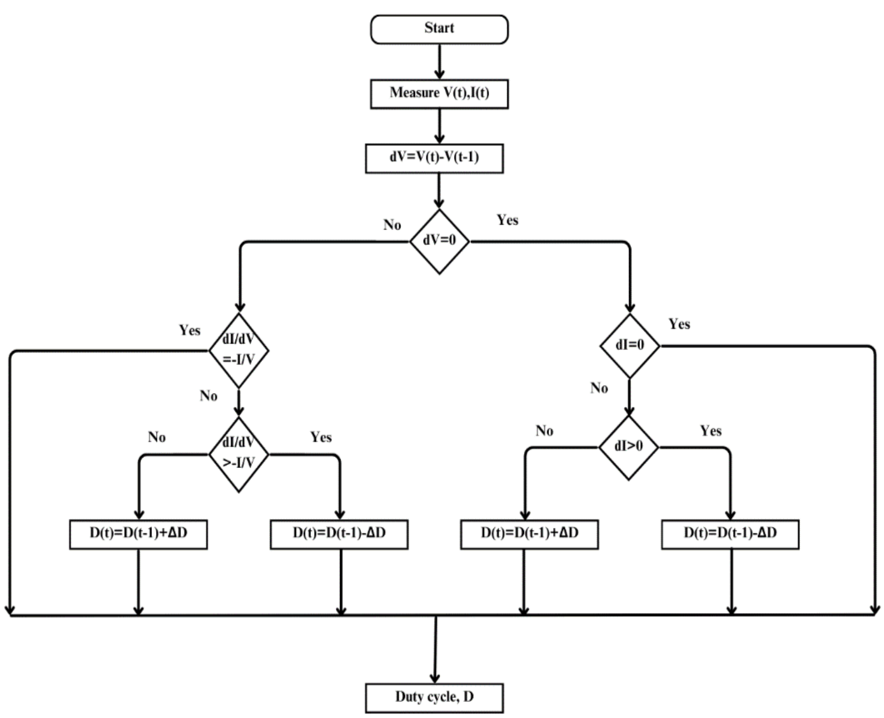

Fig. 1 Flow chart of the incremental conduction method

C. Inverter for V/F Control Technique

An Inverter circuit is a topology used to convert DC voltage into AC voltage. The dc voltage obtained from the solar panel acts as a dc-link voltage for the inverter which is converted into AC by the inverter. In an inverter, there are many PWM techniques used for conversion. For example, single pulse width modulation, Multiple Pulse Width Modulation, Sine Pulse Width Modulation, Unipolar, and Bipolar Pulse Width Modulation. Here, Sine Pulse Width Modulation (SPWM) technique is used by us to give pulses to the IGBTs of the inverter. PWM pulses are generated with the help of sine-triangle comparison. Here, the triangle will be a carrier signal, and the sine will be the reference signal. The output voltage of the inverter changes or is controlled by changing the modulation index and output frequency can be controlled by changing the frequency of the reference signal [13], [15].

In V/F control, the V/F ratio is maintained constant in such a manner that air gap flux remains constant. Hence, the speed of the induction motor can be controlled by controlling voltage and frequency in the same ratio, which provides constant maximum torque at any given operating speed. Currently, almost every application that uses induction motors implements this technology due to its many advantages. The main advantage of using an induction motor with V/F control is that, the induction motor does not draw a very high amount of current at starting and because of this it eliminates the use of the starter circuit used in the induction motor control circuit for starting of the induction motor.

III.DESIGNING OF IPM BASED SOLAR PUMP CONTROLLER

Here, the single-phase supply is transferred to an uncontrolled rectifier via variac. The variac changes the input voltage from 0V-230V. The rectifier output is ranging from 0-325Vdc. Then transfer that voltage to the IPM (Intelligent Power Module) board and to SMPS which convert the Uncontrolled input DC voltage into 15V DC for bootstrapping voltage required for Inverter Fig. 5.

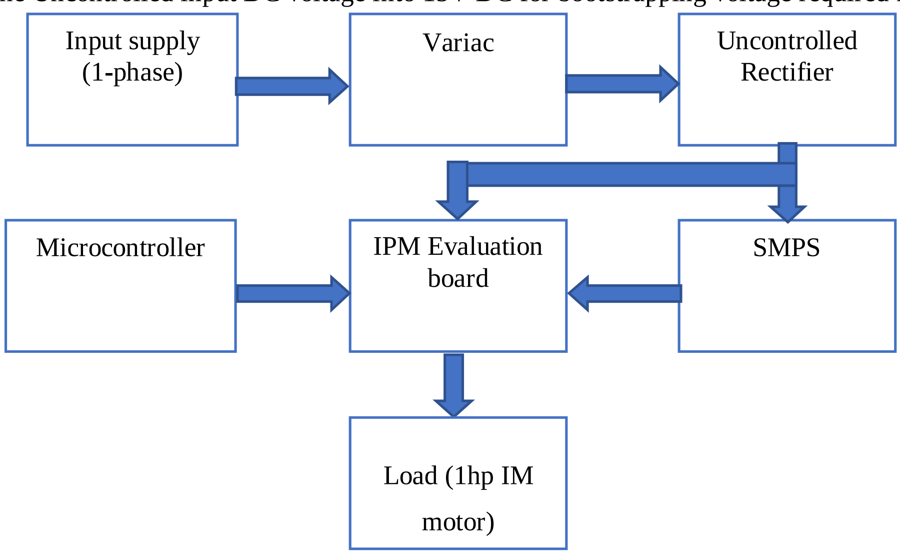

Fig. 2 Block diagram of IPM based solar pump controller

A. Component's Description

1) *Input supply*: The input supply can be AC or DC, if the supply is dc then it can be directly delivered to the IPM board, else with AC it can be controlled and converted to DC via Variac and Uncontrolled Rectifier. The Input range for this prototype is 1500W, 400Vdc max which can efficiently run up to a 2hp motor.
2) *IPM evaluation board*: IPM consists of IGBT switches and gate driver ICs in a single module which helps to reduce the complexity of the circuit and is efficiently implemented as a 3-phase inverter for motor drive. To increase its flexibility, the evaluation board is designed to work in single or three-shunt configurations and with double current sensing options such as three dedicated op-amps and a separate hall sensor.
3) *SMPS*: The SMPS is a type of regulated power supply that is designed to deliver a constant voltage to the load irrespective of change in input supply. Here, we have used it to deliver 15V DC to the IPM board which is used as bootstrap Voltage.
4) *Microcontroller:* A microcontroller is the brain of any electronic circuit or model. Here, in our model, it is used to provide gate signals to the Inverter circuit and to control and manage the operation of the Solar pump Controller

IV. IMPLEMENTATION OF SPWM TECHNIQUE

The phrase "Sinusoidal pulse width modulation" (SPWM) refers to a pulse width modulation technique applied to inverters. With the use of switching circuits, an inverter creates an output of AC voltage from a DC input to generate one or more square voltage pulses for each half cycle, which are used to make a sine wave. The output is considered to be pulse width modulated if the pulse size is changed. Per half cycle, several pulses are generated using this modulation. The pulse widths are comparable to the corresponding amplitude of a sine wave at this point because the pulses near the outer edges of the half cycle are continually smaller than the pulses close to the half cycle's centre. The widths of all pulses are increased or decreased while maintaining sinusoidal proportionality for modifying the effective output voltage. PWM (pulse width modulation) only modifies the pulses' on-time during amplitude changes.

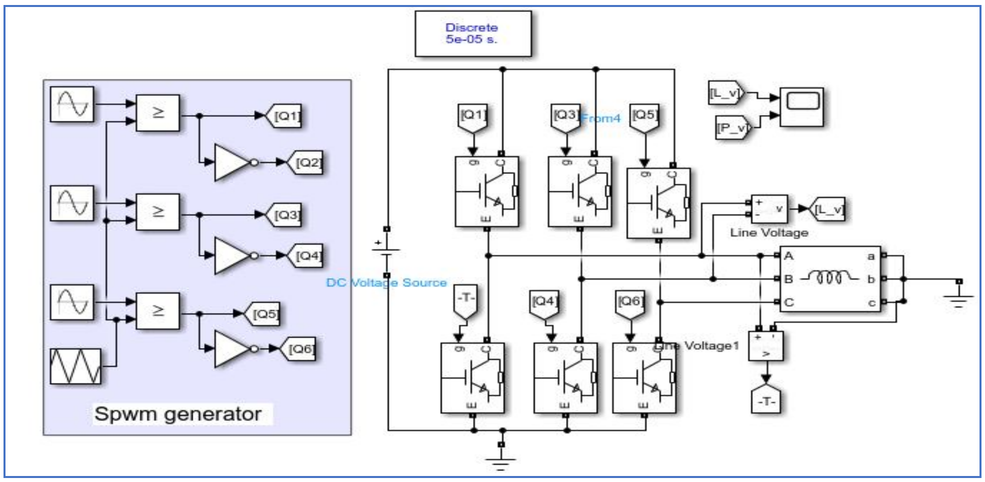

Fig. 3 Simulation diagram of SPWM based inverter

Fig. 6 shows the simulation diagram of SPWM based voltage source inverter. Through SPWM technique, by comparing a reference sinusoidal waveform with a triangular waveform the switching pulses are generated Fig.7.

Fig. 7 Gate pulse of SPWM based inverter

The reference waveform is generated at a fixed frequency, which is equal to our desired output voltage frequency whereas the carrier wave has typically a much higher frequency than the frequency of the reference wave. Generally, the carrier wave has a frequency of 1 kHz to 2 kHz. Here, we have considered the frequency of reference wave 50 Hz and carrier wave 1 kHz.

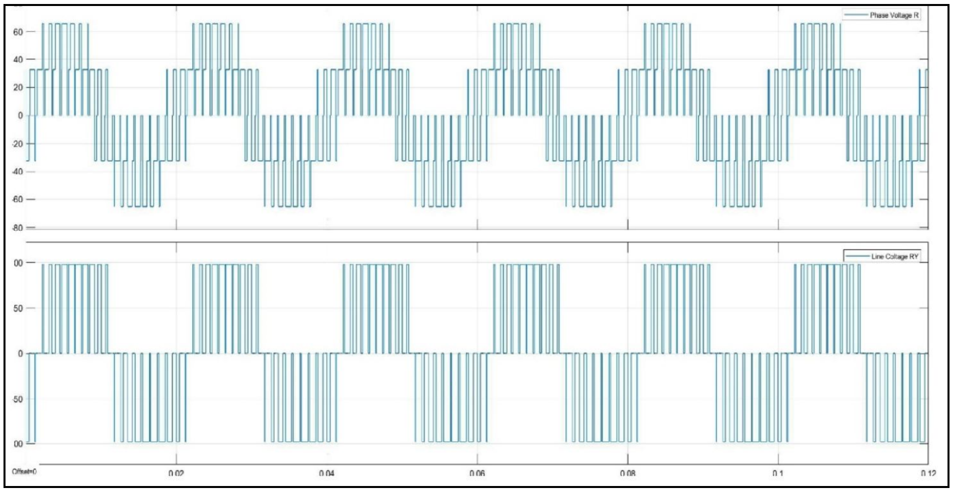

Fig. 8 Phase & Line Voltage Output waveform

In SPWM (Sinusoidal Pulse Width Modulation), the switching pattern is designed to make the output waveform closely resemble the desired sinusoidal waveform. This is accomplished by strategically turning the inverter devices on and off at specific times. The duration of each on/off state is determined by the width of the pulses in the pulse train.

The output voltage of the inverter can be described in terms of its line and phase voltages. The phase voltage refers to the voltage between the output terminals and the neutral point whereas the line voltage refers to the voltage between two of the three output terminals.

The line voltage and the phase voltage's relation in a three-phase system are described by: Line voltage = √3 x Phase Voltage. Here in Fig.8, the upper graph shows the waveform of Phase to ground voltage, where the other waveform represents the output of phase to phase (line voltage).

V. CONCLUSIONS

In conclusion, solar pump controllers offer an efficient and sustainable solution for managing solar-powered water pumping systems, encompassing both design and functionality. During the design process, careful consideration is given to optimizing the controller's performance and energy utilization. Factors such as maximum power point tracking (MPPT) algorithms, system voltage compatibility, and efficient power conversion are considered to ensure the controller's effectiveness. Additionally, the design incorporates features like overvoltage protection, dry run prevention, and remote monitoring capabilities to enhance reliability and user convenience. By integrating intelligent algorithms, these controllers dynamically adjust pump speed based on real-time solar irradiation levels, maximizing energy efficiency and water delivery. Overall, the design of solar pump controllers combines innovative technologies and engineering principles to provide a reliable and eco-friendly solution for sustainable water management.

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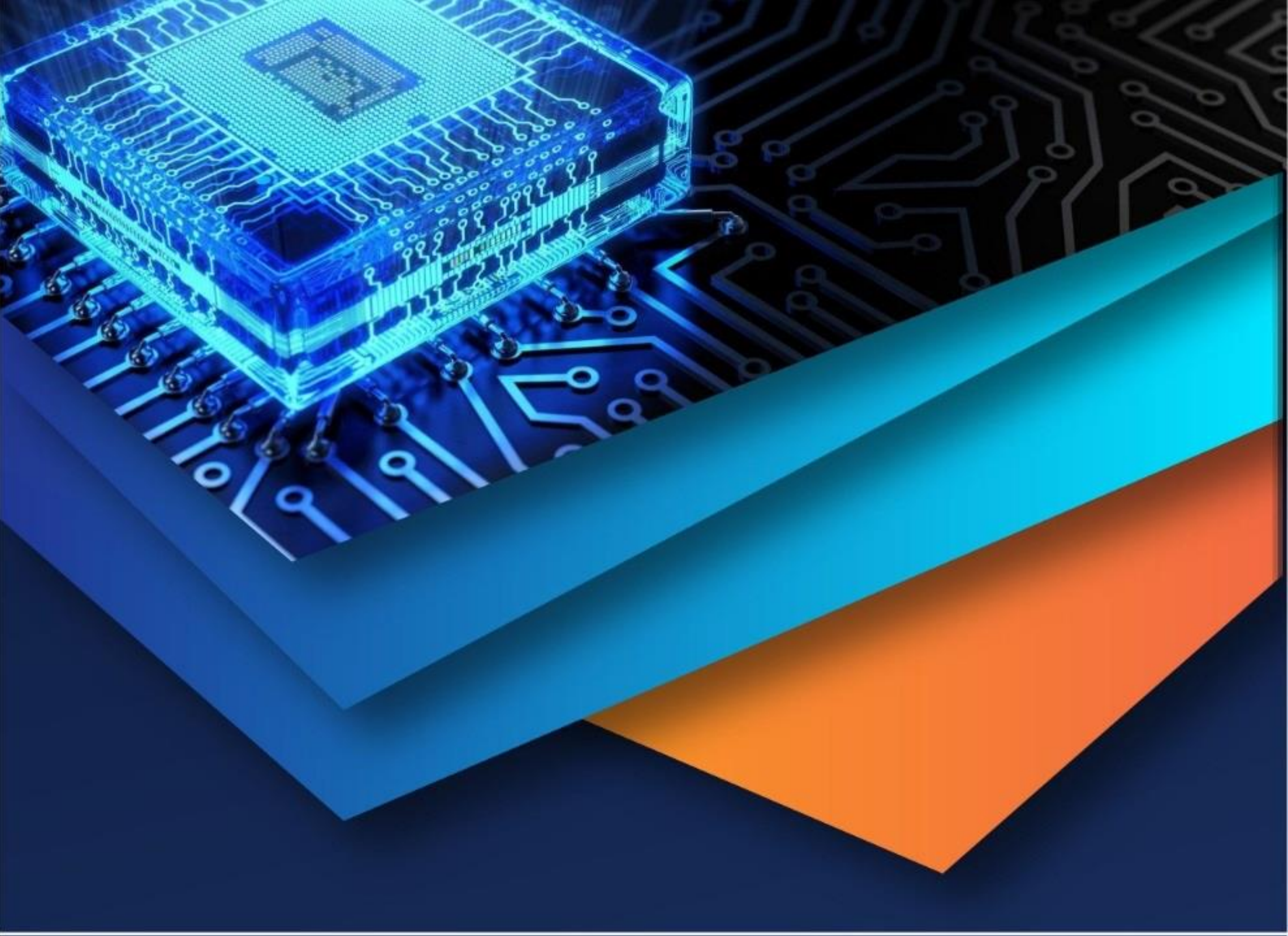

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