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Performance Enhancement of Solar PV Fed BLDC Motor Drive Using Fuzzy Logic Control with Zeta Converter

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Abstract: This paper proposes a simple, cost effective and efficient brushless DC (BLDC) motor drive for solar photovoltaic (SPV) array fed water pumping system. A zeta converter is utilized in order to extract the maximum available power from the SPV array. The integration of solar photovoltaic (PV) systems with Brushless DC (BLDC) motors offers an efficient and eco-friendly solution for applications such as water pumping and electric drives. However, improving dynamic performance parameters like starting response, overshoot, and settling time remains a challenge. This paper presents a performance enhancement strategy for a solar PV-fed BLDC motor drive by employing a Fuzzy Logic Controller (FLC) in conjunction with a Zeta Converter. The Zeta converter provides a continuous input current and voltage regulation, making it suitable for solar energy systems. The proposed FLC replaces the conventional PI controller to enhance the dynamic performance, particularly under varying irradiance conditions. Simulation results show that the FLC achieves smoother motor starting, reduced overshoot, and faster settling time compared to the PI controller, validating its effectiveness in renewable-powered drive systems.The proposed water pumping system is designed and modeled such that the performance is not affected under dynamic conditions. The suitability of proposed system at practical operating conditions is demonstrated through simulation results using MATLAB/ Simulink.

I. INTRODUCTION

The global shift toward renewable energy has brought solar photovoltaic (PV) systems to the forefront due to their clean, abundant, and decentralized nature. Among various applications, solar PV-fed motor drives have emerged as a reliable solution for rural water pumping and agricultural irrigation. Brushless DC (BLDC) motors are increasingly favored in such systems for their high efficiency, reliability, and low maintenance.

However, integrating solar PV systems with motor drives poses challenges due to the nonlinear and variable nature of solar irradiance. To address this, power conditioning circuits such as DC-DC converters and intelligent control strategies are essential. The Zeta converter is a suitable choice in PV applications due to its ability to both step-up and step-down voltage with continuous input current, making it ideal for PV systems.

Traditionally, Proportional-Integral (PI) controllers have been used for motor speed control. However, they often fail to maintain performance under dynamic and nonlinear conditions. In contrast, Fuzzy Logic Controllers (FLCs) offer a rule-based, nonlinear control approach capable of adapting to system uncertainties and fluctuations without requiring an accurate mathematical model.

In this study, a solar PV-fed BLDC motor drive is modeled using a Zeta converter for voltage regulation and a Fuzzy Logic Controller for speed control. The system's performance is analyzed and compared with a conventional PI controller through MATLAB/Simulink simulations. Key parameters such as rise time, settling time, overshoot, and steady-state error are evaluated to demonstrate the superiority of the proposed fuzzy-based system.

II. LITERATURESURVEY

The global push toward sustainable energy has led to increased research and implementation of renewable energy systems for rural and agricultural applications. Among these, solar photovoltaic (PV) powered water pumping systems have become particularly important due to their reliability, environmental friendliness, and ease of implementation in remote areas.

A comprehensive review by Gopal, Mohanraj, Chandramohan, Chandrasekar [01] covered various technologies including wind, biomass, and solar energy, with solar PV emerging as the most practical and adaptable option in regions with high solar insolation.

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The authors pointed out that while PV systems offer several advantages, their intermittent nature demands effective energy management and control mechanisms to ensure consistent performance. The study also highlighted the importance of selecting efficient motor drives and power converters to maximize the extraction of energy from PV panels and improve water pumping output.

The need for high-performance power conditioning units in PV-fed motor systems has led researchers to investigate various DC-DC converter topologies. Among them, the Zeta converter stands out due to its unique ability to both step-up and step-down voltage while maintaining continuous input current, which is ideal for PV sources.

In this context, Kumar and Singh [04] proposed a model effectively regulated the DC link voltage and allowed smooth operation of the BLDC motor under varying irradiance conditions. They also integrated Maximum Power Point Tracking (MPPT) to maximize energy extraction from the PV source. Their work confirmed that the Zeta converter offered superior voltage control compared to traditional buck or boost converters, especially in standalone PV systems. Furthermore, the Zeta converter's ability to reduce input current ripple contributes to longer PV panel life and more stable system behavior.

Traditional control techniques like Proportional-Integral (PI) controllers are often inadequate in systems with nonlinear dynamics or unpredictable environmental conditions, such as solar-powered drives. To address this, several researchers have explored the use of Fuzzy Logic Controllers (FLCs), which are rule-based and do not require an exact mathematical model of the system.

Maamoun,Alsayed,Shaltout [05] designed a controller was capable of adapting to changes in irradiance and load without performance degradation. The results showed that fuzzy logic improved the dynamic response, reduced torque ripple, and shortened settling time, all of which are critical for reliable motor operation. This approach proved more resilient and effective than the conventional PI controllers, especially in solar-powered applications where the input energy is not constant.

III. SYSTEM OVERVIEW

The structure of proposed SPV array fed BLDC motor driven water pumping system employing a zeta converter is shown in Figure 3.1(a). The proposed system consists of (left to right) a SPV array, a zeta converter, a VSI, a BLDC motor and a water pump. The BLDC motor has an inbuilt encoder. The pulse generator is used to operate the zeta converter. A step-by-step operation of proposed system is elaborated in the following section in detail.

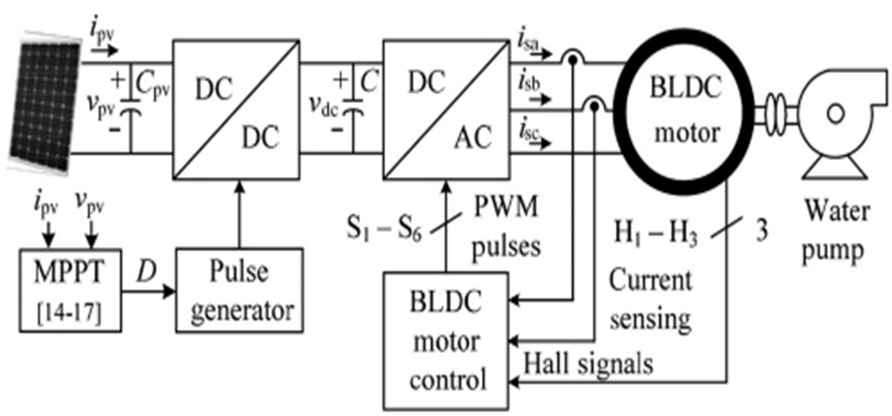

Figure3.1(a)Simplified SPV fed BLDC motor driven water pumping system

The SPV array generates the electrical power demanded by the motor-pump. This electrical power is fed to the motor-pump via a zeta converter and a VSI. The SPV array appears as a power source for the zeta converter as shown in Figure.3.1(b). Ideally, the same amount of power is transferred at the output of zeta converter which appears as an input source for the VSI. In practice, due to the various losses associated with a DC-DC converter, slightly less power is transferred to feed the VSI. The pulse generator generates, through INC-MPPT algorithm, switching pulses for IGBT (Insulated Gate Bipolar Transistor) switch of the zeta converter. The INC-MPPT algorithm uses voltage and current as feedback from SPV array and generates an optimum value of duty cycle. Further, it generates actual switching pulse by comparing the duty cycle with a high frequency carrier wave. In this way, the maximum power extraction and hence the efficiency optimization of the SPV array is accomplished.

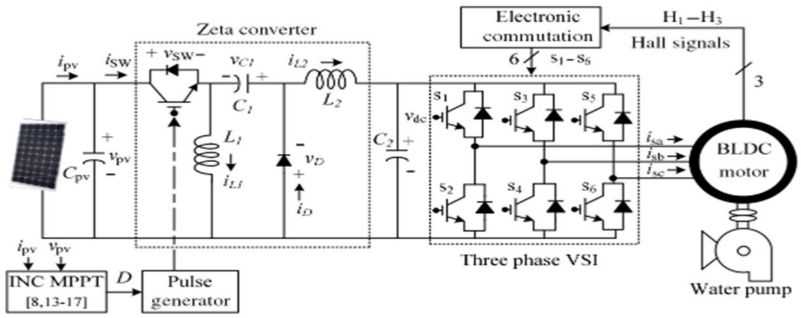

Figure 3.1(b) Proposed SPV-zeta converter-fed BLDC motor drive for water pump.

The VSI, converting DC output from a zeta converter into AC, feeds the BLDC motor to drive a water pump coupled to its shaft. The VSI is operated in fundamental frequency switching through an electronic commutation of BLDC motor assisted by its built-in encoder. The high frequency switching losses are thereby eliminated, contributing in an increased efficiency of proposed water pumping system

Fuzzy logic (EXTENSION) Fuzzy logic is a form of many-valued logic in which the truth values of variables may be any real number between 0 and 1. By contrast, in Boolean logic, the truth values of variables may only be 0 or 1. Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false. Furthermore, when linguistic variables are used, these degrees may be managed by specific functions. Usually fuzzy logic control systems are created from four major elements presented on Figure fuzzification interface, fuzzy inference engine, fuzzy rule matrix and defuzzification interface. Each part along with basic fuzzy logic operations will be described in more detail below

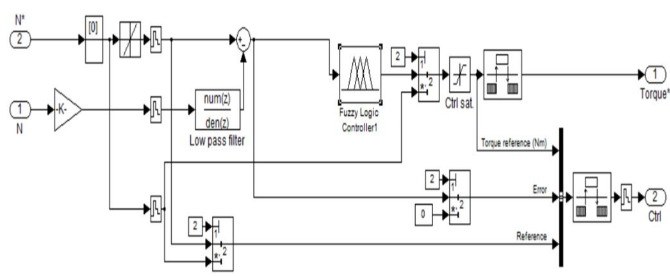

Figure.3.4.3fuzzy logic controller Simulink design

The fuzzy logic analysis and control methods shown in Figure can be described as:

1) Receiving one or large number of measurements or other assessment of conditions existing in some system that will be analyzed or controlled.
2) Processing all received inputs according to human based, fuzzy “if-then” rules, which can be expressed in simple language words, and combined with traditional non-fuzzy processing.
3) Averaging and weighing the results from all the individual rules into one single output decision or signal which decides what to do or tells a controlled system what to do. The result output signal is a precise defuzzied value.

IV. RESULTS AND DISCUSSION

A. *Overview of System*

Performances evaluation of proposed SPV array fed BLDC motor driven water pump employing a zeta converter is carried out using simulation results. The proposed system is designed, simulated considering the random and instant variations in the solar irradiance level and its suitability is demonstrated by testing the starting, steady state and dynamic behavior as illustrated in cases 4.2 to 4.5.To demonstrated the suitability of the system under dynamic condition, solar irradiance level is instantly reduced from 600 w/m2 to 200 w/m2 and then increased to 1000 w/m2 as shown Figure 4.3.1 and 4.5.1.

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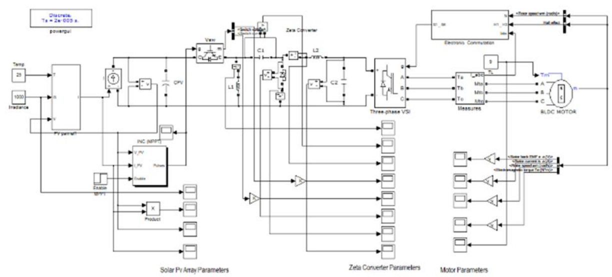


Figure 4.1(a)Proposed SPV-Zeta converter fed BLDC motor drive for water pump(constant irradiance)

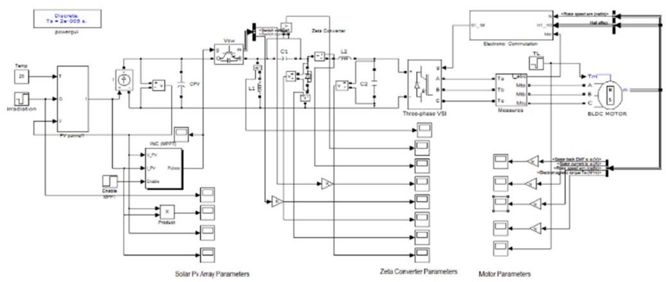


Figure.4.1(b)Proposed SPV-Zeta converter fed BLDC motor drive for water pump(variable irradiance)

1) Performance of SPV Array

SPV array exhibits the starting and steady state performances of SPV array at 1000 W/m2. The MPP is properly tracked. The tracking time is intentionally increased at the starting by adapting a low value of perturbation size (ΔD = 0.001) in order to achieve the soft starting of BLDC motor. The low value of ΔD causes the reduced rate of rise of DC link voltage of VSI resulting in a smooth and soft starting of the motor. However, a negligible tracking time is required under the dynamic variation in irradiance level.

2) Performances of Zeta converter

Steady state performances of zeta converter at 1000 w/m2. The input inductor current $i(\text{L1})$,intermediate capacitor voltage $v(C1)$, output inductor current $i(L2)$, voltage stress on IGBT switch $v(sw)$, current stress on IGBT switch $i(sw)$, blocking voltage of the diode $v(D)$,current through diode $i(D)$, and DC link voltage $v(DC)$ are presented. The zeta converter operates in CCM. The operation of the converter of this mode reduces the stresses on power devices and components. These converter indices the follow the variation in the weather condition and vary in proportion to the solar irradiance level, such as $i(L1)$,$v(C1)$, $i(L2)$ and$v(DC)$,the zeta converter is automatically changes its mode of operation from back mode to boost mode and vice versa according to the irradiance level in order to optimize the output power of SPV array. A small number of ripples in the zeta converter variables are observed caused by permitting the ripples up to an extent in order to optimize the size of the components.

3) Performance of BLDC Motor-Pump

The starting and steady state behaviors of the BLDC motor-pump at 1000 W/m2 is shown in Figure. 4.2.13, 4.2.14 and 4.4.13 to 4.4.14. All the motor indices such as the back EMF, *ea*, the stator current*is ia*, the speed, *N*, reach their corresponding rated values under steady state condition.

The soft starting along with the stable operation of motor–pump is observed and hence the successful operation of proposed system is verified. However, a small pulsation in *Te* results due to the electronic commutation of the BLDC motor. As the solar irradiance level alters, all the BLDC motor – pump indices vary in proportion to the solar irradiance level as shown in Figure.4.3.9 to 4.3.10 and 4.5.9 to 4.5.10 The BLDC motor always attains a higher speed than 1100 rpm, a minimum speed required to water pump at minimum solar irradiance level of 200 W/m2. Performances of the BLDC motor-pump is not deteriorated by weather conditions, and it pumps the water successfully as shown in figure 4.2.15 and 4.3.11 and 4.4.15 and 4.4.11.

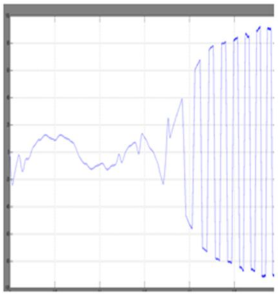


Figure 4.2.13 Motor phase voltage

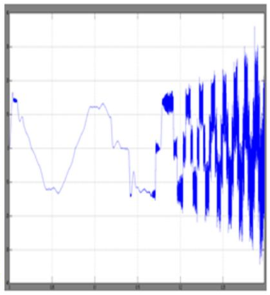


Figure 4.2.14 Motor stator current

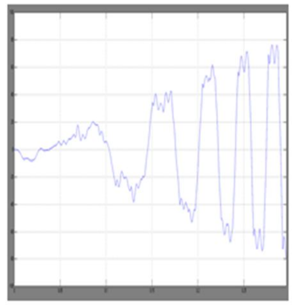


Figure 4.3.9 Motor Phase Voltage

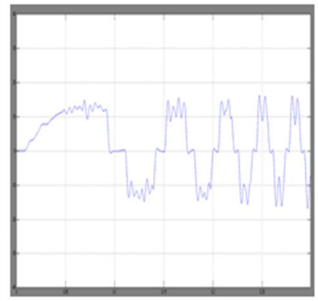


Figure 4.3.10 Motor Phase Current

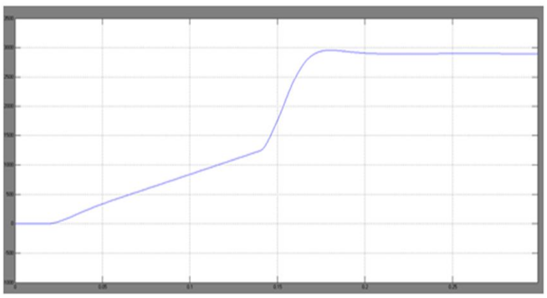


Figure 4.2.15 Motor speed

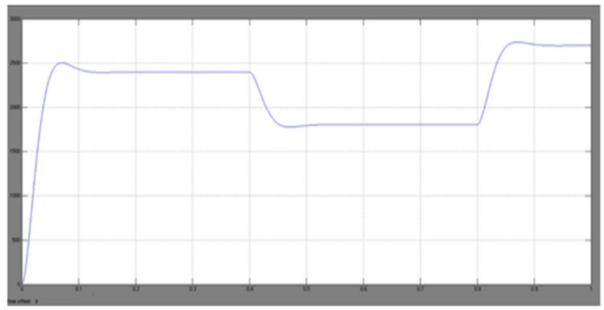


Figure 4.3.11 Motor Speed

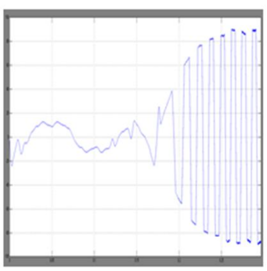


Figure 4.4.13 Motor Phase Voltage

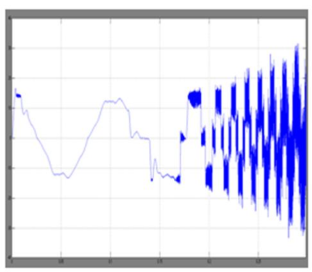


Figure 4.4.14 Motor Phase Current

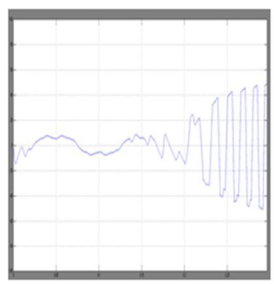


Figure 4.5.9 Motor Phase Voltage

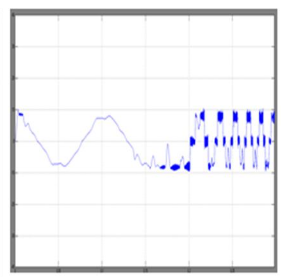


Figure 4.5.10 Motor Phase Current

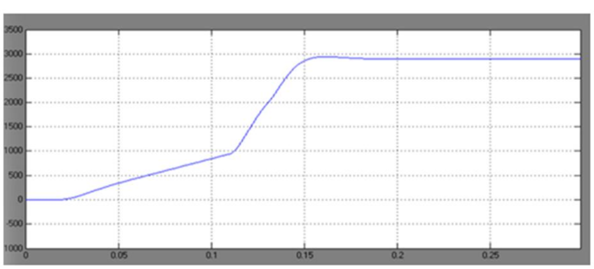


Figure 4.4.15 Motor Speed

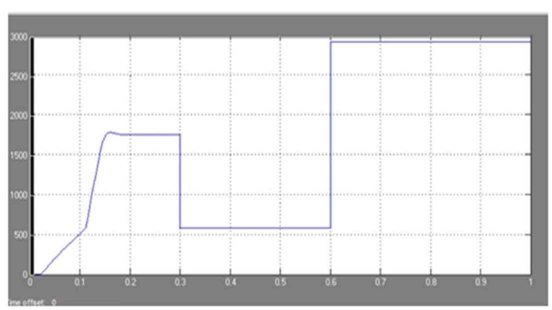


Figure 4.5.11 motor speed

The Table 1 compares PI Controller vs Fuzzy Controller in terms of Back EMF fluctuation (Ea) and Armature Current ripple (Ia) under both constant and variable irradiance. Back EMF (Ea %) represents the percentage fluctuation of motor's induced voltage. Lower values indicate smoother motor operation. Armature Current (Ia %) represents current ripple/distortion. Lower values mean less torque ripple and lower losses.

Case(Solar Irradiation)	Parameter	PI controller (%)	Fuzzy controller(%)	Improvement with fuzzy (%)
Constant irradiance	Back emf (Ea) fluctuation	45.34%	40.01%	5.33% smoother
	Armature (Ia) current	97.87%	52.27%	45.6% reduced ripple
Variable irradiance	Back emf (Ea) fluctuation	68.83%	64.99%	3.84% smoother
	Armature (Ia)current	84.59%	50.55%	34.04% reduceed ripple

Table 1 Comparison of Ea. and Ia using PI and fuzzy controllers

Solar irradiance variation is relatively slow compared to motor dynamics. Both PI and Fuzzy can track these gradual changes reasonably well. Therefore, the difference between PI and Fuzzy under irradiance fluctuation is small (only 3–5%).

In other words, Fuzzy's adaptive advantage is less visible when the disturbance is slow and smooth, but very clear when the disturbance is fast (motor current/voltage ripple).

<u>Under constant irradiance</u>:

Back EMF fluctuation reduced from 45.34% (PI) to 40.01% (Fuzzy) about 5.33% improvement. Armature current ripple reduced drastically from 97.87% (PI) to 52.27% (Fuzzy) about 45.6% improvements shown in Figure. 4.4.13 and 4.4.14 for fuzzy and Figure. 4.2.13 and 4.2.14 for PI.

<u>Under variable irradiance</u>:

Back EMF fluctuation reduced from 68.83% (PI) to 64.99% (Fuzzy) about 3.84% improvement. Armature current ripples reduced from 84.59% (PI) to 50.55% (Fuzzy) about 34.04% improvement. as shown in Figure. 4.5.10 and 4.5.9 for fuzzy and Figure. 4.3.9 and 4.3.10 for PI.

Fuzzy controller achieves significant reduction in current ripple, which improves efficiency and smoothness of motor torque. Back EMF fluctuations are also minimized, though the improvement is smaller compared to current ripple.

Table 2 compares settling times of PI vs Fuzzy controller based on motor speed (RPM) response. Settling time is the time taken for the speed to reach and stay within a steady-state value after disturbance ,Lower settling time indicates faster dynamic response and better control adaptability

Case(solar irradiation)	PI settling time(s)	Fuzzy settling time(s)	% Improvement in settling time	Remarks
Constant irradiation	0.26 s	0.20 s	23.1% faster	Fuzzy gives quicker and smoother speed achievement
Variable irradiation	0.11 s	0.07 s	36.4% faster	Fuzzy tracks step changes more smoothly with reduced overshoot/undershoot

Table 2 Comparison of settling time(ts) of motor using PI and fuzzy controllers.

Fuzzy logic provides faster speed achievement, ensuring the BLDC motor reaches reference speed more quickly than with PIUnder variable solar input, the advantage of fuzzy is more evident (≈36% faster response), showing its ability to handle nonlinear and uncertain conditions better. Overall Fuzzy controller ensures quicker, smoother, and more reliable speed tracking, making it superior to PI for solar-based BLDC pumping.

V. CONCLUSIONS

The SPV array zeta converter fed VSI-BLDC motor pump has been proposed and its suitability has been demonstrated through simulated results. The proposed system has been designed and modeled appropriately to accomplish the desired objectives and validated to examine the various performances under starting, dynamic and steady state conditions. This work presents an efficient control strategy for a solar photovoltaic-powered BLDC motor drive using a Zeta converter and a fuzzy logic controller. The integration of the Zeta converter ensures stable and continuous voltage regulation, effectively accommodating the variable nature of solar irradiance. The fuzzy logic controller, when compared to a traditional PI controller, significantly improves the system's dynamic response by offering smoother motor starting, reduced overshoot, faster rise time, and shorter settling time.

Simulation results validate the superior performance of the fuzzy logic-based system in terms of accuracy and adaptability under fluctuating solar input conditions. The enhanced drive system is well-suited for water pumping applications in off-grid or rural locations where energy reliability and minimal maintenance are critical. Overall, the combination of intelligent control and efficient power conversion offers a promising solution for sustainable and high-performance solar water pumping systems. Fuzzy reduces electrical ripples and fluctuations, making the motor operate more efficiently, reduces settling time significantly, ensuring faster and smoother speed response. Together fuzzy over PI provides 23–46% improvement in real performance metrics.

REFRENCESES

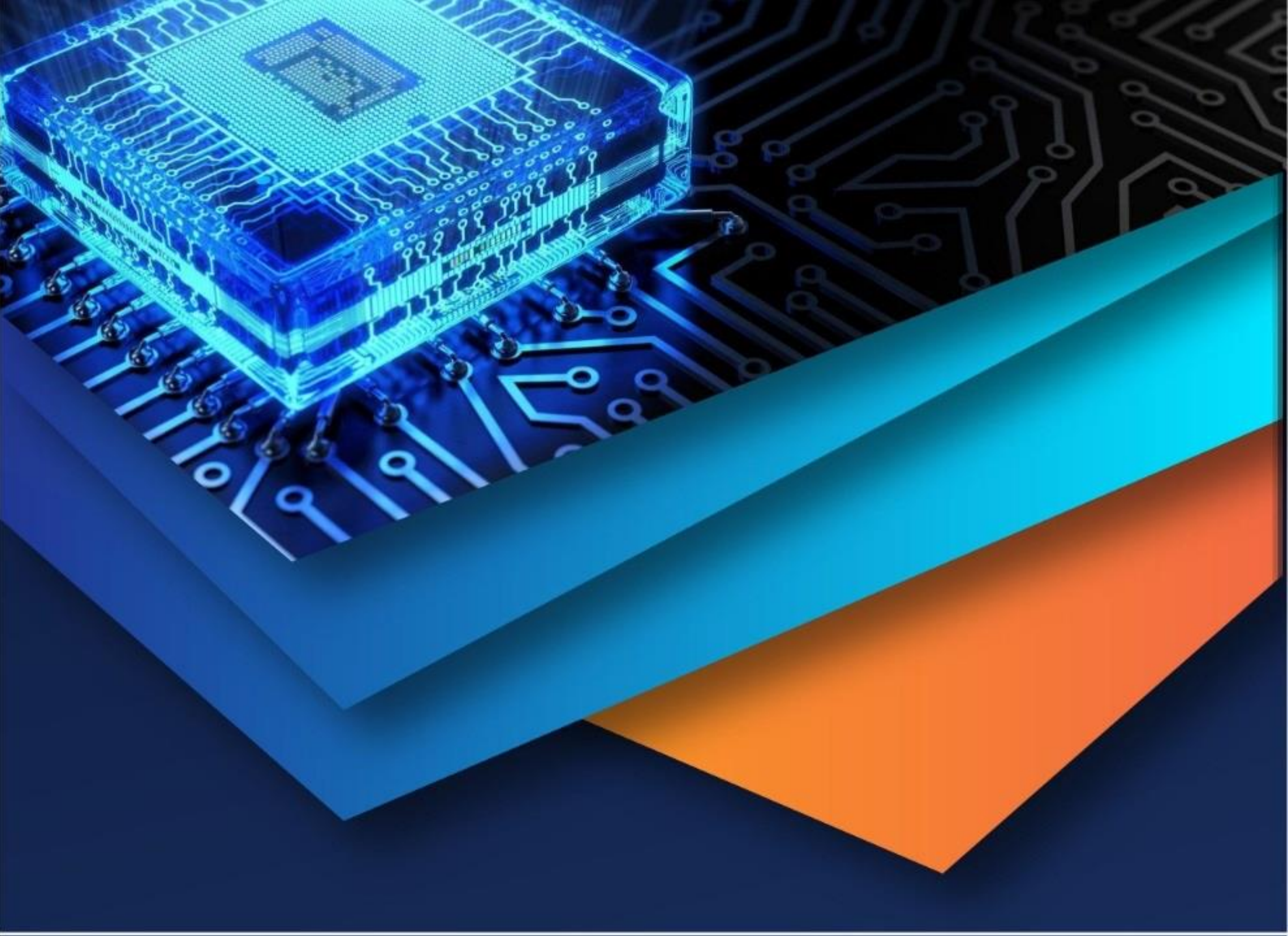
[1] C. Gopal, M. Mohanraj, P. Chandramohan and P. Chandrasekar, "Renewable Energy Source Water Pumping Systems—A Literature Review," Renewable and Sustainable Energy Reviews, vol. 25, pp. 351- 370, September 2013

[2] Z. Xue song, S. Daichun, M. Youjie, and C. Deshu, "The simulation and design for MPPT of PV system based on incremental conductance method," in Proc. WASE Int. Conf. Inf. Eng. (ICIE), Aug. 14–15, 2010

[3] R. Kumar and B. Singh, "Buck–boost converter fed BLDC motor drive for solar PV array based water pumping," in Proc. IEEE Int. Conf. Power Electron. Drives Energy Syst. (PEDES), Dec. 16–19, 2014

[4] R. Kumar and B. Singh, "BLDC motor driven solar PV array fed water pumping system employing zeta converter," in Proc. 6th IEEE India Conf. Power Electron. (IICPE), Dec. 8–10, 2014

[5] A.Maamoun,Y.M.Alsayed,A.Shaltout, "Fuzzylogic based speed controller for permanentmagnet synchronous motor drive", in IEEE International Conference on Mechatronics andAutomation (IEEE, 2013), pp. 1518–1522



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