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A Composite Control Method for Power Quality Enhancement: PI Controller with Neural Network

Pratibha Tiwari[1], Nisheet Soni[2]
[1]Master Candidate, [2]Asst. Professor, Jabalpur Engineering College, Jabalpur, Madhya Pradesh – 482005, India

Abstract: The number of installations of Micro-Grid will increase to quadruple by 2020. The purpose is to improve the power quality while reducing the cost and the consumption of electricity in transmission and distribution networks, using a hybrid system powered by solar and wind sources, as well as integrating storage devices. This paper reviews and discusses the Micro-Grid Model with PI controller and neural network for power quality enhancement. Then, a comparative study of different battery types used for large-scale electricity storage is carried out, followed by a review of control strategies. In this research work, designed a model in MATLAB 2015A, indicating all the power quality parameters.
Keywords: Power quality, hybrid, solar, wind, Power converter, Micro-grid, PI controller

I. INTRODUCTION

Today, the high penetration of hybrid renewable energy sources (HRES) and the reduction or complete CO2-free systems is being widely accepted and included in energy policies all over the world [1]. Micro-grids have become a promising solution to handle local energy supply and increase the reliability of electrical power systems. Among the reasons to adopt microgrids as feasible solutions, there is their relatively low environmental impact, ability to meet the diverse needs of end users for higher-quality power supplies, the restructuring of the electric power industry, and restrictions on the extension of power transmission and distribution facilities [2]. Electrical power systems can minimize increasing fuel costs by introducing renewable energy (RE) generation into their energy system. In the past, RE technologies were costly affairs due to low efficiencies and high prices. However, the cost of such technologies has decreased over recent decades along with an increased efficiency e.g., on photo voltaic (PV) panels and wind turbines. The cost reduction of RE technologies is caused by growing global investments [3]. As a result, challenges such as the high intermittence of renewables and the design of such systems should be addressed. Several policies, models, and frameworks have been reported in the literature. For example in [4] there is an extensive literature review in the context of rural energy microgrid planning in different economic scenarios. The authors show how social and political factors considerably affect the overall performance and feasibility of the final solution. In [5] a jointly optimization energy portfolio of conventional power source, solar, wind, battery, and demand response was developed.

Micro-grid (MG) is defined as a voltage-distribution network with distributed renewable energy sources (RES), storage devices and loads. Generally, MG could be operated in either grid-connected or stand-alone [1]-[3]. In the literature, several combination of RES have been proposed, such as, Wind Turbine (WT)/DG (Diesel Generator) [4], Photovoltaic (PV)/FC (Fuel Cell), WT/PV [1],[5]-[9], WT/PV/DG [8],[10], WT/PV/FC/MT (Micro-Turbine) [3], PV/DG [11], PV/WT/FC [1].

II. THEORETICAL BACKGROUND

The Department of Energy (DOE) defines the microgrid as “a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode” [13]. The main functions of microgrids can be defined as [14, 15]:

A. Provide enough and continuous energy
B. Internal control and optimization strategy
C. Can connect and reconnect to the grid
D. Used as a flexible entity to provide services to the grid or energy market
E. Applicable to various voltage levels
F. Includes an energy storage.

According to [14], microgrids can provide economic, environmental, and technical benefits to the relevant stakeholders, e.g., consumers and Distribution System Operators (DSOs) (shown in Figure 1). Consumers can get cheap electricity either from microgrids or the main grids. DSOs can benefit from the local generation and demand management initiatives to reduce the load on distribution grids at peak periods. Micro generators can benefit from providing electricity to the micro-grids or the main grids. Some governments provide subsidies to the micro generators for using renewable energy technologies. There are two environmental benefits of the microgrid: the reduction of greenhouse gas emissions and the adoption of more energy-efficient energy supply solutions [16].

III. CONTRIBUTION

Due to the reliability of available renewable energy sources throughout the year and the commercial availability of different appliances, there are still ambiguities on off-grid system preferences, as well as on the selection of appliances with different efficiency levels for diverse applications, as well as on the system sizing. On the other hand, there is also limited literature on the electrification of off-grid schools. To address this knowledge gap and contribute to the literature in the area of the energy supply system of off-grid schools, this paper proposes the design and modeling of a DC-microgrid for off-grid schools' application, based on different load estimation and generation scenarios. The main objective of this paper is to design and model a standalone DC microgrid composed of a solar PV system, system controller and battery storage system using MATLAB/Simulink for rural off-grid energy-efficient school applications. In many studies [5,6] of off-grid solutions for rural energy access SIMULATION SOFTWARE and other mathematical models are used as design and optimization tools. In this study, MATLAB/Simulink is used due to its higher flexibility compared with SIMULATION SOFTWARE. It has the advantage of to easily modify the system and optimization rules depending on the analysis outputs and optimizations needs, whereas in SIMULATION SOFTWARE it is not possible to change the design and the model except the inputs such as load demand and energy sources, as well as optimal cost for each energy sources. On the other hand, the chosen modeling and optimization tool for this study allows the assessment of data, development of algorithms, build and deployed models.

A. Power Quality Problems

Manufacturers have developed a range of equipment to help consulting engineers and facility personnel address specific power-quality issues. In some cases, the options are pretty cut and dried, while situations may require a bit more thought.

1) *Transients:* Transient voltage surge suppressors are the best option for protecting against transients in a power system.
2) *Voltage Sags and Interruptions:* The best choice here depends on extent of any interruption. Uninterruptible power supplies and other energy-storage options could do well with shorter-term sags or interruptions, but back-up generators or self-generation equipment is needed when longer outages are encountered. Other solutions could include static transfer switches and dynamic voltage restorers with energy storage.
3) *Harmonics:* Active filters are the recommended solution for harmonic mitigation, thanks to their flexibility and high correction performance. Alternative approaches could involve passive filters, multi-pulse arrangement transformers or harmonic correction at the equipment level (for example, by integrating harmonic filtering into variable speed drives).
4) *Power Factor:* Reducing power factor requires producing reactive energy as close as possible to connected loads.

IV. MICROGRID

The microgrid is nothing but the integration of number of renewable energy sources, storage system, and different power electronics converters for controlling the power flow between grid and load. Here the energy sources are solar PV/Fuel cell/Wind and battery. PV/Fuel/Wind and battery power is converted to DC power by using maximum power point tracking (MPPT) and boost converter and is again converted to AC by using inverter. In the last couple of decades, a major shift has been observed in power systems due to the change in generation and transmission systems. The need of improving power quality, optimizing the operation and maintenance cost, increasing energy access in places where the power grid far away, environmental and social sustainability, are some of the main reasons behind these changes. The increasing penetration of renewable energy sources along with the depletion of fossil fuels and its associated environmental issues and investment costs, are among the factors for the observed power system changes [6]. However, with the randomness and intermittence of renewable sources, like wind and solar power, it is necessary to integrate different renewable sources for their better utilization and to have continuous energy supply. With this regard, microgrids can have a key role to achieve these goals and accommodate the changes required in the current power system, as well as to supply energy locally for people located in rural and remote locations of developing countries [7].

A microgrid is a power system composed of distributed generation, loads, energy storage and control systems that can function as an isolated system or connected with the main grid. It is important to achieve more operational flexibility compared with conventional power systems. Microgrids can then provide solutions for commercial, industrial, and residential consumers in order to achieve objectives such as lower greenhouse gas (GHG) emissions; lower stress on the transmission and distribution system and ensure local, reliable, and affordable energy security for urban and rural communities [7–12]. Figure 4.1 presents a schematic diagram of a microgrid that consists of different components including distributed renewable generation, diesel generator, energy storage, loads connection to utility grid and control systems. Based on the compatibility among different components and operating voltage microgrids can be classified as AC and DC.

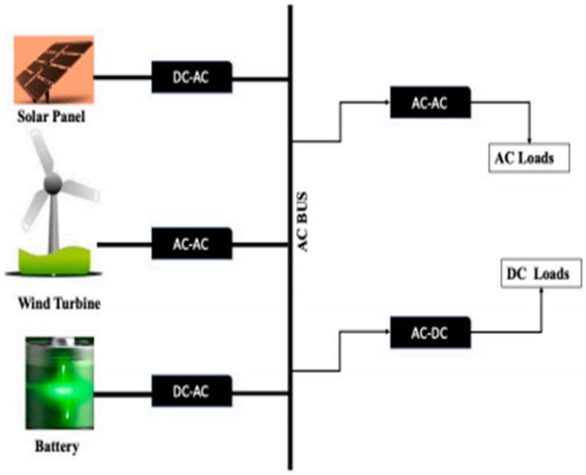


Figure 4.1. Typical off-grid AC microgrid.

A. Utility Grid

The utility grid is the distribution side energy source. The microgrid and UPQC is connected to the utility grid through a common bus. The linear and nonlinear loads are connected to PCC through UPQC.

B. Power Inverter/Converter

The purpose of DC to DC converter is required for PV system for proper voltage level at DC bus. It consists of MPPT with boost converter which will provide proper voltage and power at the output. In order to integrate the microgrid with the utility grid a power inverter is inserted in between these two.

V. COMPONENT OF MICROGRID

A. Flat Panel Photovoltaic Systems

A flat panel photovoltaic (PV) system will generate DC electricity in direct proportion to the amount of surface area that is exposed to sunlight. Modules are designed to supply this electricity at a certain voltage; however the current produced is directly dependent on how much light is absorbed by the system. Any desired combination of voltage and current can be produced by connecting an array of panels in a series or parallel topology. The PV panels themselves are comprised of modules, which are in turn comprised individual PV cells. Each PV cell is actually a very thin semiconductor wafer of photosensitive silicon or selenium that has been “doped” with boron (positively-charged, p-type material) and phosphorous (negatively-charged, n-type material) to increase its electrical conductivity to a level that is sufficiently for the cell to distribute charge and induce an electric field. By themselves, PV modules or arrays do not represent an entire PV system. Systems also include structures that point them toward the sun and components that take the direct-current electricity produced by modules and "condition" that electricity, usually by converting it to alternate-current electricity. PV systems may also include batteries and/or back-up generators. These items are referred to as the balance of system (BOS) components. Combining PV modules with BOS components creates an entire PV system. A system is usually everything needed to meet a particular energy demand, such as an industrial appliance, the lights in a home, or – if the system is large enough – the electrical demand of an entire community. A BOS may also include any or all of the following: a renewable energy credit revenue-grade meter, a maximum power point tracker (MPPT), a battery system and charger, a GPS solar tracker, energy management software, solar irradiance sensors, and an anemometer.

B. Wind Turbine Systems

A wind power system relies on the fluid flow of air to apply a force on its rotor blades, causing the turbine to rotate; the system will then convert the rotational kinetic energy of the turbine into DC electricity via an electric generator. The two critical factors for power generation are wind speed and the quality of wind. Environmental (buildings) and atmospheric factors (turbulence) can interfere with the available wind; thus wind turbines are most efficient when constructed in elevated, open areas. The primary difference between wind and solar systems is that wind systems convert pure mechanical (kinetic) energy into electrical power, whereas solar systems rely on chemical reactions and thermal properties to generate electrical power. Consequentially, the physical design of a wind turbine is far simpler than something like a PV array. A wind turbine's most visible components are its blades, which are aerodynamically designed to capture the maximum amount of the wind's kinetic energy. The blades turn a rotor, which in turn rotates a shaft. Ultimately, the most important part of any wind turbine is its generator, which is driven by the shaft and functions similarly to an electric motor. The generator consists of a rotor and a stator; the wind turbine's shaft is connected to the rotor such that it causes the rotor to spin, creating (inducing) a rotating magnetic field within the stator (stationary portion of the motor). This induced magnetic field (B) effectively rotates the North-South poles of the stator, which "pulls along" the loops on the armature (rotor) windings, ultimately causing the armature to "follow" the rotation of the field and create an electromotive force (E) that is harnessed as electrical power.

C. Proposed Hybrid PV/Wind Micro-grids

When a reliable grid can be accessed from the location at which renewable energy sources are being used, it is common for excess power generated by those renewable sources be fed into the main power grid. This allows consumers to save money on their electric bills because they are generating power for the electric company. Feeding some amount of renewable-sourced power back into the grid is also a common practice because batteries are one of the most expensive components in renewable systems' designs. Batteries take up space, need to be properly stored, require extra circuitry for control purposes, and even after all of that, they will still eventually need to be replaced. Although grid connection is a more common practice than battery storage, there are some challenges and considerations to take into account when connecting a renewable system to the main grid. The first challenge is making sure that the hybrid system will be able to reliably output the same voltage and frequency, so as to input that voltage and/or frequency into the grid on a continuous cycle. This is especially important for the grid side of the system, because if the voltage and frequency are not what they needs to be, then there will be a loss of power quality within the grid. In a PV-wind hybrid system, the power generated from both wind and solar components is stored in a battery bank for later use, thus increasing the reliability of the system. In some cases, the size of the battery storage may be slightly reduced compared to a pure-solar or pure-wind system, because the system is capable of generating power from more than one source. Wind speeds are often low in periods when the sun resources are at their best (summer). The wind is often stronger in seasons when there are fewer solar resources (winter). Even during the same day, in many regions worldwide or in some periods of the year, there are different and opposite patterns in terms of wind and solar resources. Additionally, these different patterns can render the hybrid systems the "best of both worlds" for power generation.

D. Battery Storage Considerations

The available power from the PV system is highly dependent on solar radiation. To overcome this deficiency, the PV module was integrated with the wind turbine system that requires a Cuk-converter. Towards this. When operating a PV, wind, or hybrid system, there are times when more power will be generated than what is needed to drive the load. In such a case, the extra power can be stored in a battery bank. Even in the case of a grid-connected system, a battery back-up is often preferred. Battery specifications to consider when designing a PV system include the charge/discharge cycle history, ambient temperature, and battery age. Lead-Acid batteries must not be overcharged, in order to avoid hydrogen particles to separate from the oxygen. Overcharging will cause the battery to start gassing, which results in water loss. Water loss will decrease the battery's charging efficiency and reduce the battery's operating life. Similarly, Lead-Acid batteries should not be undercharged because undercharging makes them susceptible to freezing, which also shortens their operating life. Many PV, wind, or hybrid systems are "sized" or rated in terms of their battery capacity. Ideally, a battery bank should be sized to provide power to a load for up to five days during inclement weather conditions [5]. If the battery bank is smaller than a three day capacity, the battery will be deep-cycling on a regular basis, which will shorten its operating life. Lead-acid batteries are used most frequently in PV systems, and various types include starting batteries, RV or marine "deep cycle" batteries, lead-calcium (Pb-Ca) batteries, and true deep-cycle batteries. A true deep cycle battery is a battery that delivers on average a few amperes of current to the load for hundreds of hours between charges. In contrast, shallow-cycle batteries deliver hundreds of amperes to a load in a very quick amount of time and then the battery is recharged, making them ideal for automobile applications [5].

E. Grid-Tied Hybrid System Simulation

The hybrid system operates on dual three-phase, 60Hz input signals. The wind turbine inputs an AC signal, while the PV array inputs a DC signal that must be inverted prior to the load bus. The two AC signals are joined at the load bus, which feeds into the main grid and/or an alternate AC load given in Figure 6. The hybrid model outputs a significant amount of data to the MATLAB workspace, which is vital for system analysis and proof of concept before construction. To prove the hybrid model's precision, separate simulations were run for the PV array and the wind turbine, with each being simulated under stand-alone and grid-connected conditions. In all four of these cases, the Simulink model compiled and the simulation ran smoothly and without errors.

F. Microgrid Power Quality Improvement Techniques and Solutions:

Power quality problems can be defined as the difference between the quality of power supplied and the quality of power required for reliable operation of the load equipment. Several types of power enhancement devices have been developed over the years to protect equipment from power disturbances. Some of the effective and economic measures can be identified as following:

1) Power conditioning devices
2) Custom power devices

We have used Power quality improvement in custom power device using PI controller.

VI. RESULT AND SIMULATION

The main objective of this paper was to design and model a microgrid system composed of a solar PV system, system controller and battery storage system for a primary school in the rural sub-Saharan region, using Ethiopia as a case study. For the design of the microgrid two load estimation and two scenarios of generation profiles were considered. The first scenario was the estimation of daily load based on standard efficiency appliances and the second scenario was the estimation of the daily load based on emerging high-efficiency appliances, which is one of the novel aspects of this study. On the other hand, the average maximum generation and average minimum generation days were considered to assess the system performance in both scenarios.

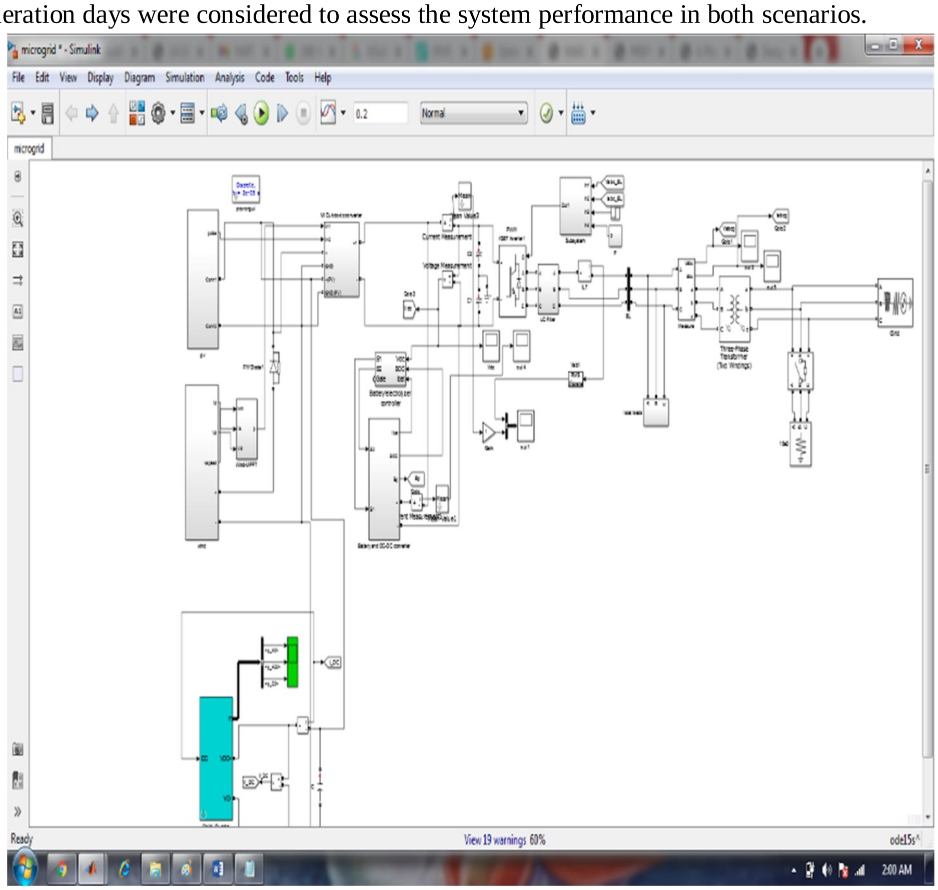
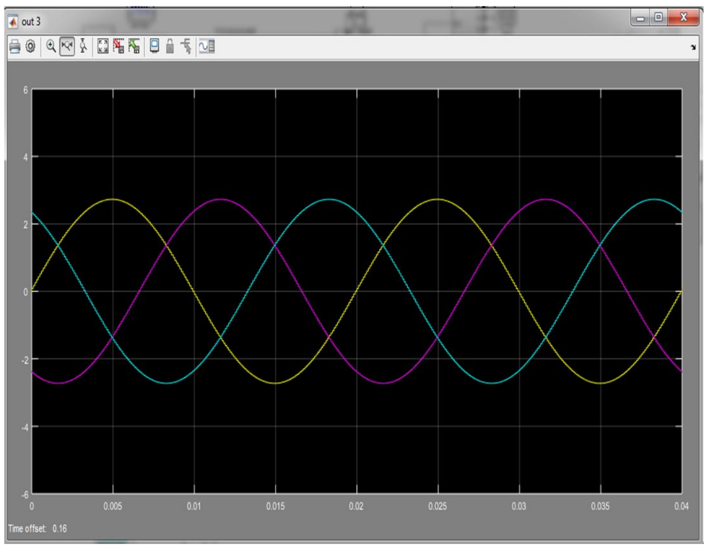


Fig (6.1) MATLAB microgrid modelling.

Fig (6.2) Transient response of Microgrid.



Fig(6.3) Voltage Outcomes.

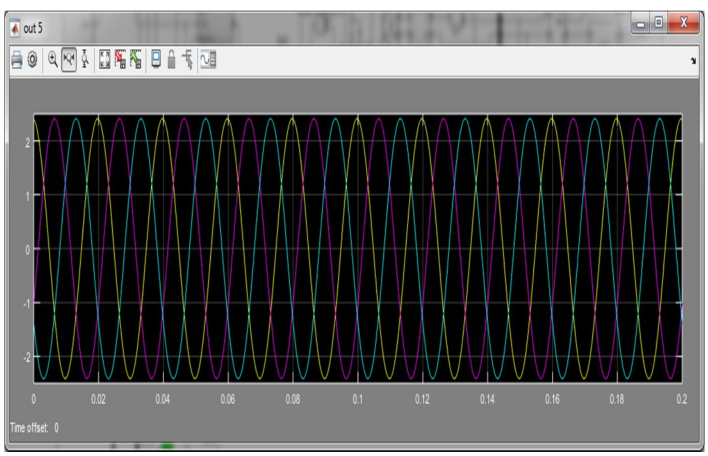


Fig (6.4) Current outcomes.

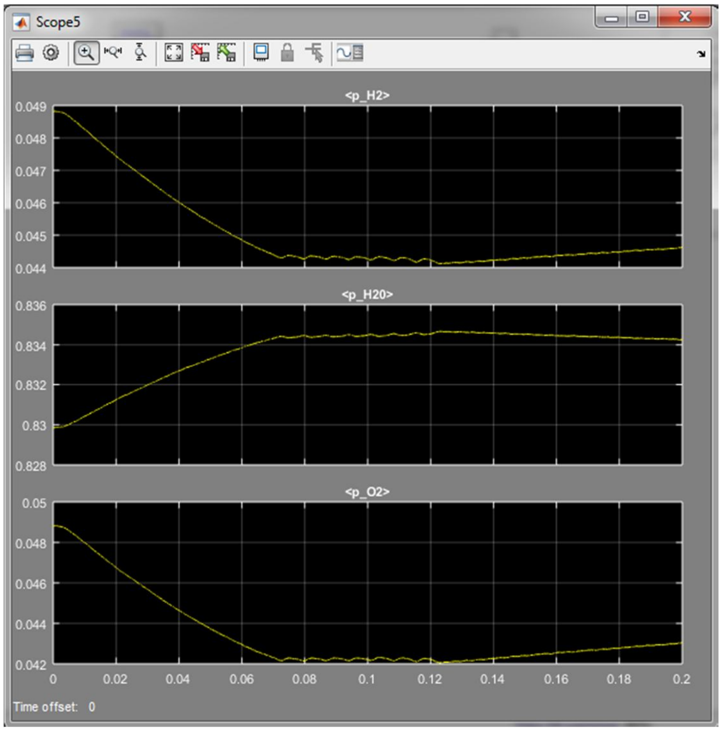


Fig (6.5) Fuel cell battery Outcomes.

VII. CONCLUSIONS

Summary In this paper, an isolated micro-grid model which contains miniature wind power system, PV system and energy storage system is built based on the MATLAB/Simulink environment. In order to improve the quality of electrical energy, a composite control method with PI controller and neural network is designed. Simulation result shows the presented control method is effective. The available power from the PV system is highly dependent on solar radiation. To overcome this deficiency, the PV module was integrated with the wind turbine system that requires a Cuk-SEPIC converter. Towards this end, a new multi-input Cuk-SEPIC converter stage for hybrid wind/solar energy systems has been presented. By implementing this converter, we can increase the power transfer efficiency, and we can extract maximum power from the hybrid system without any interruption.

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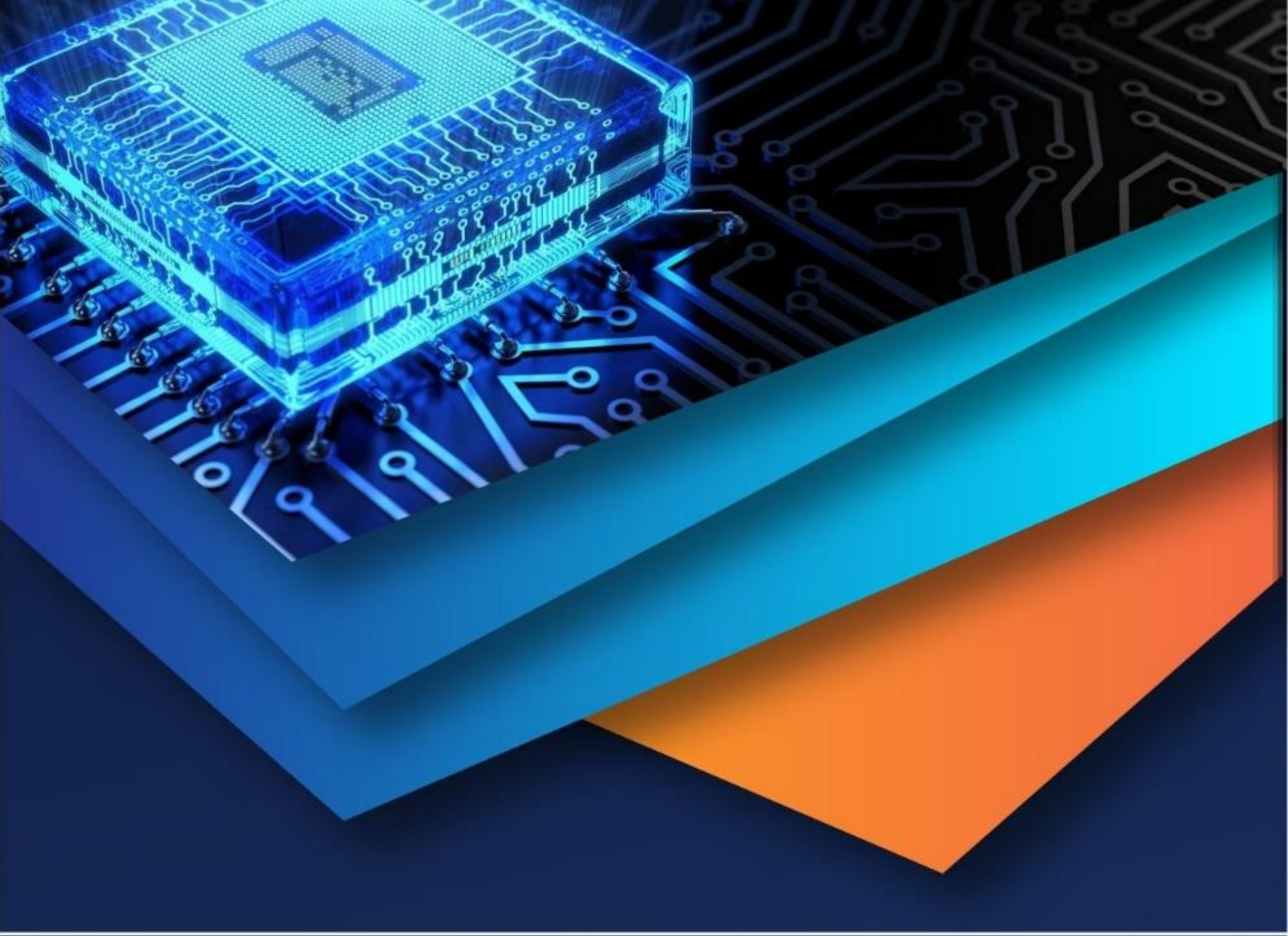

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