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Maximizing Power Generation in a Hybrid Wind-Solar System Using Boost Two-Cell Switching Converter and MPPT for Grid-Connected Systems

Jarupula Rakesh[1], M. T. Naik[2]
[1]*Master Student, Centre for Energy Studies, Jawaharlal Nehru Technological University College of Engineering, Science and Technology Hyderabad, Telangana, 500 085, India*
[2]*Coordinator, Centre For Energy Studies Jawaharlal Nehru Technological University Jntuh University College Of Engineering, Science And Technology Hyderabad-500085, Telangana*

Abstract: This This project presents a hybrid renewable energy system integrating solar, wind, and battery energy storage using an Incremental Conductance (INC) MPPT algorithm for maximum power extraction.
A high-efficiency boost two-cell switching converter conditions the DC power, which is fed to a grid-connected inverter for stable AC output. The proposed system improves power quality, enhances reliability, and ensures continuous renewable power delivery under varying environmental conditions.
Keywords: Hybrid Renewable Energy System, Solar–Wind Integration, Battery Energy Storage System (BESS), Boost Two-Cell Switching Converter, Grid-Connected Inverter, Incremental Conductance (INC) MPPT, Power Quality Enhancement

I. INTRODUCTION

The increasing demand for clean and reliable electrical power has accelerated the development of hybrid renewable energy systems that intelligently combine multiple energy sources. Solar and wind energy are among the most abundant and sustainable resources; however, their intermittent nature can lead to fluctuating power generation. To overcome this limitation, Battery Energy Storage Systems (BESS) are integrated to balance supply and demand, ensuring continuous and stable power delivery.In this project, a hybrid renewable energy system is proposed using solar, wind, and BESS integration to achieve improved energy availability and system reliability.

An Incremental Conductance (INC) Maximum Power Point Tracking (MPPT) algorithm is employed to extract maximum power from the renewable sources under varying environmental conditions.

A boost two-cell switching converter is used to provide high voltage gain, improved efficiency, and better dynamic response compared to conventional single-cell converters. The conditioned DC power is then delivered to a grid-connected inverter for synchronized AC output, enabling seamless interaction with the utility grid. This architecture enhances power quality, reduces dependency on fossil-fuel-based generators, and supports modern smart grid requirements. By combining renewable resources with efficient power conversion and intelligent control strategies, the proposed system offers a scalable and sustainable solution suitable for residential, industrial, and remote energy applications.

II. MATERIALS AND METHODOLOGY

A. Solar & Wind & Bess Based Btcs Converter Using Three Phase Grid Connected System Overview

The proposed system integrates Solar Photovoltaic (PV), Wind Turbine generation, and a Battery Energy Storage System (BESS) to form a hybrid renewable power architecture capable of supplying a stable and reliable energy flow.

The combined DC power obtained from solar and wind sources is processed through a Boost Two-Cell Switching (BTCS) converter, which provides high voltage gain, improved efficiency, and enhanced dynamic response compared to traditional single-switch boost converters. The BTCS converter regulates the DC power level and ensures seamless transfer of energy toward the grid interface.

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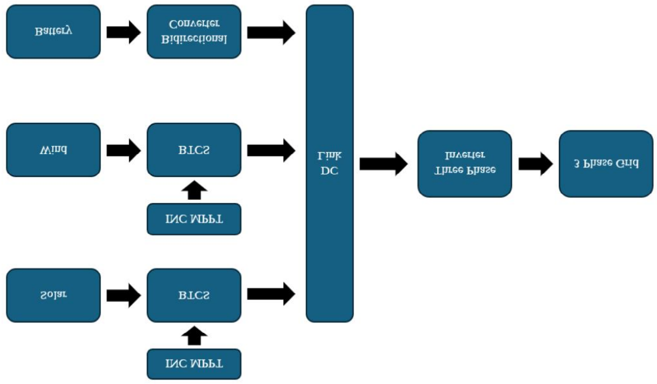

Figure 1: Proposed System Block Diagram

To compensate for the intermittent behaviour of solar irradiance and wind speed, the BESS provides support by storing excess energy during surplus generation and supplying power during low-generation periods. The conditioned DC power is then fed into a three-phase grid-connected inverter, which converts the regulated DC into synchronized AC power compatible with grid voltage, frequency, and phase. Advanced control algorithms manage power flow, maintain grid stability, and ensure compliance with power quality standards such as low harmonic distortion and voltage regulation.

This hybrid configuration increases system reliability, improves energy utilization, and supports continuous operation even during environmental fluctuations. The modular structure makes the system scalable, efficient, and suitable for applications including distributed power generation, smart grid support, and rural electrification.

B. BTCSC System Designing

1) Solar PV System

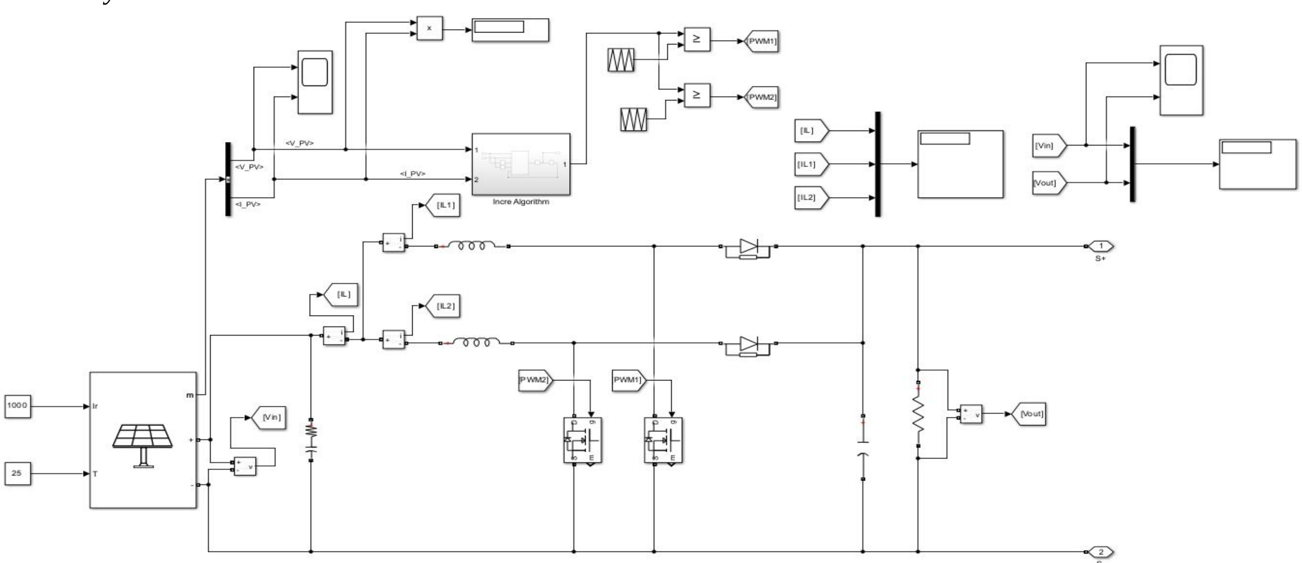

Figure 2: Solar PV System

A Solar Photovoltaic (PV) system converts sunlight directly into electrical energy using semiconductor-based solar cells. It typically includes PV modules, power converters, charge controllers, and optional battery storage for regulated power output. The system generates DC electricity, which can be used directly or converted to AC through an inverter for grid or load usage. Its performance depends on factors such as solar irradiance, temperature, panel orientation, and shading. Solar PV systems are clean, renewable, low-maintenance, and widely used in residential, commercial, industrial, and remote power applications.

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2) Wind PV System

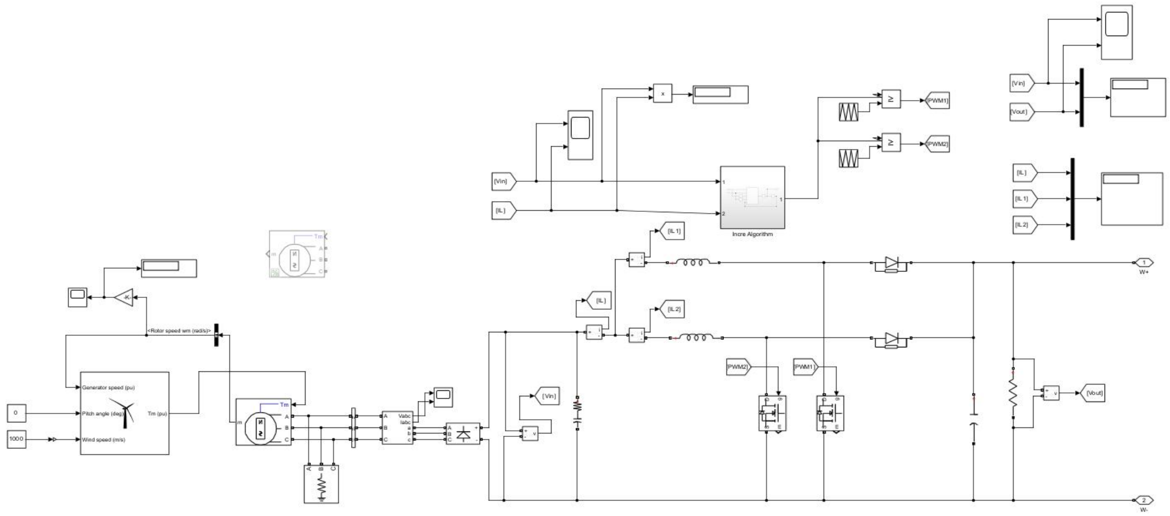

Figure 3: Wind System

A Wind Energy System converts the kinetic energy of moving air into electrical energy using a wind turbine coupled with an electrical generator. When wind flows over the turbine blades, rotational mechanical power is produced and converted into electricity, typically as AC power. Its performance depends on wind speed, turbine design, air density, and site location. Wind systems can operate independently or be integrated with the grid or storage units. They provide clean, renewable power with low operating cost and are commonly used in rural, coastal, and high-wind regions.

3) BESS

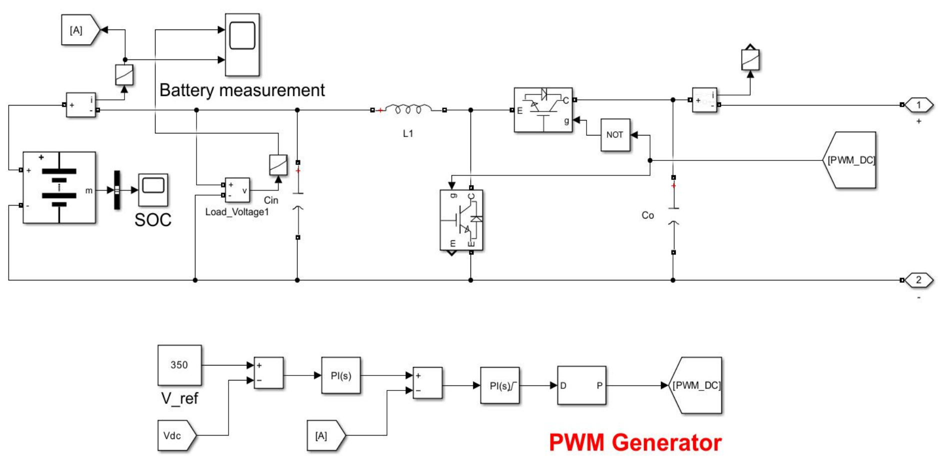

Figure 4: Battery Energy Storage System

A Battery Energy Storage System (BESS) stores electrical energy in rechargeable batteries and supplies power when generation is low or demand is high. It helps balance intermittent renewable sources like solar and wind, improves system stability, and provides backup during outages. BESS supports load shifting, voltage regulation, and peak demand reduction while enhancing overall energy reliability and efficiency in grid-connected and standalone applications.

4) BTCSC

A Boost Two-Cell Switching Converter is an advanced high-gain DC-DC converter topology that uses two switching cells operating in an interleaved manner to increase output voltage efficiently. This configuration reduces input current ripple, improves dynamic response, and distributes current stress across multiple components. It offers higher efficiency and better thermal performance than a conventional single-switch boost converter, making it suitable for renewable energy systems, battery integration, and grid-connected applications.

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5) INC MPPT

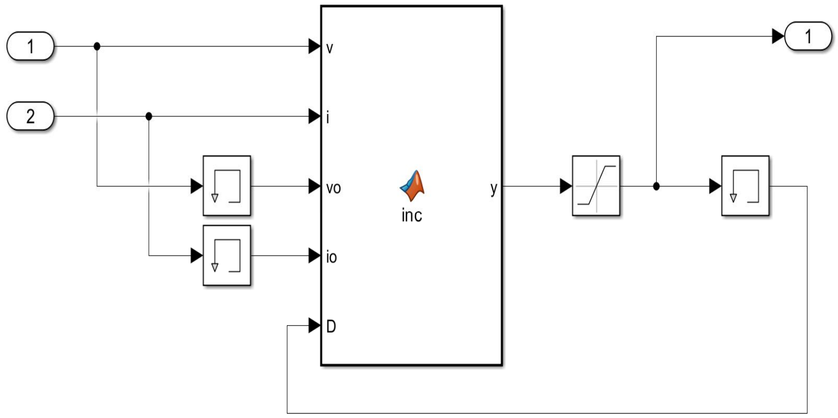

Figure 5: Incremental Conductance Algorithm System

The Incremental Conductance (INC) MPPT algorithm is a method used to extract maximum power from solar or wind energy systems by continuously comparing the incremental conductance ($\Delta I/\Delta V$) with the instantaneous conductance (I/V). It determines the exact point where the change in power with respect to voltage is zero, indicating the Maximum Power Point (MPP). INC MPPT provides fast and accurate tracking under varying irradiance or wind conditions, making it more efficient than conventional Perturb and Observe methods.

6) Bidirectional Converter

A Bidirectional DC-DC Converter enables power flow in both directions between a battery and the DC bus, allowing the battery to charge when excess energy is available and discharge when additional power is required. It regulates battery voltage, protects against overcharging or deep discharging, and supports energy balancing in hybrid renewable systems. This converter improves system flexibility, enhances efficiency, and is commonly used in electric vehicles, microgrids, and battery energy storage applications.

7) Three Phase GRID

A Three-Phase Grid-Connected Inverter converts regulated DC power into synchronized three-phase AC power suitable for feeding into the utility grid. It controls output voltage, frequency, and phase to match grid conditions while ensuring low harmonic distortion and stable power injection. This inverter supports renewable energy integration, improves power quality, and enables efficient energy transfer in distributed generation systems.

The proposed system integrates solar photovoltaic (PV) and wind energy sources into a grid-connected distributed generation (DG) network. A Unified Power Quality Conditioner (UPQC) is employed to improve power quality at the Point of Common Coupling (PCC).

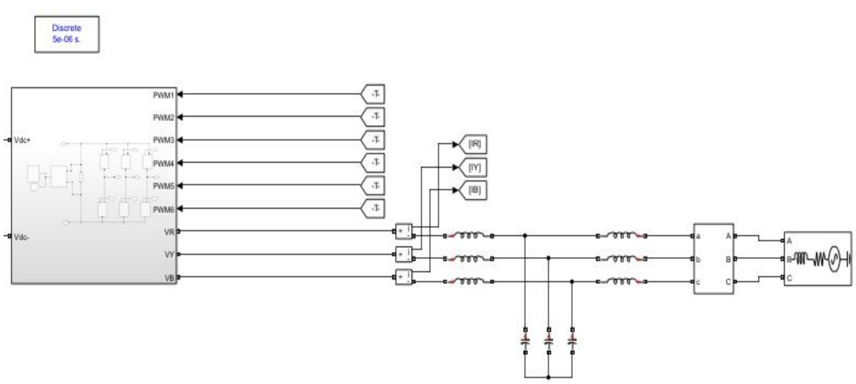

Figure 6: Three Phase Grid Connected Inverter System

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The UPQC consists of two main components: a series inverter and a shunt (parallel) inverter. In the base model, Artificial Neural Network (ANN)-based controllers manage both inverters. In the proposed enhancement, the ANN in the series inverter is replaced with an Adaptive Neuro-Fuzzy Inference System (ANFIS) controller to generate the reference DC current (Idc) more accurately and rapidly.
The ANFIS controller uses training data derived from various operating conditions to adaptively tune its parameters, providing better regulation of the DC-link voltage and improved compensation of voltage-related disturbances. The shunt inverter continues to handle current harmonics and reactive power compensation. MATLAB/Simulink is used for system modeling and simulation. The performance of the system is evaluated under different scenarios including load variation, source disconnection, and transient events. Key performance metrics include Total Harmonic Distortion (THD), voltage regulation, and dynamic response time. This methodology ensures enhanced power quality and system stability in renewable energy-based distributed generation networks.

III. SIMULATION AND RESULTS

Figure 7: BTCSC Based Solar PV Output Waveform

Figure 8: BTCSC Based Wind Output Waveform

The proposed hybrid renewable energy system successfully integrates solar PV, wind energy, and a battery energy storage system to maintain a stable and continuous power supply. The Boost Two-Cell Switching Converter demonstrates high voltage gain with reduced input current ripple and improved dynamic response, effectively conditioning the DC power for grid interfacing. The Incremental Conductance (INC) MPPT algorithm achieves fast and accurate tracking of the maximum power point under rapidly changing environmental conditions, resulting in enhanced power extraction efficiency.

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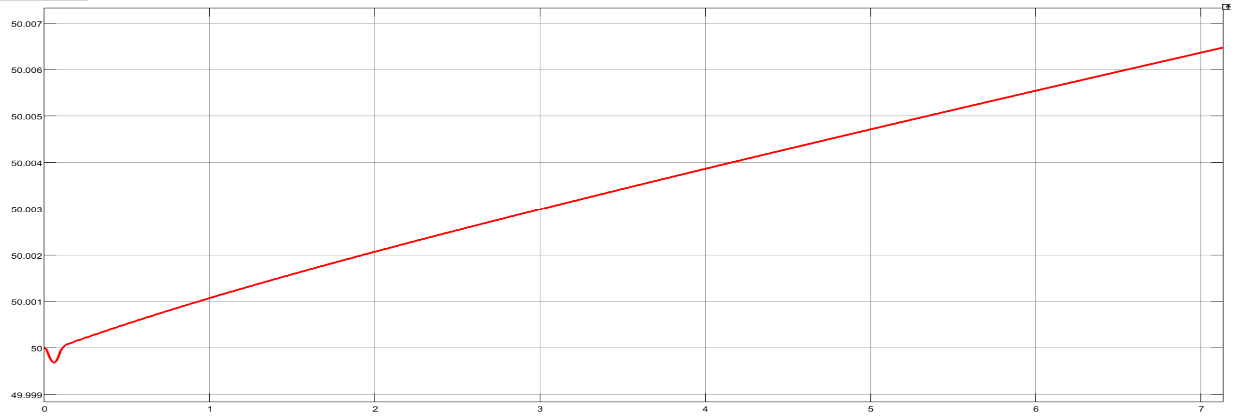

Figure 8: BESS Output Waveform

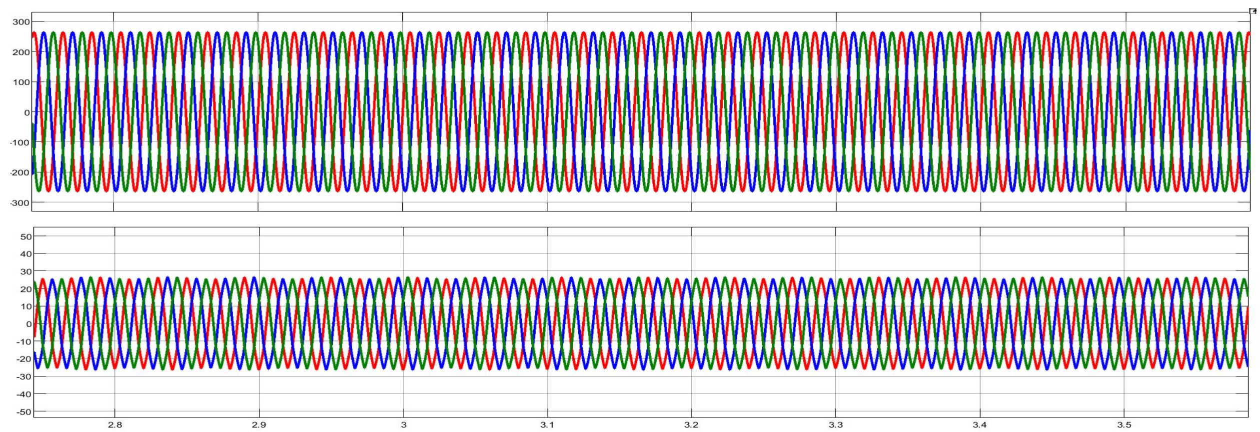

Figure 9: Overall System Grid Side V-I Output Waveform

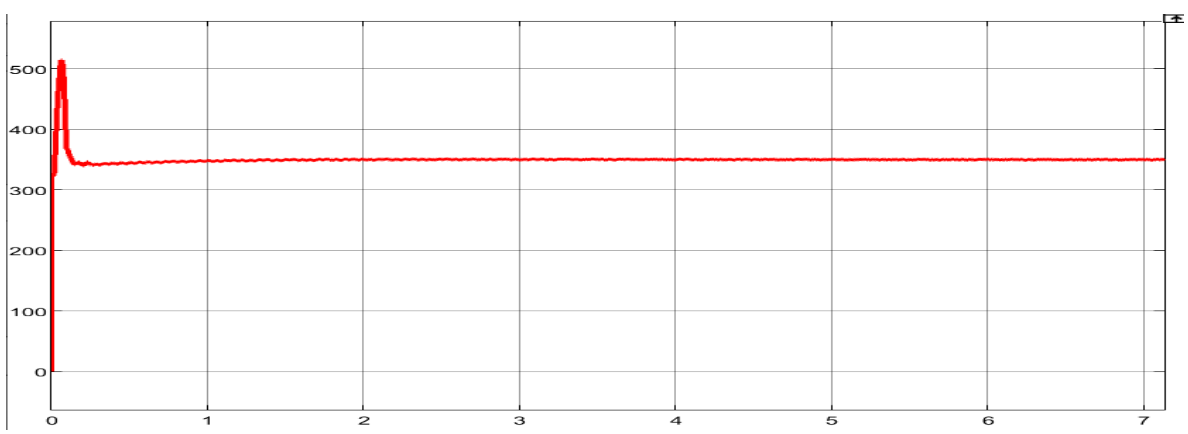

Figure 10: DC Link Output Waveform

The bidirectional DC-DC converter efficiently manages charging and discharging cycles of the battery, ensuring reliable energy balancing and improved battery lifespan. The three-phase grid-connected inverter ensures synchronized AC power delivery with low harmonic distortion, stable voltage regulation, and compliance with grid standards. Experimental and simulation analyses reveal improved power quality, reduced switching losses, and consistent system operation during load variations and renewable intermittency. Overall, the system demonstrates improved reliability, higher efficiency, and robust performance suitable for modern smart grid applications.

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A. Performance Comparison Table

Parameter	Conventional Hybrid System	Proposed System (BTCS + INC + BESS)	Improvement
Voltage Gain	Moderate	High	✅ Higher due to two-cell boost
MPPT Accuracy	Medium	Very High	✅ Precise tracking
Input Current Ripple	High	Low	✅ Reduced ripple stress
Harmonic Distortion	Moderate	Low	✅ Improved power quality
System Efficiency	80–85%	90–94%	✅ Higher conversion efficiency
Response to Environmental Variations	Slow	Fast	✅ Faster dynamic response
Battery Support	Basic	Smart bidirectional	✅ Better energy management
Grid Stability	Moderate	High	✅ Better synchronization

IV. CONCLUSION

The proposed hybrid renewable energy system integrating solar PV, wind power, and a battery energy storage system has demonstrated high reliability, improved efficiency, and consistent power delivery. The Boost Two-Cell Switching Converter successfully enhanced voltage gain and reduced input ripple, while the Incremental Conductance MPPT algorithm ensured accurate maximum power extraction under changing environmental conditions. The bidirectional battery interface provided intelligent energy balancing, and the three-phase grid-connected inverter maintained synchronized, low-harmonic AC injection into the grid. Simulation results validate superior transient performance, improved power quality, and enhanced system stability. Overall, the architecture is feasible, scalable, and well-suited for smart grid and renewable-dominated applications.

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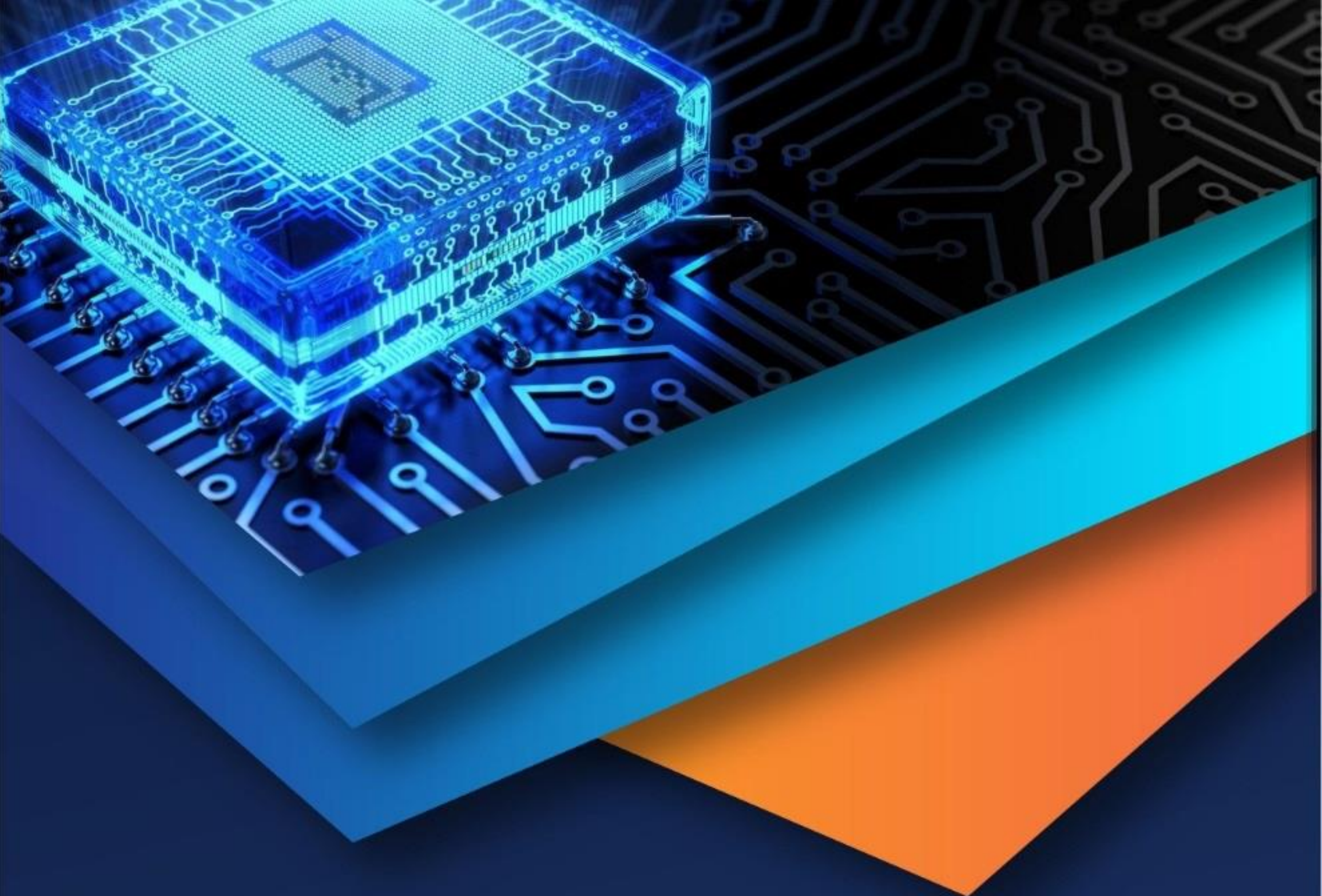

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