ISSN (Online): 2583-648X

IJIRID

International Journal of Ingenious Research, Invention and Development

An International, High Impact Factor, Double,Blind Peer,Reviewed, Open,Access, Multidisciplinary Online Journal

www.ijirid.in

Volume 4 | Issue 2 | April 2025

Design and Control of Wind, Solar and Battery Based DC Microgrid

Nikita T. Nagave[1], Karan A. Veer[2], Rutuja S. Jadhav[3], Prof. Chaitanya V. Deshpande[4]

[1,2,3]Student, Department of Electrical Engineering, Zeal College of Engineering and Research, Pune, India

[1]Assistant Professor, Department of Electrical Engineering, Zeal College of Engineering and Research, Pune, India

Abstract: *DC microgrids are increasingly recognized for their ability to enhance energy efficiency and integrate renewable energy sources, such as solar power. However, the incorporation of significant amounts of renewables introduces challenges related to voltage regulation, energy management, and uncertainty control. While several solutions, including droop control and virtual inertia control, have been proposed, a comprehensive overview of these methods is currently lacking. This article reviews the challenges and opportunities associated with integrating renewable energy into DC microgrids, assessing existing techniques and pinpointing areas for further research. Renewable energy-driven systems are becoming popular among end-users for both large-scale and small-scale applications due to their numerous benefits. Small-scale systems, like microgrids, offer distinct advantages over larger setups. To meet the demands of DC loads, establishing DC microgrids is essential for community power needs with fewer power converters. Utilizing renewable energy sources in DC microgrids has emerged as a promising research area, particularly with solar energy as a key technology for generating DC power. This project presents a DC microgrid based on solar photovoltaic (PV) and wind energy sources. The proposed system includes a wind energy conversion system utilizing a self-excited induction generator, a PV system with basic MPPT control, a boost converter connected to the PV system, a battery energy management system, and a DC load. Different MPPT techniques for the PV system are explored through MATLAB simulations in this work.*

Keywords: DC Microgrids, Renewable Energy Integration, Voltage Regulation, MPPT Control, Energy Management.

I. INTRODUCTION

As the world shifts toward sustainable energy solutions, the integration of renewable sources like solar and wind power into microgrid systems has gained significant attention. This system combines the strengths of solar photovoltaic (PV) panels and wind turbines to generate clean electricity while utilizing battery storage for energy management. By operating on a direct current (DC) framework, these microgrids can enhance efficiency and reduce energy losses compared to alternating current (AC) systems. Effective design and control strategies are critical to optimize energy production, ensure reliable supply, and manage energy storage, making them an essential component of the transition to a more sustainable energy future.

Microgrid is a low voltage (LV) power network that contains various distributed energy sources (DERs) like photovoltaic (PV) arrays, wind turbines, fuel cells, and energy storage devices (e.g., batteries, supercapacitor and flywheel). The Cluster of loads and micro sources operating as a single controllable

 DOI: 10.5281/zenodo.15634494

ISSN (Online): 2583-648X
IJIRID
International Journal of Ingenious Research, Invention and Development
An International, High Impact Factor, Double,Blind Peer,Reviewed, Open,Access, Multidisciplinary Online Journal
www.ijirid.in
Volume 4 | Issue 2 | April 2025

system provides power and heat to its local area is called as Microgrid [8]. The concept of Microgrid provides an appropriate solution to integrate more and more renewables in the existing distribution network. At the same time, Microgrids can supply the local and sensitive loads. It has the capability of operation in both islanded and connected modes increases the power grid's reliability from the viewpoint of loads consumers [6].

The Microgrid is defined as a group of power-generating sources and loads that are operated in a separated network. This Microgrid can be used in island mode or integrated with the utility grid. Microgrids is operated in two ways as grid connected and autonomous operations. Microgrids can be designed to support alternating current (AC) or direct current (DC). The Consortium for Electric Reliability Technology Solution (CERTS) states [10]. The Microgrid structure assumes an aggregation of loads and micro sources operating as a single system providing both power and heat.

The majority of the micro sources must be power electronic-based to provide the required flexibility to ensure controlled operation as a single aggregated system. This control flexibility allows the Microgrid to present itself to the bulk power system as a single controlled unit, have plug-and-play simplicity for each micro source, and meet the customers' local needs. These needs include increased local reliability and security [9].

II. LITERATURE REVIEW

Fahad Saleh Al-Ismail, critically reviews voltage control and power management strategies for direct current (DC) microgrids. He discusses the integration challenges of renewable energy sources and energy storage systems, focusing on maintaining DC bus voltage stability and efficient power distribution. The paper explores hierarchical, centralized, decentralized, and distributed control methods, evaluating their effectiveness under different operational scenarios. Key research gaps and opportunities for future advancements, such as incorporating artificial intelligence and robust hybrid control systems, are also highlighted to enhance microgrid reliability and efficiency. 2024 [1].

An overview of various Maximum Power Point Tracking (MPPT) methods to enhance the efficiency of photovoltaic (PV) systems. These techniques, categorized into classical, intelligent, optimization, and hybrid types, are analysed based on performance indicators like tracking speed and complexity. Authors Musong L. Katche, et.al, published this review in 2023 in Energies [3].

The developed third-order model and real-world tests validate the controller’s capability to maintain stable operation under dynamic conditions, in 2008 [6]. "Battery Energy Storage System (BESS) and Battery Management System (BMS) for Grid-Scale Applications" by Matthew T. Lawder, Bharatkumar Suthar, et.al., published in 2014, reviews the use of BESS and BMS for enhancing grid efficiency. It discusses challenges in the current electric grid, highlights the significance of advanced battery modelling, and outlines the architecture and control mechanisms needed for optimal BMS operation in grid-scale applications [11].

"Integration of Energy Storage System and Renewable Energy Sources Based on Artificial Intelligence: An Overview" by Ahmed N. Abdalla et al., published in Journal of Energy Storage in 2021: The paper reviews the critical role of energy storage systems (ESS) in stabilizing power systems, facilitating renewable energy integration, and enhancing system reliability. It highlights the classification and

ISSN (Online): 2583-648X
IJIRID
International Journal of Ingenious Research, Invention and Development
An International, High Impact Factor, Double,Blind Peer,Reviewed, Open,Access, Multidisciplinary Online Journal
Volume 4 | Issue 2 | April 2025
www.ijirid.in

technical characteristics of various energy storage technologies, including electrochemical, mechanical, and thermal methods. The authors advocate for continued innovation in AI-driven solutions to meet the challenges of integrating renewable energy sources with ESS, ensuring optimal performance and sustainability [13].

III. METHODOLOGY

3.1: DC Microgrid:

A DC microgrid is a localized energy system that operates primarily using direct current (DC) for power distribution, allowing for efficient integration of renewable energy sources such as solar panels and energy storage devices like batteries. DC microgrids can operate independently or in conjunction with the main grid, providing flexibility in energy management. They support energy resilience by enabling localized generation and consumption, which is especially beneficial during outages or emergencies. the ability to optimize energy flow enhances grid stability and helps manage peak loads effectively [17,18].

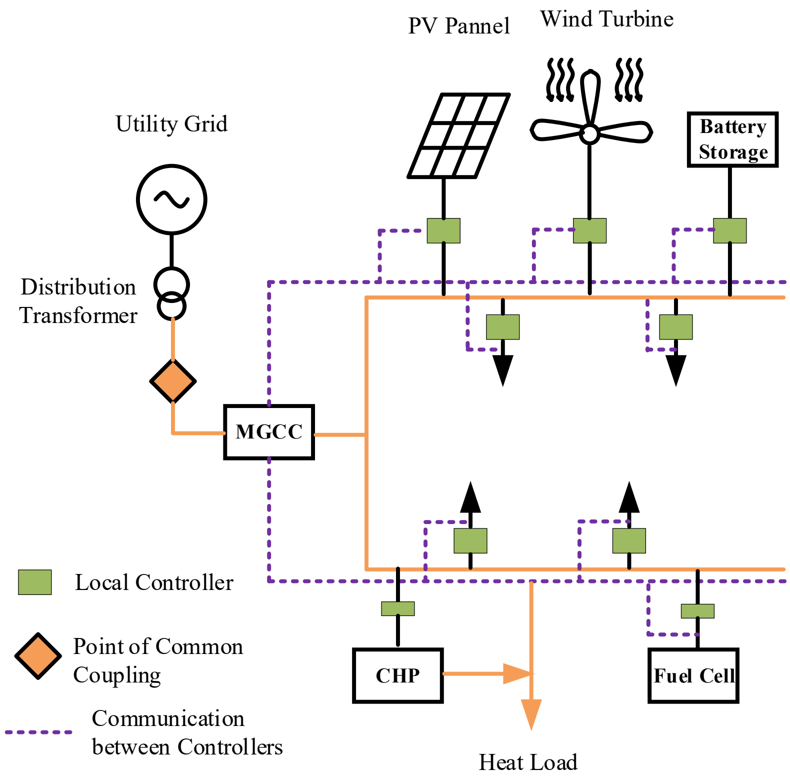

Figure 1: Block Diagram of DC Microgrid

In DC microgrids, three-phase AC-to DC rectifiers and transformers are required to connect AC DERs to the common bus, single- and three-phase DC-to-AC inverters are needed for supplying AC loads, and a three-phase DC-to-AC/AC to-DC converter, a transformer, and a point of common coupling switch are required for connecting the Microgrid to the utility grid Photovoltaic (PV) cells

 DOI: 10.5281/zenodo.15634494

ISSN (Online): 2583-648X
IJIRID
International Journal of Ingenious Research, Invention and Development
An International, High Impact Factor, Double,Blind Peer,Reviewed, Open,Access, Multidisciplinary Online Journal
Volume 4 | Issue 2 | April 2025
www.ijirid.in

generate DC electricity, and with the majority of electronic loads requiring DC, a DC microgrid would eliminate the conversion steps between AC and DC [2].

Battery Energy Storage Systems:
Batteries, like lithium-ion batteries, store electricity that can be used later. They charge up when there's excess electricity from renewable sources and can discharge electricity when it's needed. Battery Energy Storage Systems are crucial components in modern energy management, particularly within DC microgrids. They store electrical energy for later use, playing a vital role in balancing supply and demand [19].

3.2: MPPT:
MPPT stands for Maximum Power Point Tracking. It is a technology used in solar inverters and charge controllers to maximize the energy harvested from photovoltaic (PV) solar panels. The idea behind MPPT is to continuously adjust the electrical operating point of the modules or array to ensure they produce the maximum possible power under various conditions (such as changing sunlight intensity, temperature, and shading) [5].

1. ***Optimal Voltage and Current:*** Solar panels have a nonlinear relationship between the current and voltage they produce, and their efficiency depends on this relationship. The MPPT algorithm calculates the best voltage and current (known as the maximum power point) that will extract the most energy at any given moment.

2. ***Dynamic Adjustment:*** The MPPT continuously adjusts its operation based on real-time data. This is particularly important as environmental conditions fluctuate, ensuring the solar system stays at peak performance.

Types of MPPT:
1. **Perturbation and Observation (P&O):**
   A widely used algorithm for the MPPT in photovoltaic (PV) systems, wind energy systems, and other renewable energy applications. The goal of the P&O method is to continuously adjust the operating point of the energy converter (e.g., PV system's inverter) so that it operates at the Maximum Power Point (MPP), where the system can deliver the maximum possible power [20,21].

2. **Fuzzy Logic Controller:**
   The block diagram titled "Overview of a Fuzzy Logic Control System" provides a clear and systematic flow of how fuzzy logic is applied to process uncertain or imprecise inputs and generate accurate, crisp outputs for control purposes. The process starts with the Inputs, which are typically real-world analog signals or sensor measurements such as voltage, current, temperature, speed, etc. [23].

 DOI: 10.5281/zenodo.15634494

ISSN (Online): 2583-648X
IJIRID
International Journal of Ingenious Research, Invention and Development
An International, High Impact Factor, Double,Blind Peer,Reviewed, Open,Access, Multidisciplinary Online Journal
Volume 4 | Issue 2 | April 2025
www.ijirid.in

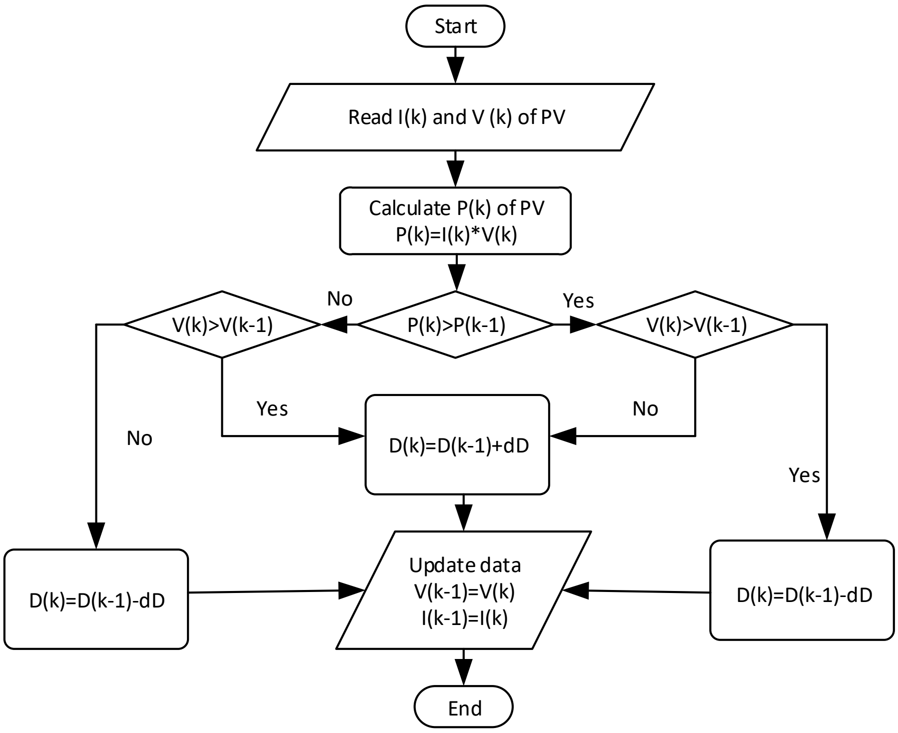

Figure 2: Flow Chat Of P&O MPPT

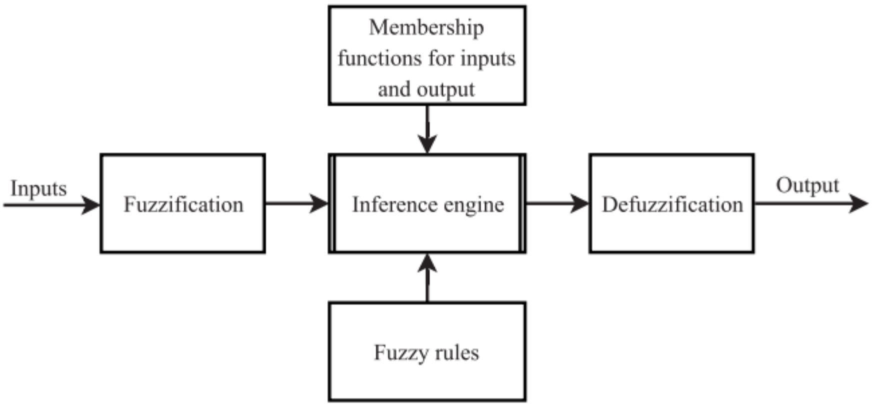

Figure 3: Overview of Fuzzy Logic Control System

Fuzzy Logic-based Maximum Power Point Tracking (MPPT) is an intelligent control technique used in renewable energy systems, especially in solar photovoltaic (PV) and wind power systems, to continuously track and extract the maximum possible power under varying environmental conditions. Unlike traditional MPPT methods like Perturb and Observe (P&O) or Incremental Conductance, Fuzzy Logic Maximum Power Point Tracking (MPPT) is a technique used in solar power systems to optimize the efficiency of energy production by constantly adjusting the operating point of the solar panel array to extract the maximum possible power under varying environmental conditions.

ISSN (Online): 2583-648X
IJIRID
International Journal of Ingenious Research, Invention and Development
An International, High Impact Factor, Double,Blind Peer,Reviewed, Open,Access, Multidisciplinary Online Journal
Volume 4 | Issue 2 | April 2025
www.ijirid.in

MPPT refers to algorithms that monitor the voltage and current output of the photovoltaic (PV) system and adjust the operating point to ensure maximum power is generated [15,16].

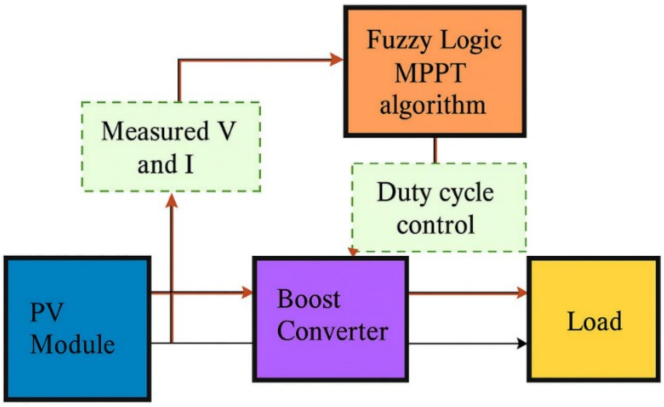

Figure 4: Block Diagram of Fuzzy Logic

The basic structure of a fuzzy logic MPPT controller includes three main stages: fuzzification, inference, and defuzzification. In the fuzzification stage, real-world input values—typically the change in power with respect to voltage (dP/dV) and the change in that error—are converted into fuzzy linguistic variables like "negative large," "zero," or "positive small." These inputs are processed through a fuzzy inference system, which consists of a set of predefined rules derived from expert knowledge or heuristic strategies [22].

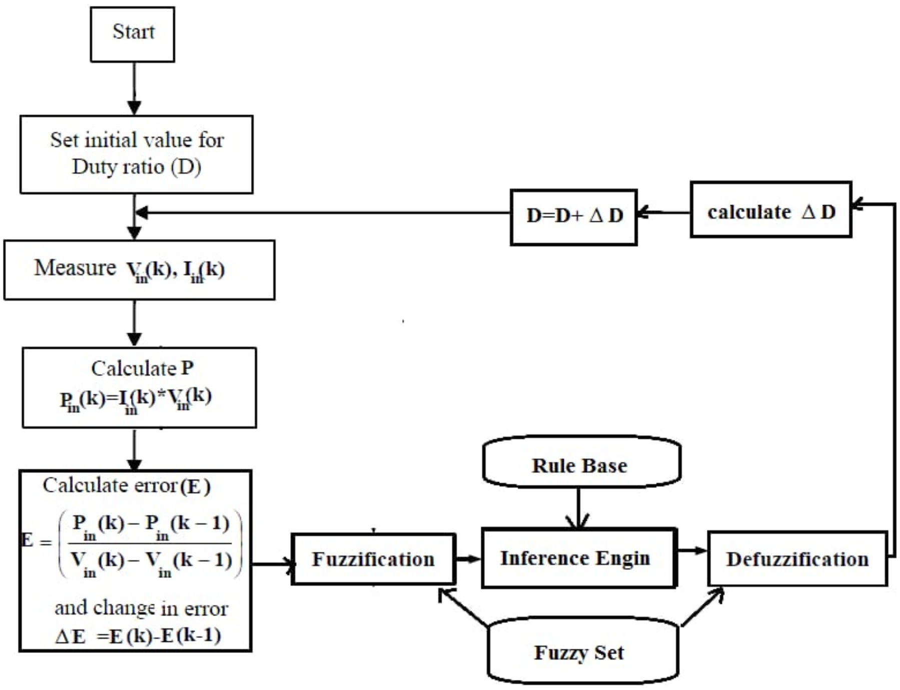

Figure 5: Flow Chart of Fuzzy Logic Control System

ISSN (Online): 2583-648X
IJIRID
International Journal of Ingenious Research, Invention and Development
An International, High Impact Factor, Double,Blind Peer,Reviewed, Open,Access, Multidisciplinary Online Journal
Volume 4 | Issue 2 | April 2025
www.ijirid.in

IV. SYSTEM CONFIGURATION AND SIMULATION RESULTS

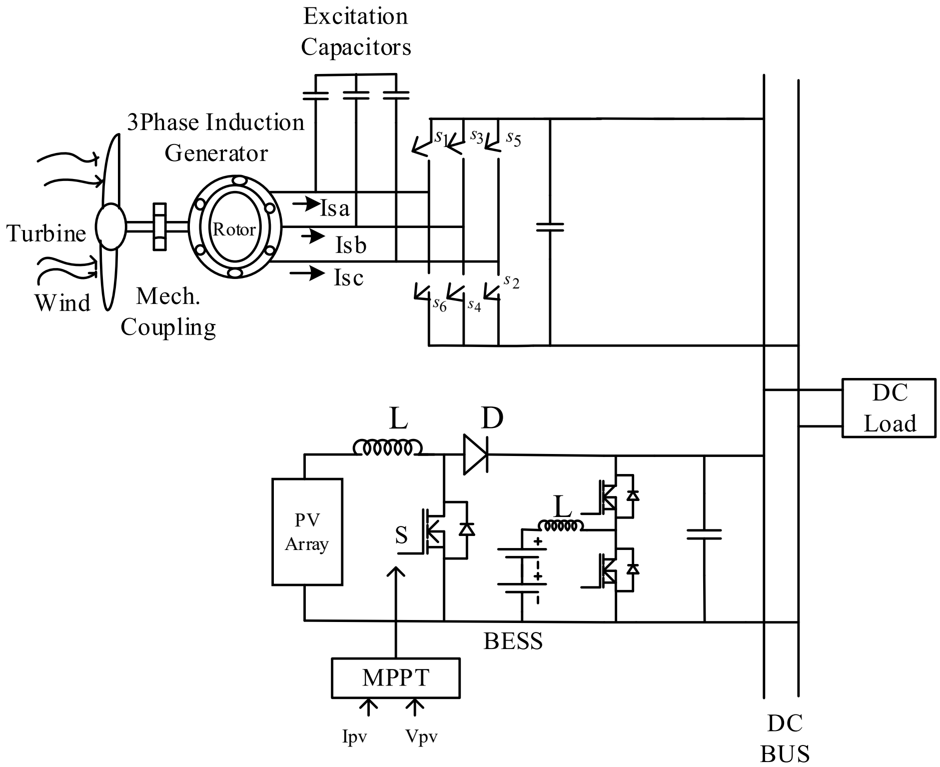

Figure 6: Simulation Model Includes PV, Wind with Battery System Connected to DC Bus & DC Load

According to block diagram shown in Figure 3, The Simulation model includes PV, wind with battery system connected to DC bus and DC load. The Wind Energy Conversion System (WECS) consists of a wind turbine coupled to the Self Excited Induction Generator (SEIG). The output of wind connected generator system is 400 V, which is then converted into DC by using universal bridge rectifier. The rectified output voltage after WECS (Vrec) is 400 V, and rectified output current (Irec) is 9.2 A. The rating of wind turbine system is 3.7 kW i.e. it can generate maximum power of 3700 W. Here, wind speed is kept constant which is 10m/sec.

The PV Panel rating is 3.7 kW i.e. it gives maximum power of 3750 W, it has open circuit voltage of 38.4 V, and short circuit current of 8.85 A. Total 8 modules are connected in series and 2 are connected in parallel, forming total output voltage of 230 V. It is connected to DC bus using boost converter. The Boost converter connected to PV panel is controlled by the Fuzzy logic based modified step size Incremental Conductance MPPT algorithm to extract the maximum power from the PV panel. The boost converter is used to increase the PV voltage from 250 V to 400 V, which is the DC bus voltage. In Battery Energy Management System (BESS), 20 batteries of 12 V are connected to get voltage of 200 V; rated capacity of battery is 48 A-h. The battery is connected to DC bus via bidirectional DC/DC converter. This bidirectional DC/DC converter is used to interface the centralized BESS to the microgrid network. Its main function is to provide an added security and enhance the stability in the overall performance of the microgrid.

ISSN (Online): 2583-648X

IJIRID

International Journal of Ingenious Research, Invention and Development

An International, High Impact Factor, Double,Blind Peer,Reviewed, Open,Access, Multidisciplinary Online Journal

Volume 4 | Issue 2 | April 2025

www.ijirid.in

This bidirectional converter consists of two converters namely, a buck converter and boost converter. The control action of the converter is made in such a way that it allows a controlled flow of power in both the directions. This bidirectional DC/DC converter are controlled with the voltage controller, where DC load voltage is compared with the reference voltage (400 V). The DC bus voltage is maintained as voltage controller is used in the bidirectional DC to DC converter. Based on power availability in PV and wind, the charging of battery changes [4].

V. SIMULATION RESULT OF P&O

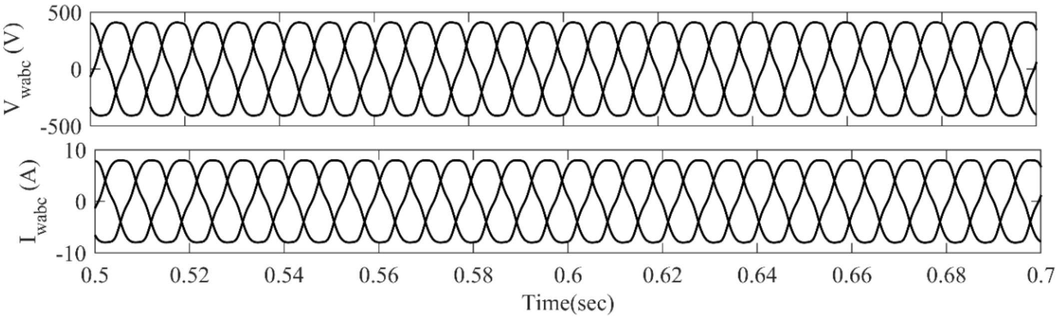

Figure 7: Voltage and Current Waveforms Produce by WECS System

Which comes out to be 400 V, and 9.2 A respectively. The output of the Wind Energy Conversion System (WECS) is converted into DC by using universal bridge rectifier. The rectified voltage (Vrec), and rectified current (Irec) as shown in Figure 3.1.1, are 400 V, and 9.2 A respectively, and the PV output power (PW) is 3700 W.

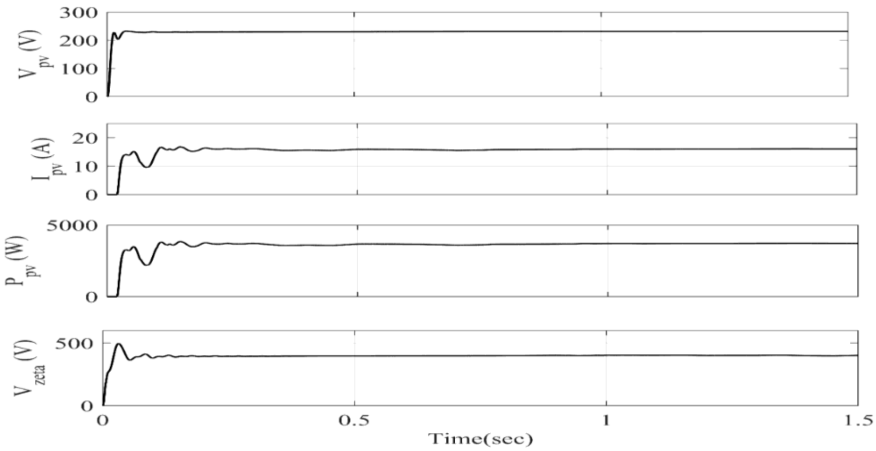

Figure 8: PV Parameters and Boost Converter Voltage

The PV Voltage (VPv), PV Current (IPv), PV Power (PPv), and boosted voltage by the Boost converter. The PV Voltage is around 230 V, PV Current is around 16 A, and PV Power is around 3680 W. The output PV voltage (VPv = 230 V) is boosted around DC bus voltage of 400 V with the boost converter.

 DOI: 10.5281/zenodo.15634494

ISSN (Online): 2583-648X
IJIRID
International Journal of Ingenious Research, Invention and Development
An International, High Impact Factor, Double,Blind Peer,Reviewed, Open,Access, Multidisciplinary Online Journal
Volume 4 | Issue 2 | April 2025
www.ijirid.in

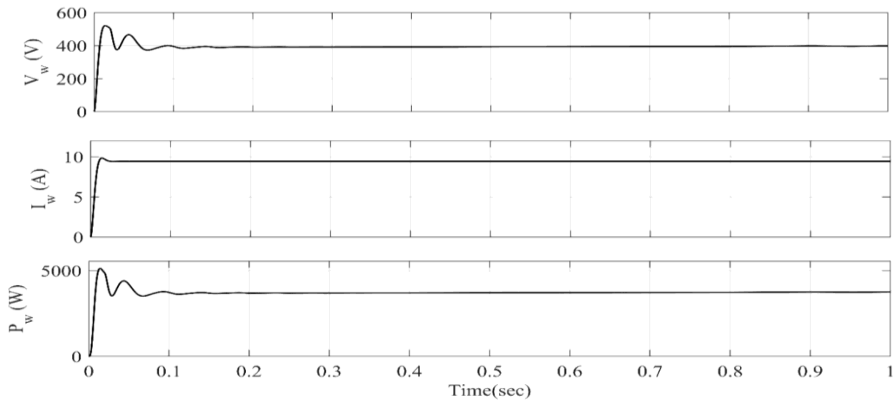

Figure 9: Rectified Wind Voltage and Wind Current with Power

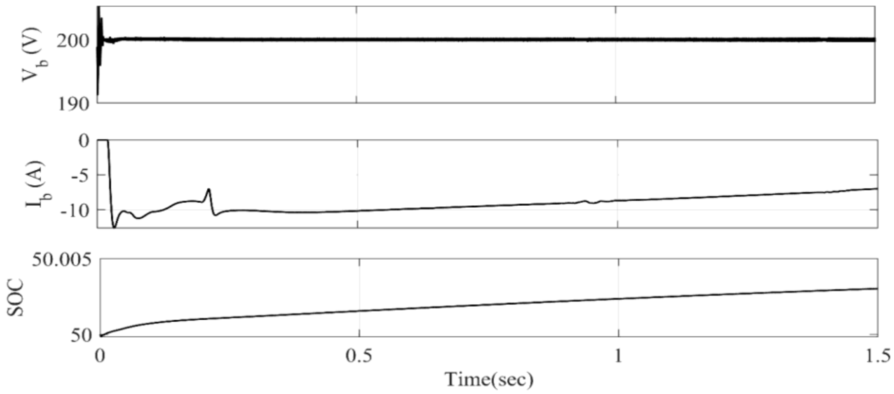

Figure 10: Battery System Parameters

Battery voltage (Vb) and current (Ib) along with the SOC of the battery. The battery nominal voltage is 200 V, with rated capacity of 50 A-h. The current is increasing in the negative direction, which shows battery SOC is increasing, i.e. increase in the current in the negative direction, will charge the battery.

VI. SIMULATION RESULT OF FUZZY LOGIC CONTROLLER

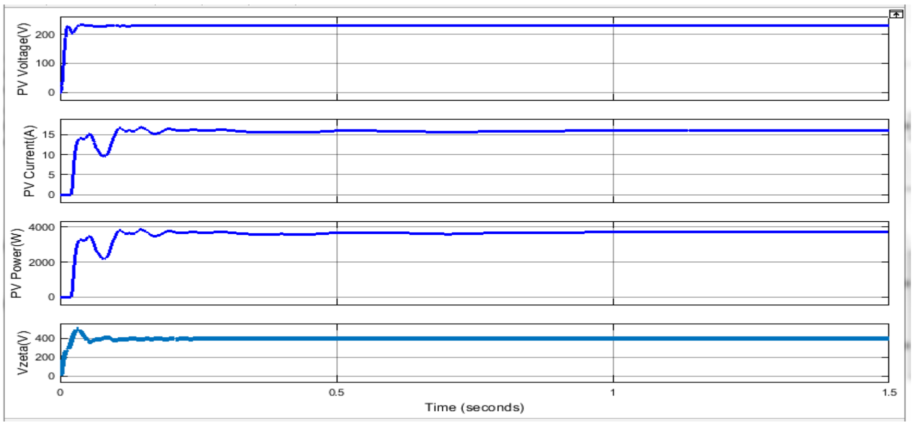

Figure 11: PV Parameters and Boost Converter Voltage

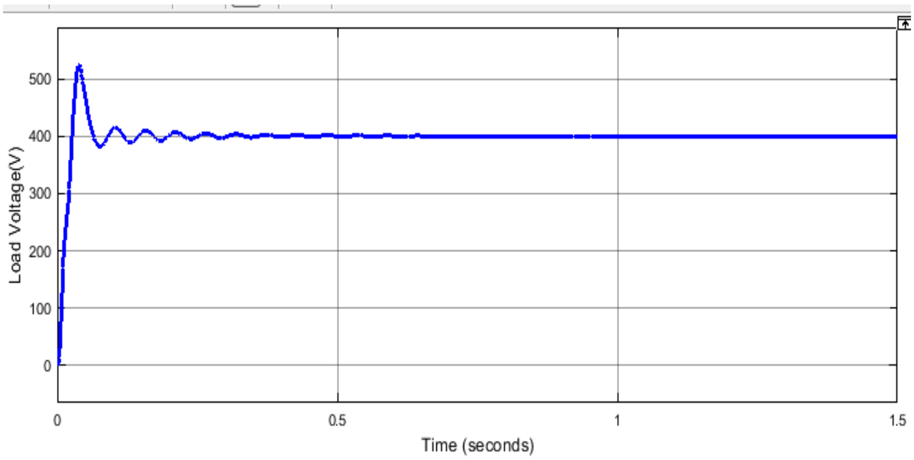

Figure 12: Load voltage

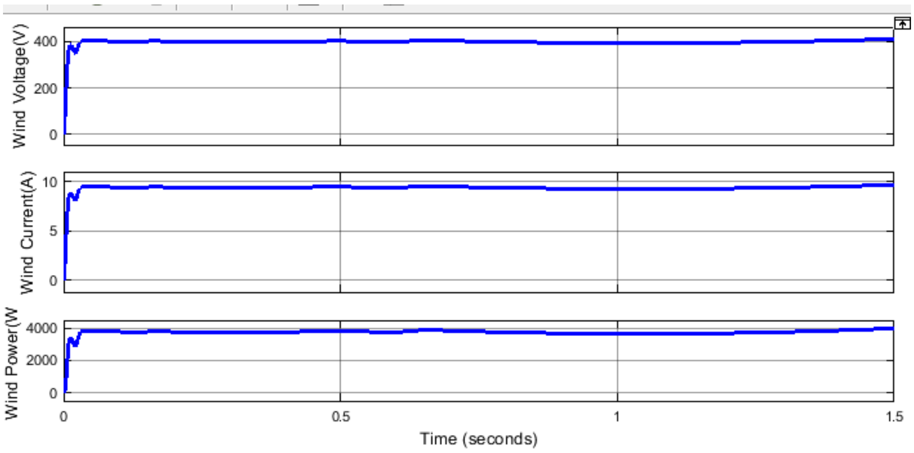

Figure 13: Wind Parameter

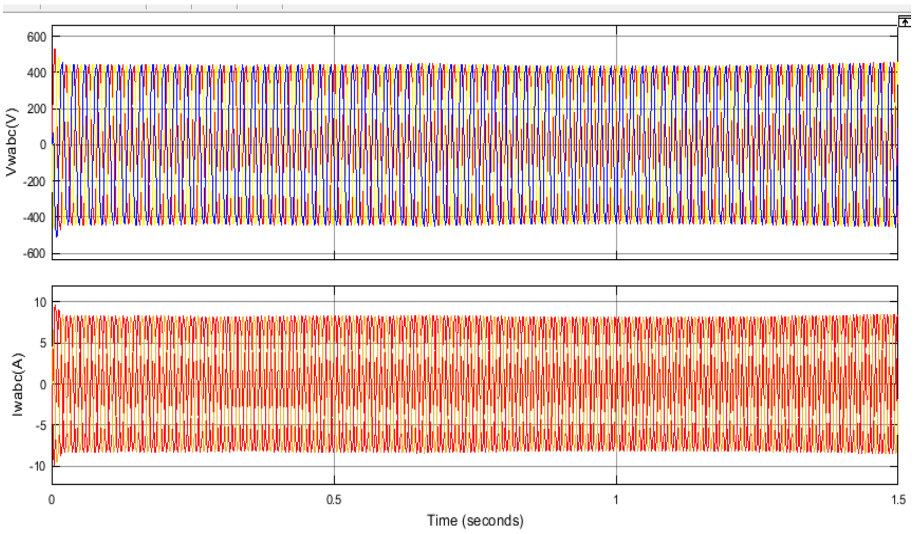

Figure 14: SEIG 3 Phase Output Parameter

ISSN (Online): 2583-648X

IJIRID

International Journal of Ingenious Research, Invention and Development

An International, High Impact Factor, Double,Blind Peer,Reviewed, Open,Access, Multidisciplinary Online Journal

Volume 4 | Issue 2 | April 2025

www.ijirid.in

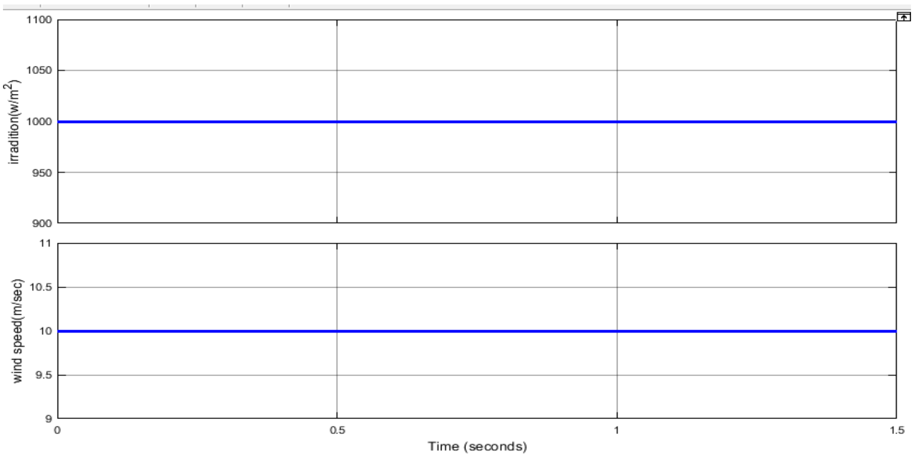

Figure 15: PV Array Irradiation and Wind Input

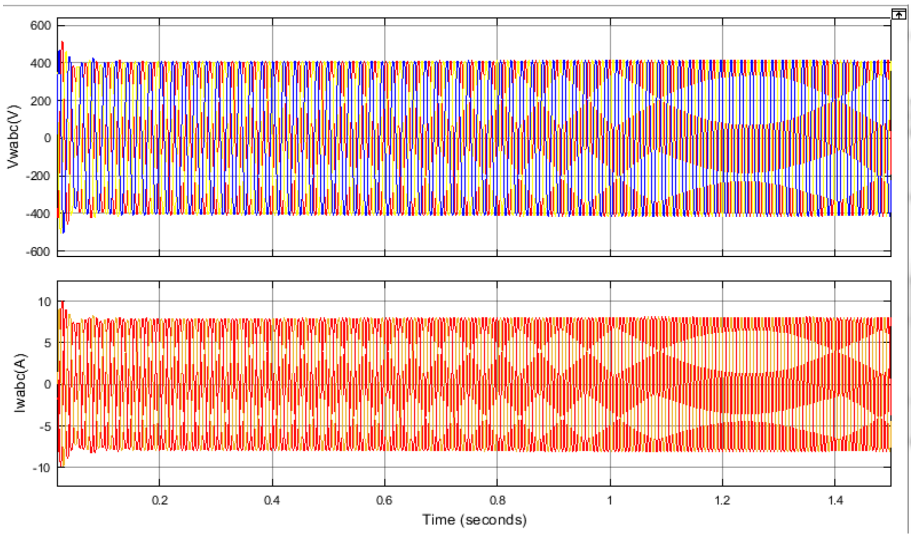

Figure 16: Wind (SEIG) 3 Phase Output Voltage and Current

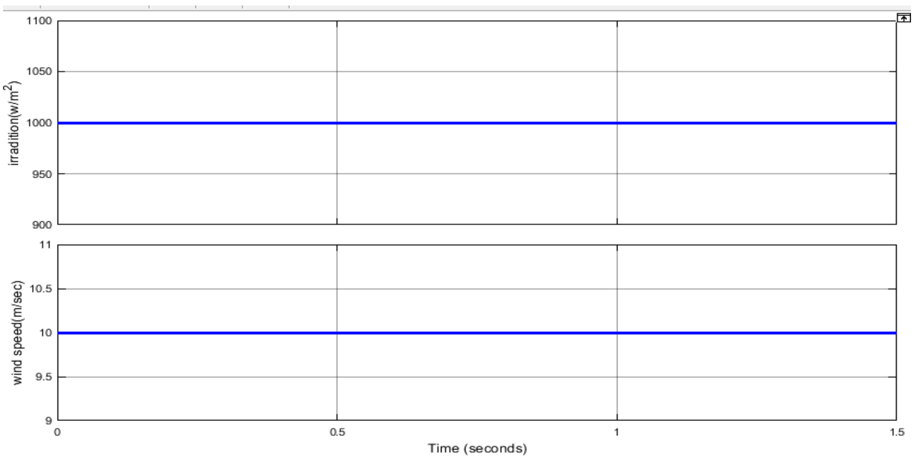

Figure 17: Sun Irradiation and Wind Speed

ISSN (Online): 2583-648X

IJIRID

International Journal of Ingenious Research, Invention and Development

An International, High Impact Factor, Double,Blind Peer,Reviewed, Open,Access, Multidisciplinary Online Journal

Volume 4 | Issue 2 | April 2025

www.ijirid.in

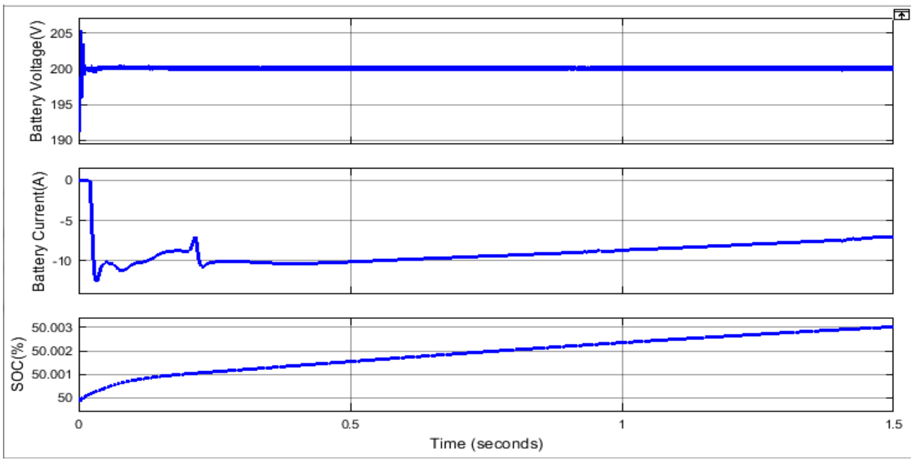

Figure 18: Battery Parameters

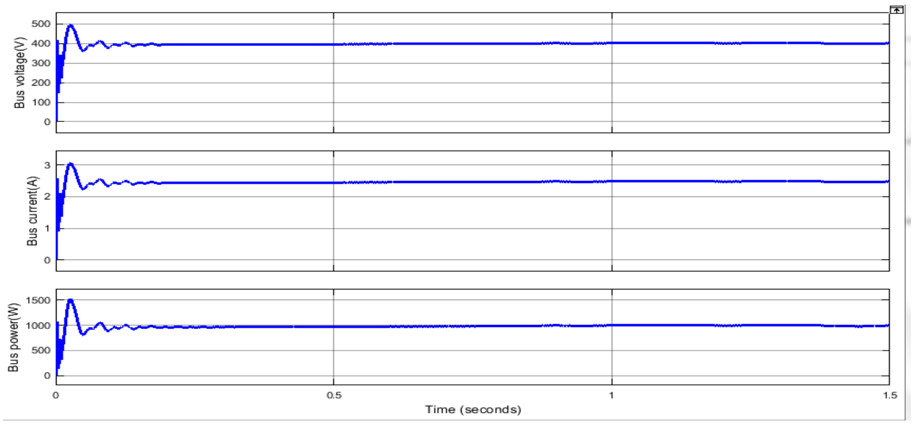

Figure 19: Bus Parameters

VII. CONCLUSION

The report concludes that integrating wind turbines, solar panels, and battery storage into a DC microgrid offers an effective and sustainable energy solution. This system design focuses on maximizing the efficiency of renewable energy by directly connecting wind and solar power to a DC bus, which minimizes energy losses from AC-DC conversions. The battery energy storage system (BESS), connected via a bidirectional DC/DC converter, plays a crucial role in stabilizing the energy supply and maintaining consistent power delivery. Advanced control strategies, such as voltage regulation and MPPT algorithms, optimize the system's performance by ensuring the DC bus remains stable at 400V and energy is effectively managed based on availability and demand.

REFERENCES

[1] F. S. Al-Ismail, "A Critical Review on DC Microgrids Voltage Control and Power Management," in Proc. IEEE Int. Conf. Power Electronics and Drive Systems (PEDS), Bangkok, Thailand, Dec. 2024, pp. 1234-1241.

[2] D. Mazumdar, et al., "Overview of Solar Photovoltaic MPPT Methods: A State of the Art on Conventional and Artificial Intelligence Control Techniques," IEEE Trans. Sustainable Energy, vol. 15, no. 2, Apr. 2024.

ISSN (Online): 2583-648X

IJIRID

International Journal of Ingenious Research, Invention and Development

An International, High Impact Factor, Double,Blind Peer,Reviewed, Open,Access, Multidisciplinary Online Journal

Volume 4 | Issue 2 | April 2025

www.ijirid.in

[3] M. L. Katche, et al., "A Comprehensive Review of Maximum Power Point Tracking (MPPT) Techniques Used in Solar PV Systems," in Proc. IEEE Int. Conf. Renewable Energy Systems (ICRES), London, UK, Oct. 2023.

[4] B. Modu, et al., "DC-based Microgrid: Topologies, Control Schemes, and Implementations," in Proc. IEEE Int. Conf. Power and Energy Systems (ICPES), Berlin, Germany, Sept. 2023, pp. 45-50.

[5] R. B. Bollipo, et al., "Hybrid, Optimal, Intelligent and Classical PV MPPT Techniques: A Review," in Proc. IEEE Int. Conf. Renewable Energy Systems (ICRES), Mumbai, India, Dec. 2021, pp. 112-117.

[6] J. Zhang, J. Lai, et al., "Bidirectional DC-DC Converter Modeling and Unified Controller with Digital Implementation," in Proc. IEEE Appl. Power Electron. Conf. Expos. (APEC), Austin, TX, USA, Feb. 2008.

[7] R. W. Erickson and D. Maksimovic, Fundamentals of Power Electronics, 2nd ed. New York, NY, USA: Springer, 2007.

[8] R. H. Lasseter and P. Paigi, "Microgrid: A Conceptual Solution," in Proc. IEEE Power and Energy Society General Meeting, Denver, CO, USA, Jul. 2004, pp. 1-5.

[9] S. A. Sarang, et al., "Maximizing Solar Power Generation Through Conventional and Digital MPPT Techniques: A Comparative Analysis," IEEE Trans. Sustainable Energy, vol. 15, no. 4, Oct. 2024.

[10] M. T. Lawder, B. Suthar, et al., "Battery Energy Storage System (BESS) and Battery Management System (BMS) for Grid-Scale Applications," IEEE Trans. Energy Convers., vol. 29, Dec. 2014.

[11] A. Kalair, et al., "Role of Energy Storage Systems in Energy Transition from Fossil Fuels to Renewables," IEEE Trans. Sustainable Energy, vol. 15, no. 2, Apr. 2024.

[12] C. Yang, et al., "Summary of Energy Storage Systems and Renewable Energy Participation in AGC Research," IEEE Trans. Power Systems, vol. 34, no. 2, pp. 675-684, Apr. 2019.

[13] U. Chikezie and Z. Chen, "Energy Storage for Power System Economics," IEEE Trans. Power Systems, vol. 35, no. 4, pp. 2431-2439, Oct. 2020.

[14] A. N. Abdalla, et al., "Integration of Energy Storage System and Renewable Energy Sources Based on Artificial Intelligence: An Overview," IEEE Trans. Sustainable Energy, vol. 12, no. 4, Oct. 2021.

[15] P. K. S. Rathore, D. S. Chauhan, and R. P. Singh, "Decentralized Solar Rooftop Photovoltaic in India: On the Path of Sustainable Energy Security," IEEE Trans. Power Energy, vol. 37, no. 6, pp. 2205-2215, Dec. 2022.

[16] E. Kabir, et al., "Solar Energy: Potential and Future Prospects," Renewable and Sustainable Energy Reviews, vol. 82, pp. 1-12, Jan. 2018.

[17] F. Oueslati, "Hybrid renewable system based on solar, wind and fuel cell energies coupled with diesel engines for Tunisian climate: TRNSYS simulation and economic assessment," Int. J. Green Energy, vol. 18, no. 4, pp. 312-326, Apr. 2021.

[18] R. R. Gajjar, "State of Charge Control Based Improved Hybrid Energy Storage System for DC Microgrid," IEEE Trans. Power Electron., vol. 39, no. 7, Jul. 2024.

[19] T. A. Zulhelmi, "Comparative Analysis of Incremental Conductance and Perturb and Observe Methods as MPPT Algorithm in Photovoltaic System," IEEE Trans. Sustainable Energy, vol. 12, no. 5, pp. 1542-1552, Oct. 2021.

[20] E. Vani, P. Balakrishnan, G. Singaram, and S. Senthil, "PV Wind Battery Based DC Microgrid with Neural Network MPPT," IEEE Trans. Power Electron., vol. 39, no. 5, May 2024.

[21] M. J. Ahmed, et al., "Optimizing MPPT for PV Systems: A Combined Study of Constant Voltage and Incremental Conductance Technique," IEEE Trans. Sustainable Energy, vol. 15, no. 5, May 2024.

[22] L. Meng, et al., "Control schemes and architectures applied to dc microgrids (MGs)," IEEE Trans. Power Electron., vol. 32, no. 10, pp. 7901-7914, Oct. 2017.

[23] R. H. Rija and A. A. Jannie, "Fuzzy Logic Control of Zeta Micro Inverter for Solar PV AC Module Fed SPIM," IEEE Trans. Power Electron., vol. 33, no. 4, pp. 2155-2165, Apr. 2018.

