International Journal of Computer Applications Technology and Research
Volume 13–Issue 08, 39 – 53, 2024, ISSN:-2319–8656
DOI:10.7753/IJCATR1308.1005

Integration of Green Energy Sources Within Distribution Networks: Feasibility, Benefits, And Control Techniques for Microgrid Systems

Joseph Nnaemeka Chukwunweike
MNSE, MIET
Automation / Process Control Engineer
Gist Limited
London, United Kingdom

Stephen Olusegun Odusanya
MNSE, MSc
MSc Energy Management
New York Institute of Technology
New York, USA

Martin Ifeanyi Mbamalu
MNSE
Department of Process Engineering and Renewable Energy Technology
University of Applied Sciences Bremerhaven
Bremerhaven, Germany

Habeeb Dolapo Salaudeen
Electrical Engineering and Computer Science EECS
Cleveland State University
USA

Abstract: This study looks into the integration of green energy sources within distribution networks, focusing specifically on the potential and advantages of microgrids. By examining the aggregation and interconnection of green micro-sources and loads through power electronics, the research aims to enhance the accessibility, usability, stability, and durability of power systems. Key areas of investigation include contemporary balance control techniques, real and reactive power regulation, and current allocation strategies. The study culminates in the development of a comprehensive microgrid model in MATLAB/Simulink, encapsulating all power sources, power electronics, loads, and mains models.

Keywords: Microgrids, Green Energy Integration, Balance Control Techniques, MATLAB/Simulink, Distribution Networks, Renewable Energy Sources, Power System Stability, Current Allocation Strategies.

1. INTRODUCTION

Background and Importance of Integrating Green Energy Sources

The global consciousness surrounding climate change has led to an accelerated adoption of environmentally friendly energy sources. These alternatives to fossil fuels are not only abundant and sustainable but also play a crucial role in mitigating environmental damage (Garg and Niazi, 2022). However, integrating these renewable energy sources (RES) into the existing power grid presents significant challenges due to their variable output and dispersed nature (Ishaq et al., 2022) as shown in figure 1. This variability necessitates innovative approaches to ensure effective energy production and consumption management.

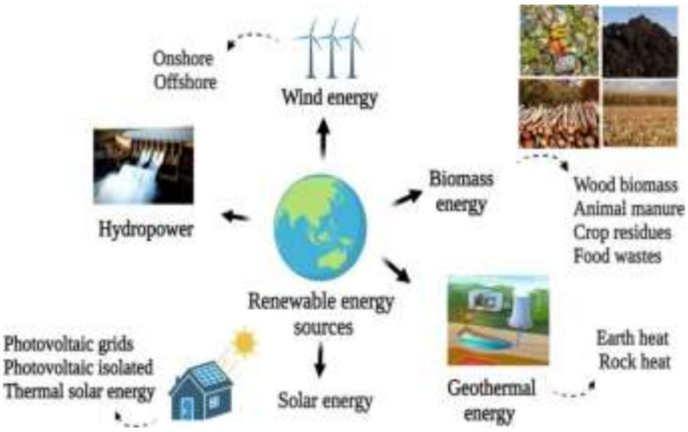


Figure1 Renewable energy sources (Osman *et al.*, 2023)

Unlike conventional power plants that generate a steady energy output, RES such as solar and wind are dependent on weather conditions, creating inconsistencies that complicate grid coordination (Behzadi et al., 2023). These challenges underscore the need for novel solutions like microgrids (MGs), which offer a localized and self-sufficient approach to energy management (Jyothi et al., 2021). By incorporating RES and energy storage technologies, MGs enhance grid resilience and stability, thereby supporting a cleaner, more reliable energy future (Ahmad et al., 2022).

Overview of Microgrid Concepts and Their Significance

Microgrids (MGs) are decentralized energy systems integrating renewable energy sources (RES), energy storage, and advanced control mechanisms as depicted in figure 2. They provide a robust solution to the challenges of renewable energy integration, reducing greenhouse gas emissions and reliance on fossil fuels while enhancing energy system resilience (Chukwunweike JN, et al. 2024).

Figure. 2 Schematic of a MG with different connected energy sources (Shahgholian, 2023)

MGs can operate autonomously or with the larger grid, improving energy management and reducing transmission losses (Amir et al., 2022). This localized approach is crucial for meeting carbon emission reduction targets, particularly in the United Kingdom (Panda and Das, 2021). MGs support a stable, sustainable energy landscape through advanced control and storage solutions.

Objectives of the Research

The Research aims to:
- Review renewable energy sources for hybrid systems.
- Analyse literature on microgrids and their grid integration.
- Examine current balancing control and power regulation methods.
- Implement and simulate a microgrid model with a balanced current control scheme in Simulink.
- Analyse the simulation results.

2. LITERATURE REVIEW

Current State of Microgrid Research

Microgrids (MGs) have emerged as a pivotal technology for enhancing the integration of renewable energy sources (RES) into existing power grids. By addressing the challenges of intermittency and distribution associated with RES, MGs improve energy security and reduce greenhouse gas emissions (Butt et al., 2021). Recent research highlights the potential of MGs to boost grid stability, energy efficiency, and economic sustainability, particularly in regions like the United Kingdom (Alotaibi et al., 2023). Current studies focus on various aspects of MGs, including control systems, electricity distribution, energy storage potential, and operational scaling. Key areas of investigation include the development of sophisticated control mechanisms that enable MGs to balance and stabilize intermittent RES such as solar and wind (Behzadi et al., 2023). The research also addresses the distribution and management of electricity within MGs to ensure effective integration and operation within larger grids. Additionally, energy storage solutions, which are critical for managing the variable output of RES, are a significant area of focus (Ishaq et al., 2022).

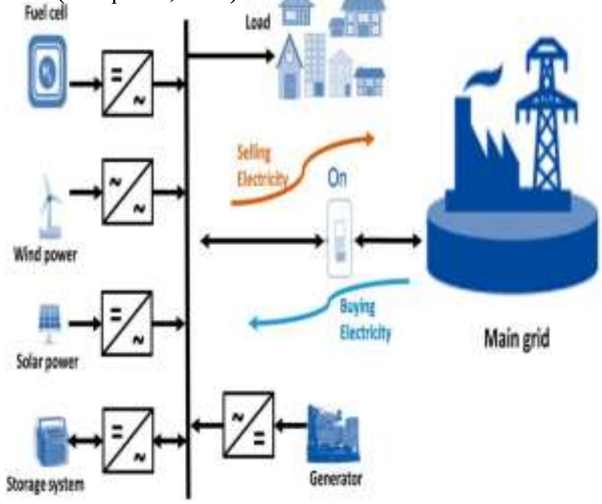


Figure 3: The model of the grid-connected MG (Tran, Davies and Sepasi, 2021)

Despite these advances, several obstacles hinder the widespread adoption of MGs. Regulatory frameworks, technical limitations, and interoperability issues pose significant challenges (Alotaibi et al., 2023). Overcoming these barriers is crucial for realizing the full potential of MGs in transitioning towards a more sustainable energy future. Overall, while substantial progress has been made, continued research is essential to address existing limitations and optimize the integration of MGs into national energy networks, thereby supporting the global shift towards cleaner and more resilient energy systems.

Existing Balance Control Techniques and Power Regulation Methods

To address the intermittency of renewable energy sources (RES), effective balance control and power regulation techniques are essential. RES such as solar and wind power generate electricity irregularly due to variable weather conditions, necessitating robust storage solutions and control strategies to ensure a stable power supply.

Energy Storage Solutions: Key technologies include pumped hydro storage (PHS) and electrochemical energy storage (EES). PHS involves storing energy by pumping water to a higher elevation during periods of excess generation, which can be released to generate electricity when needed (Jia et al., 2023). EES, such as batteries, stores electrical energy generated by solar panels or wind turbines for use during periods when RES output is low. For example, solar batteries store the direct current produced by photovoltaic panels, ensuring a continuous supply during cloudy days or at night (Romanov & Leiss, 2022). Similarly, batteries are used to balance the intermittent nature of wind power by storing energy when wind speeds are high and releasing it during calm periods (Ali et al., 2023).

Control Techniques: Advanced control strategies are crucial for balancing and regulating power within microgrids. These include real-time monitoring and dynamic adjustment of energy flows to match supply with demand. Techniques such as predictive control and demand response management help optimize the operation of energy storage systems and RES integration, maintaining grid stability and efficiency (Jia et al., 2023).

Power Regulation: Methods for managing real and reactive power are employed to stabilize voltage and frequency within the grid. These methods ensure that power quality is maintained and that any fluctuations in generation are effectively managed to prevent disruptions (Ali et al., 2023).

PREVIOUS MODELS AND SIMULATIONS OF MICROGRIDS

Microgrids (MGs) have been extensively studied through various models and simulations to understand their performance, efficiency, and integration with larger power systems. These models and simulations are crucial for analysing the potential benefits and challenges associated with MGs, particularly in the context of renewable energy integration.

1**. Simulation Tools and Frameworks:**

Microgrid simulations often utilize software tools like MATLAB/Simulink, PSCAD, and HOMER to model and analyse MG performance. MATLAB/Simulink, in particular, is widely used due to its comprehensive library for power system components and its ability to model complex control strategies and interactions between components (Amir et al., 2022). PSCAD is favoured for its detailed electromagnetic transient simulations, which are useful for studying fast dynamics and transient responses (Behzadi et al., 2023). HOMER is employed for optimizing the economic and operational aspects of microgrid systems, particularly in evaluating different configurations and technologies.

2. **On-Grid and Off-Grid MG Models**:

Previous studies have explored both on-grid and off-grid MG configurations. On-grid MGs, which maintain a connection with the main grid, are modelled to evaluate their ability to provide ancillary services such as frequency and voltage regulation. These models often include simulations of grid-connected operation, islanding scenarios, and the transition between these modes (Shirkhani et al., 2023). The performance of on-grid MGs is assessed based on their contribution to grid stability, power quality, and economic benefits.

Off-grid MGs, or stand-alone systems, are modelled to assess their independence from the main grid. These simulations focus on the integration of renewable energy sources (RES) and energy storage systems (ESS) to ensure reliable power supply in remote or isolated locations (Totaro et al., 2021). The models often evaluate the effectiveness of various storage technologies, such as batteries and pumped hydro storage, in managing the intermittency of RES.

3. **AC, DC, and Hybrid MG Models**:

Simulations of AC MGs typically involve the integration of both distributed and conventional generation sources using AC buses. These models analyse the impact of integrating RES such as solar and wind power, addressing issues related to synchronization and reactive power compensation (Shahgholian, 2023). AC MG simulations often highlight challenges such as reactive power losses and the need for robust control systems to manage voltage and frequency (Soyibjonov, 2023). DC MGs are modelled to explore their efficiency and stability advantages. These models focus on the integration of RES with DC outputs, examining the performance of bidirectional converters and the handling of arc extinction issues in circuit breakers (Pires et al., 2023). The simulations evaluate the efficiency of DC MGs in terms of energy conversion and distribution, and address challenges related to power interruptions due to converter failures (Ilyushin et al., 2023) as shown in figure 4.

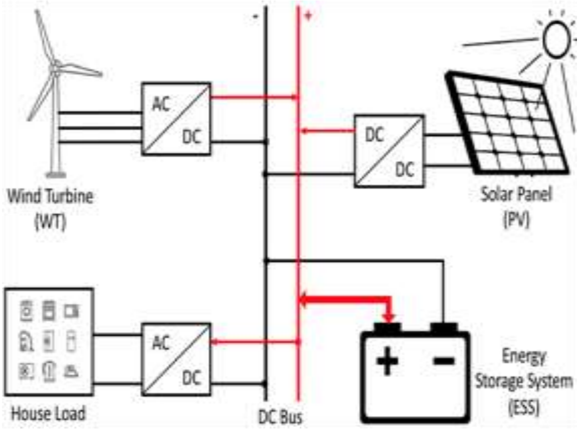


Figure 4: Architecture of hybrid PV/Wind/Battery off-grid MG with power converters (Traoré, Elgothamy and Zohdy, 2018)

Hybrid MGs, which combine AC and DC systems, are simulated to leverage the benefits of both technologies. These models explore configurations such as series, parallel, and switched hybrids, assessing their ability to deliver power to different types of consumers (Badal et al., 2023). The simulations evaluate the performance of hybrid MGs in terms of flexibility, integration with existing infrastructure, and the management of diverse energy sources.

MICROGRID ARCHITECTURE AND DESIGN

1. Microgrid Architecture and Design

Microgrids (MGs) integrate various energy sources and loads into a coherent system designed to enhance energy reliability and efficiency. At the core of MG architecture are micro-sources and load aggregation mechanisms. Micro-sources include distributed energy resources (DERs) such as photovoltaic panels, wind turbines, and combined heat and power (CHP) units. These sources generate electricity locally and can be coupled with energy storage systems (ESS) like batteries or flywheels to manage intermittent power supply. Load aggregation involves grouping various loads within the MG to optimize energy distribution and ensure stability. This aggregation allows for effective load management, minimizing disruptions and improving overall system efficiency.

2. Integration of MGs with the Distribution Network

The integration of MGs into the distribution network facilitates the inclusion of hybrid renewable energy sources (HRES) and addresses the challenges posed by their intermittent nature. As shown in figure 5, the incorporation of MGs into the distribution grid provides several advantages. It ensures a continuous power supply during grid outages, enhances grid reliability and flexibility, and offers sustainable power at a lower cost (Arar Tahir et al., 2023; Abbasi et al., 2023; Rosales-Asensio et al., 2023).

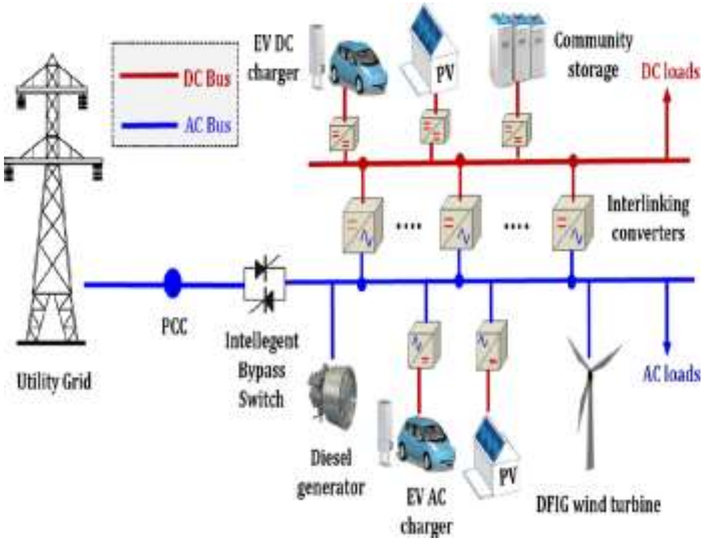


Figure 5: A conceptual hybrid AC/DC MG structure (Rahman, 2022)

Research has led to significant advancements in MG integration. For instance, (Mieński et al., 2023) developed a control algorithm for a 3-phase, 4-wire PV inverter to mitigate voltage perturbations and enhance power quality in MG-integrated grids. (Kumari et al., 2023) utilized digital twin technology to create accurate virtual models of MGs, facilitating real-time monitoring, fault detection, and improved integration. (Silva et al., 2023) proposed an IoT-based energy management system to optimize operation and adherence to grid limits. Additionally, (Tajdinian et al., 2023) introduced a sensitivity-based islanding detection algorithm to manage islanding states and address cyber-security threats. (Reddy et al., 2023) focused on identifying vulnerable nodes and optimizing the placement of RES to boost grid resilience.

3. Benefits of Microgrids in Distribution Networks

Microgrids offer transformative benefits within distribution networks. They enhance grid stability, efficiency, and resilience by decentralizing power generation. This decentralization alleviates the load on traditional power facilities and reduces transmission losses (Bagherzadeh et al., 2019; Nwaigwe et al., 2019). By localizing generation, MGs reduce the risk of outages and support critical loads during emergencies. They also facilitate the integration of renewable sources, improving energy efficiency and sustainability (Ganesan et al., 2020). Economically, MGs reduce the need for extensive transmission infrastructure and central power facilities, resulting in cost savings in maintenance and energy production (Worighi et al., 2019). They also foster local economic development and create job opportunities, aligning with carbon reduction goals and enhancing energy independence (Worighi et al., 2019; Dileep, 2020). Despite these advantages, challenges such as technical complexities, interoperability issues, regulatory hurdles, and funding constraints need to be addressed for widespread MG adoption. Advancements in technology, control algorithms, and energy storage continue to progress towards overcoming these barriers (Dileep, 2020).

ROLE OF POWER ELECTRONICS IN MICROGRID INTEGRATION

Power electronics play a crucial role in the effective integration and management of microgrids (MGs), particularly in handling the interface between renewable energy sources (RES), energy storage systems (ESS), and the grid. They are essential for controlling and optimizing the flow of electrical power, ensuring stability, reliability, and efficiency within MGs.

1. Power Electronics in Microgrid Integration

Power electronics are pivotal in MGs for several reasons:

1. *Conversion and Regulation*: Power electronics devices such as inverters, converters, and rectifiers convert the direct current (DC) generated by RES like photovoltaic panels and wind turbines into alternating current (AC) suitable for the grid. This conversion is necessary because the MG needs to interface seamlessly with the AC distribution network while managing different types of energy sources and loads (Hosseini et al., 2021).

2. *Energy Storage Management*: ESSs, including batteries and supercapacitors, require power electronics for efficient energy storage and retrieval. Controllers regulate the charging and discharging processes, optimizing the state of charge (SoC) and ensuring that energy is stored when excess power is available and released during periods of high demand or low generation (Tiwari et al., 2022). This regulation is crucial for maintaining grid stability and balancing supply and demand.

3. *Voltage and Frequency Regulation*: Power electronics help in regulating voltage and frequency within the MG, ensuring that these parameters remain within acceptable limits despite fluctuations in generation or load. Devices such as voltage-source converters (VSCs) and frequency controllers manage these variations, contributing to the overall stability and reliability of the MG (Roslan et al., 2022).

4. *Seamless Transition Between Modes*: Power electronics facilitate smooth transitions between grid-connected and islanded modes. This is achieved through sophisticated control systems that manage the synchronization of the MG with the main grid or operate independently when disconnected. This capability is vital for ensuring uninterrupted power supply during grid outages or in isolated scenarios (Ganthia and Barik, 2022).

5. *Current Balancing and Load Sharing*: Effective load sharing and current balancing across various RES and loads in MGs are managed by power electronics. These systems ensure that electrical currents are evenly distributed, preventing overloading of components and optimizing the overall performance of the MG (Machado et al., 2023).

CONTROL STRATEGIES FOR BALANCING AND POWER MANAGEMENT

To address the complexities of integrating multiple RES and managing power within MGs, several control strategies have been developed:

1. *Droop Control*: This method adjusts the output power of DERs based on changes in frequency or voltage. It allows for automatic balancing of power across DERs without requiring centralized control (Worighi et al., 2019).

2. *Hierarchical Control*: Hierarchical control systems manage different levels of MG operations, from primary frequency control to secondary voltage regulation. This approach ensures comprehensive oversight and management of the MG’s components (Ourahou et al., 2020).

3. Model Predictive Control (MPC): MPC uses real-time data to forecast future states of the MG and adjust operations accordingly. This predictive capability helps in optimizing power management and maintaining grid stability (Ourahou et al., 2020).

4. Virtual Inertia Emulation: By simulating the inertia of traditional generators, this method helps in stabilizing the grid against fluctuations caused by intermittent RES (Ganthia and Barik, 2022).

5. Adaptive Control and Machine Learning: Advanced algorithms leverage historical and real-time data to adapt control strategies, improving the efficiency and responsiveness of MGs. Machine learning models predict demand patterns and optimize performance, enhancing the overall functionality of the MG (Dileep, 2020; Strielkowski et al., 2020).

DESIGN CRITERIA FOR STABLE AND DURABLE POWER SYSTEMS

Designing stable and durable power systems, particularly in the context of microgrids (MGs) with distributed energy resources (DERs), involves several key criteria to ensure efficient operation and reliability. The integration of DERs, including renewable energy sources and energy storage devices, demands careful consideration of current sharing mechanisms, control strategies, and adaptability to varying conditions.

1. **Current Sharing and Load Balancing**

Current sharing is crucial for preventing overloads and enhancing system reliability. Droop control is a widely used method where the output power of each DER is proportional to deviations in local voltage or frequency. This technique ensures an equitable distribution of load, thereby preventing any single DER from becoming overloaded (Pathan et al., 2021). Additionally, the concept of virtual impedance simulates the impedance of resistors within DER control loops, enabling automatic load reallocation based on the impedance values (Ganthia and Barik, 2022). By dynamically adjusting virtual impedance, the system maintains a balanced current distribution, with DERs of lower impedance handling more load.

2. **Advanced Control Systems**

Complex control systems are essential for managing current sharing in real-time. Inter-DER communication and cooperative control techniques, such as consensus-based algorithms, allow DERs to adjust their outputs based on the status of neighboring units. This cooperative approach enhances the adaptability and reliability of the system, particularly under changing load and generation conditions (Ganthia and Barik, 2022).

3. **Energy Storage Integration**

Energy storage technologies add complexity to current sharing but are vital for maintaining grid stability. These technologies manage the dynamic storage and release of energy, which helps in balancing supply and demand (Ali et al., 2020). However, their integration requires precise measurement of line impedances and effective communication among DERs to ensure optimal performance.

4. **Adaptability and Control Challenges**

Adaptive control systems are necessary to address the challenges posed by nonlinear loads and intermittent renewable energy sources. These systems must be able to handle variations in energy generation and demand, ensuring accurate current distribution and maintaining system stability (Ali et al., 2020). The effectiveness of these systems depends on the precision of measurements and the latency of DER communications (Dagar, Gupta, and Niranjan, 2021). In the context of the UK’s evolving grid infrastructure and regulatory environment, selecting and implementing robust current sharing and control strategies is crucial for the successful integration of microgrids and renewable energy sources (Butt et al., 2021).

CONTROL TECHNIQUES AND POWER REGULATION IN MICROGRIDS

Examination of Balance Control Techniques

In microgrids (MGs), maintaining stable and efficient operation involves sophisticated control techniques to manage the balance of power and regulate current distribution. Key techniques include droop control, virtual impedance, and advanced communication-based methods.

1. ***Droop Control***

Droop control is a prevalent method used to manage the output of distributed energy resources (DERs) in a microgrid. This technique adjusts the power output of DERs in response to deviations in local voltage or frequency. By linking power output to voltage or frequency deviations, droop control ensures that power is distributed proportionally among DERs, preventing any single unit from being overloaded and enhancing overall system efficiency (Pathan et al., 2021). This method is effective in both grid-connected and islanded modes of operation.

2. ***Virtual Impedance***

Virtual impedance is another crucial technique used to balance current distribution in MGs. This method involves simulating the impedance of resistors within the DER control loop, which adjusts the load allocation based on the impedance values (Ganthia and Barik, 2022). By dynamically adjusting virtual impedance, DERs with lower impedance handle more of the load, helping to maintain balanced current distribution and system stability.

3. ***Advanced Communication-Based Methods***

Recent advancements include complex control systems that utilize inter-DER communication. These systems enable DERs to exchange real-time information and collaboratively adjust their outputs based on the current status of neighboring units. Techniques such as consensus-based algorithms facilitate efficient current sharing by allowing DERs to agree on the optimal load distribution strategy (Ganthia and Barik, 2022). This cooperative approach enhances the system’s adaptability and reliability, particularly in response to fluctuating load and generation conditions.

3. SIMULATION AND MODELLING APPROACH USING MATLAB AND SIMULINK

Simulation tools like MATLAB and Simulink are invaluable for modelling and analysing microgrid performance. These platforms offer comprehensive frameworks for simulating the interactions between various components, including renewable energy sources, energy storage systems, and control algorithms (Strielkowski et al., 2020).

1. **Modelling Transient Behaviour**

MATLAB and Simulink allow researchers to model the transient behaviour of microgrids under various scenarios, such as demand fluctuations or the sudden connection or disconnection of renewable energy sources. This capability helps in evaluating the system's stability and adjusting control strategies to maintain voltage and frequency within safe limits (Phurailatpam et al., 2019).

2. **Control Algorithm Evaluation**

These tools are also used to design and assess various control algorithms for load balancing and power management. Researchers can incorporate custom control logic and simulate different control strategies to optimize performance. The real-time visualization of simulation results provides insights into how control algorithms impact system behaviour (Mojumder et al., 2022).

3. **Performance Optimization**

Optimization algorithms within MATLAB and Simulink help determine the optimal use of renewable energy, energy storage, and load management. These simulations aim to enhance system efficiency, reduce energy costs, and maximize the integration of renewable resources (Dagar et al., 2021). In the UK, these tools are used to tailor models to specific national conditions, including unique energy resources and regulatory frameworks (Harsh and Das, 2021).

3.1 Microgrid Integration in the UK: Current State and Challenges

Please The UK's transition towards a decentralized and environmentally friendly energy infrastructure prominently features microgrids. These systems, integrating renewable energy sources and advanced control technologies, promise increased energy resilience and reduced transmission losses (Dileep, 2020).

1. **Benefits and Current Research**

Microgrids offer numerous benefits, including enhanced energy resilience and reduced peak demand on the main grid. Research and demonstration projects across residential, commercial, and industrial sectors are underway, showcasing the potential for increased use of local renewable resources and improved energy security (Hannan et al., 2020).

2. **Regulatory and Technological Challenges**

Despite the advantages, several challenges need addressing. Existing regulatory frameworks, designed for centralized systems, often pose difficulties for microgrid development and management. Issues such as market participation, tariffs, and grid regulations need reform to accommodate the decentralized nature of microgrids (Shahinzadeh et al., 2019). Technological obstacles, including the need for advanced communication infrastructure and interoperable technologies, also complicate integration efforts (Tan et al., 2021).

3. **Economic Considerations**

The financial viability of microgrids involves analysing initial investment costs, operational expenses, and potential returns on investment. Researchers are developing economic models to assess the long-term benefits and cost-effectiveness of microgrid projects, focusing on lifecycle costs and financial sustainability (Ganesan et al., 2020). In summary, the successful integration and operation of microgrids require advanced control techniques, robust simulation and modelling tools, and careful consideration of regulatory, technological, and economic factors. The UK’s evolving energy landscape presents both opportunities and challenges for the widespread adoption of microgrids.

3.2 Simulation and Modelling

Development of the microgrid model in MATLAB/Simulink.

MATLAB Simulink® (R2024a) by MathWorks is used for modelling and testing microgrids, offering a block diagram environment for continuous simulation, verification, automatic code generation, and system-level design.

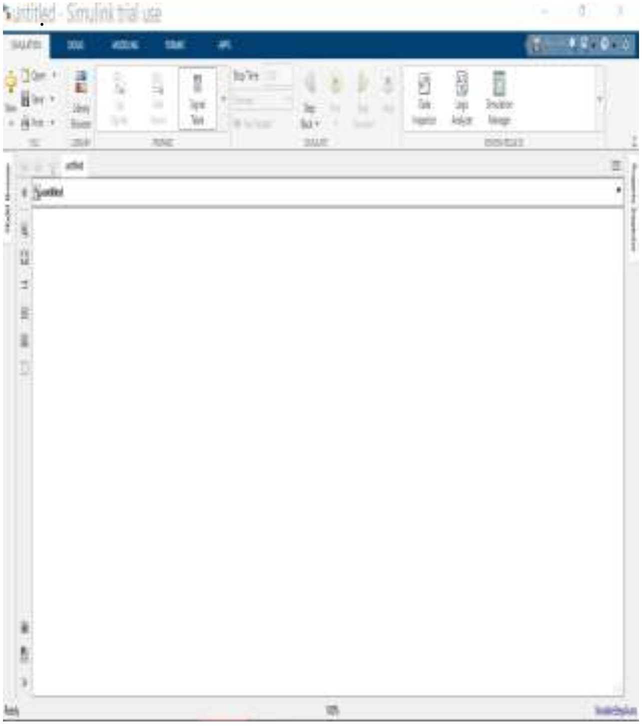


Figure 6: Simulink modelling and simulation environment

Renewable energy sources (RES) selected include solar and wind, due to their compatibility and availability in the UK (Miao et al., 2020). A PV model was designed using Simulink, with a 10-kW array. The I-V and P-V characteristics were verified, using irradiance of 100 W/m² and temperature of 25°C to assess performance.

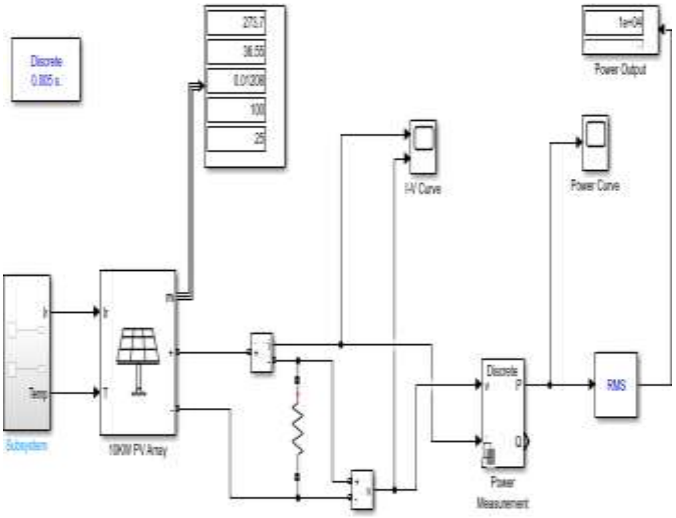


Figure 7 PV model

3.3 WTG MODEL

The WTG model was built as well in the Simulink environment. A WTG rated at 20KW was designed and modelled with a wind speed of15m/s. The reactive power required for the excitation of the doubly fed wind induction generator (DFWIG) was supplied by a 3 Phase 400V Capacitor bank.

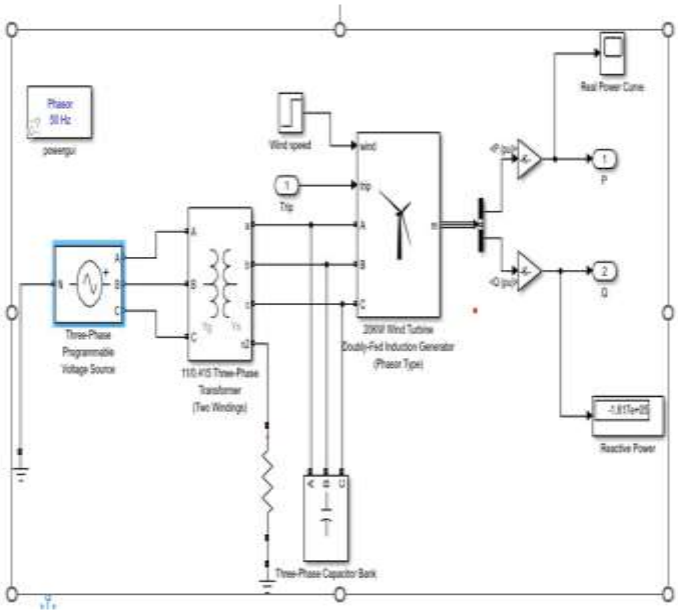


Figure 8 WTG Model

3.4 Energy Storage System

A bank of Lithium-Ion batteries was used for the model. An efficient battery management system (BMS) that incorporates state of charge (SOC) was used to monitor the charging and discharging rates of the battery. When the SOC rises above 80% the battery discharges and recharges when the SOC falls below 40%. The programming was done using a chart block and other components.

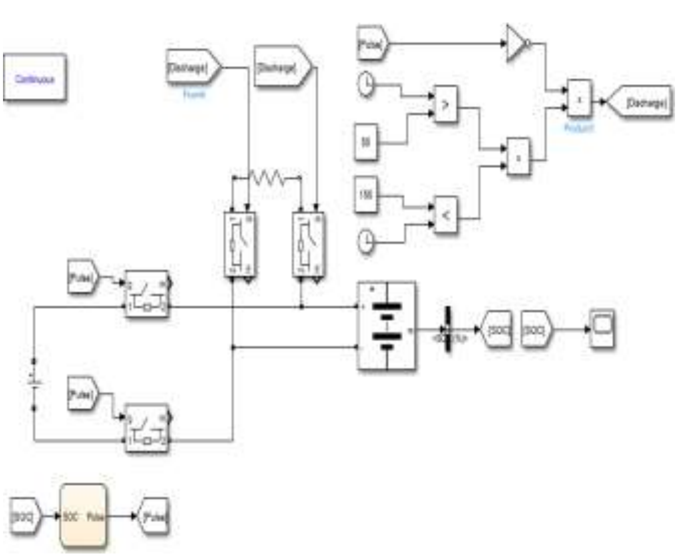


Figure 9 Battery model

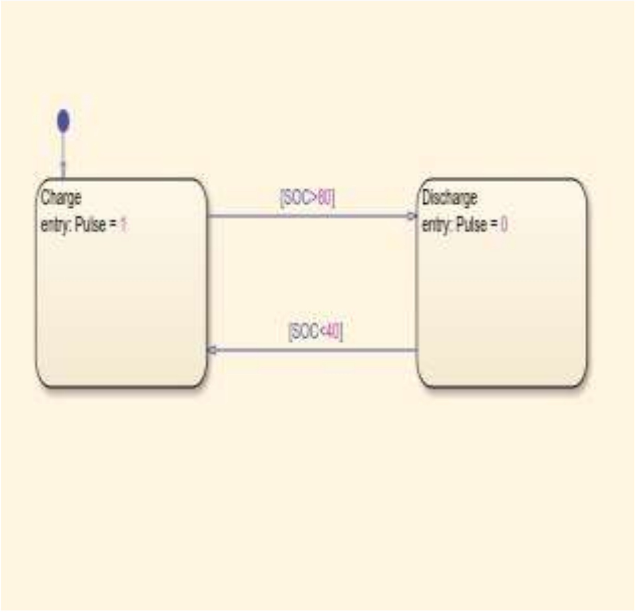


Figure 10 Embedded SOC Program

3.5 MG Inverter Controller

This is the brain behind the MG operations. It converts the DC output of the PV array and provides real-time control of the renewable energy sources such as the PV and WTG by balancing their generation with demand.

3.6 Distribution Grid

The grid was built from the components in the SimPower system. Like a typical grid, it has voltage source, a 3 phase two-winding transformer and a capacitor bank for improving the power factor.

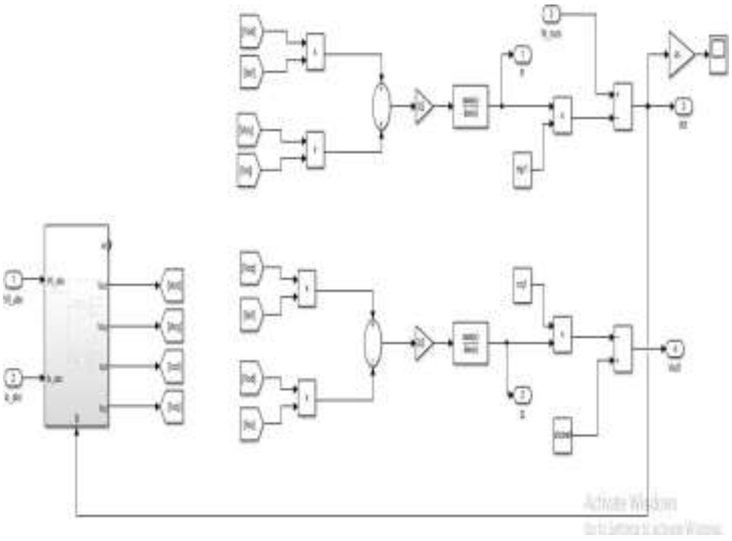


Figure 11 Centralized Droop Inverter MG Controller

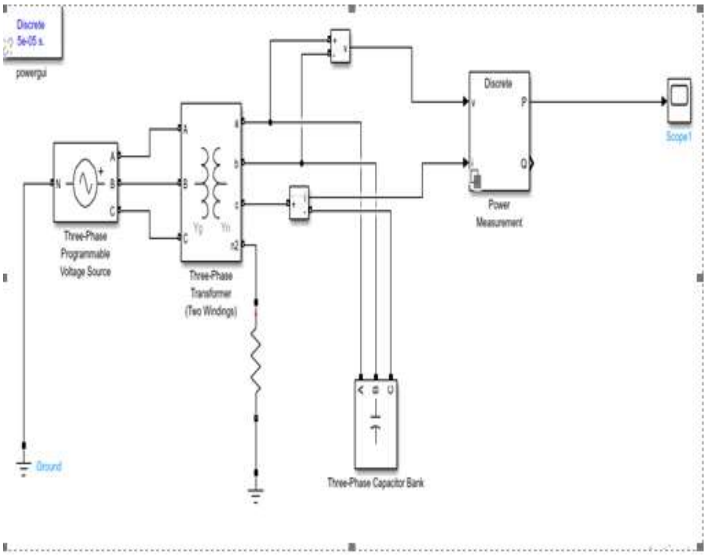


Figure 12 Distribution Grid

4. Complete Diagram

The various components of the integrated MG were put together to form the complete diagram on the Simulink environment Captions should be Times

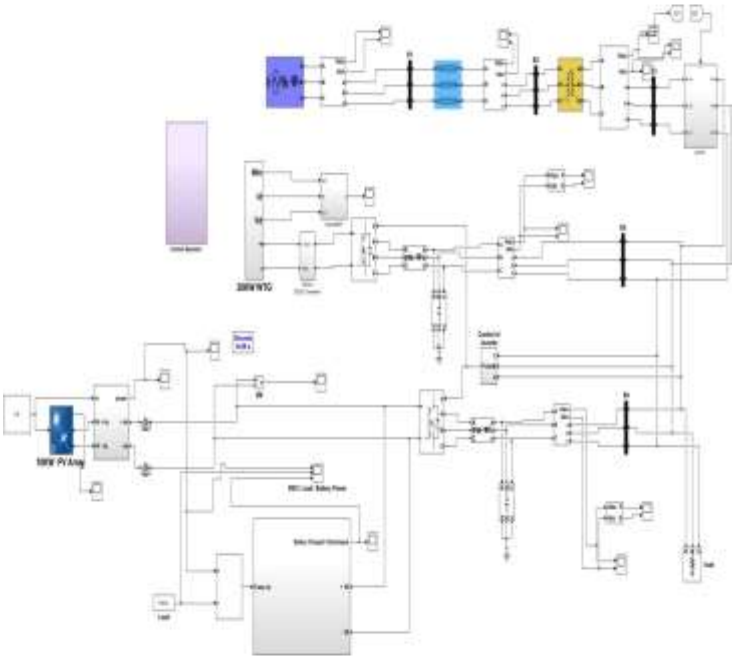


Figure 13 Complete Diagram

4.1 Simulation Result of PV Array

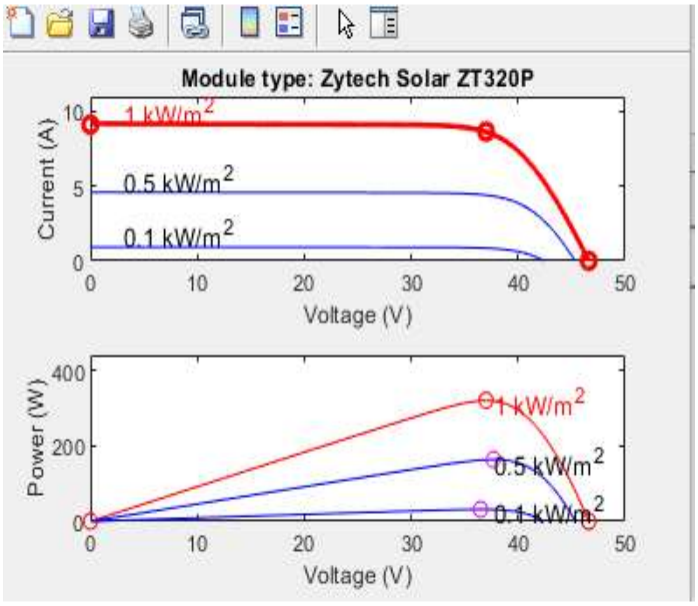
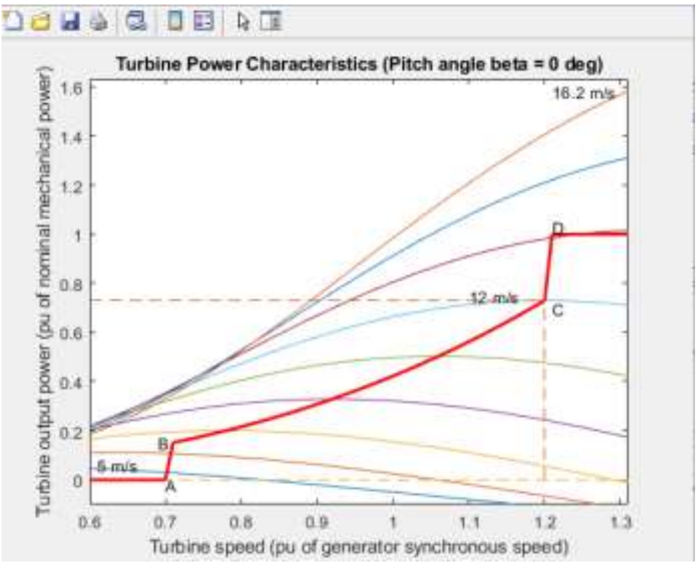


Figure 14 I-V and P-V Performance characteristics of the PV



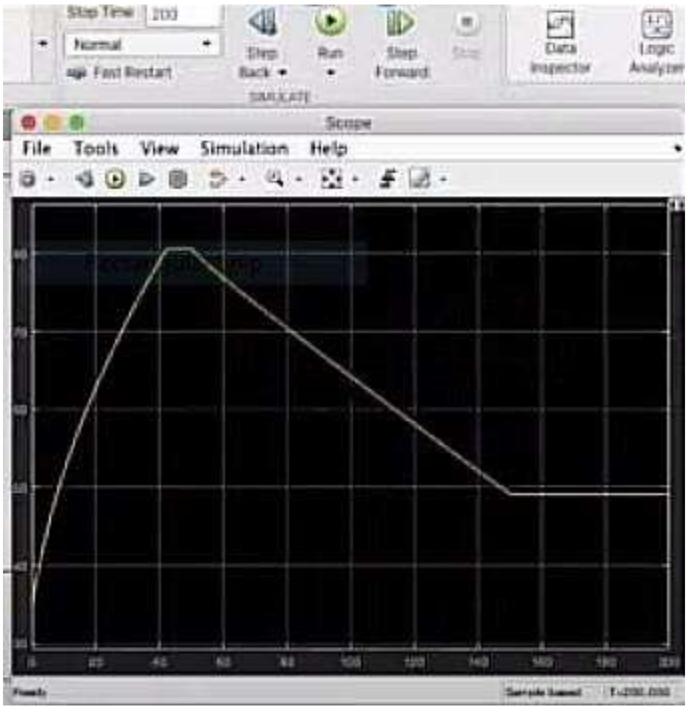


Figure 15 WTG Plot showing the effect of wind speed

Figure 16 BMS Simulation report

4.2 Simulation Result of the Loading of the PV And WTG

From the simulation result presented by the scope, it can be seen that when the SOC of the battery attained 80%, it started to discharge and dropped to 40%. The battery would remain at this SOC and it does not fall below 40%. If it does, the battery will start a charging regime for the SOC to rice to 80%.

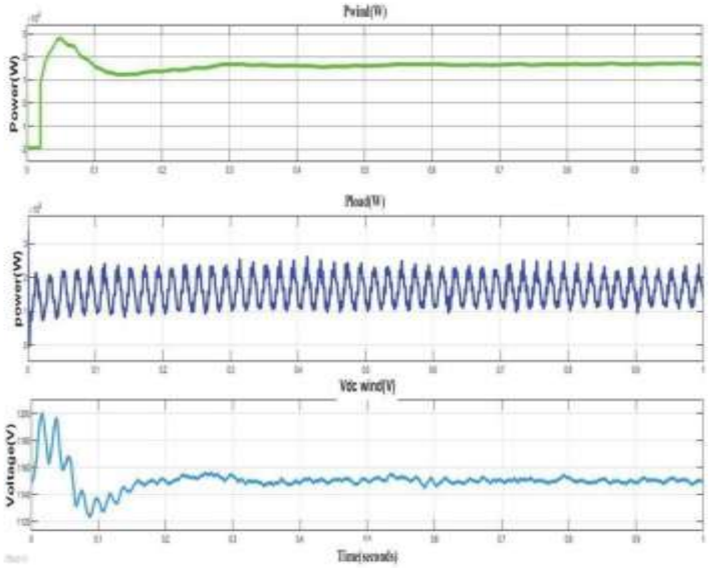


Figure 17a PV outputs under different loading conditions

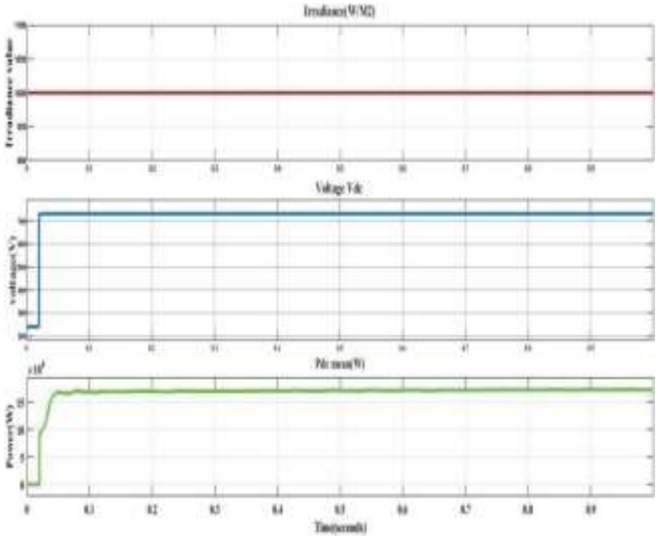


Figure 17b PV outputs under different loading conditions

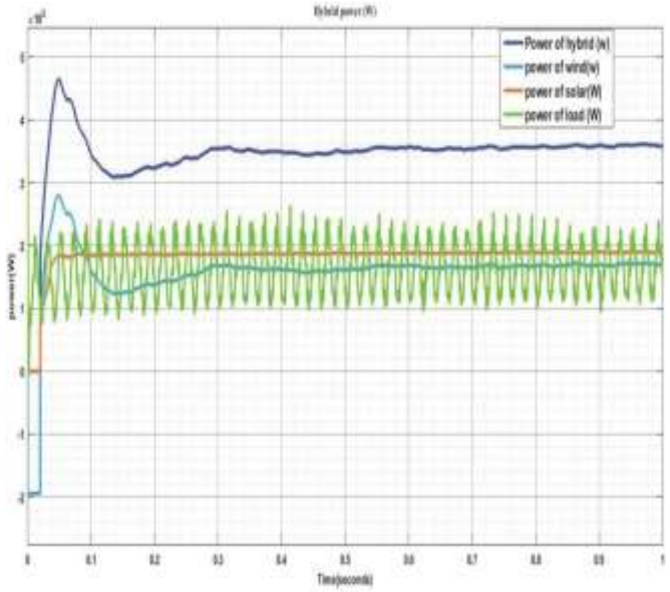


Figure 18 Combined loading of PV and WTG

The simulation results of the PV and WTG reveals that they both generate 8.5KW and 19.2KW respectively. When they were both integrated with the grid, the combined output rose to 27.7KW. That means more loads can be supplied and the efficiency of the system will increase.

4.3 Simulation of the Inverter output

The inverter faithfully replicated an AC wave when the DC voltage output of the PV array is applied to it. The waveform obtained was a sinusoidal square wave.

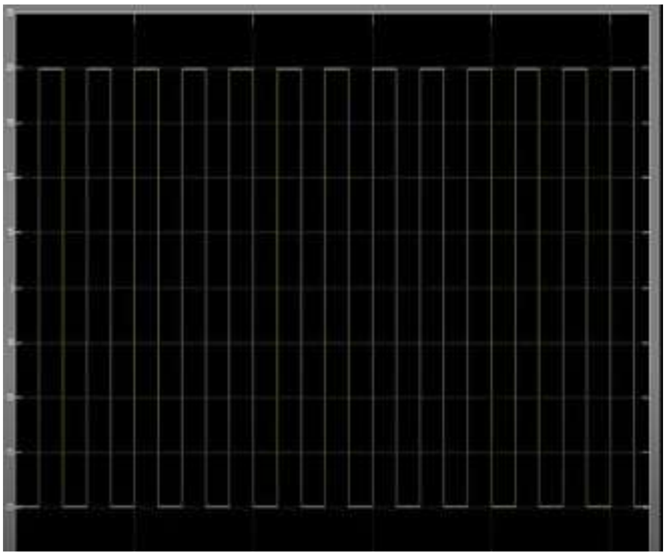


Figure 19 AC output of Inverter

5.0 CONCLUSION AND FUTURE WORK

The project successfully demonstrated the integration of renewable energy sources (RESs) into a microgrid (MG) using MATLAB/Simulink R2024a. The main objective was to explore how MGs can efficiently incorporate RESs, specifically solar photovoltaics (PV) and wind turbines (WTGs), into the distribution grid. The simulation revealed that a hybrid integration of a 10 kW PV system and a 20 kW WTG provided a more substantial and reliable power output compared to their individual capacities. This combined output was significantly higher than the separate performances, highlighting the improved efficiency of the MG system.

Key findings include:

- ***Enhanced Power Output*** The hybrid system achieved greater efficiency and reliability in power supply, confirming that the integration of RESs can enhance overall system performance.

- ***Island Mode Operation*** the MG controller, implemented in Simulink, demonstrated effective regulation of RESs and grid integration, ensuring seamless transition to island operation during grid outages.

- ***System Performance*** Simulation results indicated that the MG system could effectively meet power demands through the integrated RESs, validating the potential of MGs for sustainable and affordable electricity provision.

The potential for real-world application is significant. The successful integration of PV and WTG in the MG system suggests that similar approaches could be applied to other regions, leveraging local RESs to improve grid stability and sustainability. This is particularly relevant for regions aiming to increase their use of renewable energy and reduce reliance on fossil fuels.

SUGGESTIONS FOR FUTURE RESEARCH AND DEVELOPMENT

1. **Advanced Control Strategies**

Future research should focus on developing and testing more advanced control algorithms to optimize performance under varying conditions and improve real-time response.

2. **Integration of Additional RESs**

Exploring the integration of other RESs such as biomass or hydropower could provide a more comprehensive understanding of MG performance and efficiency.

3. **Real-World Validation**

Conducting field tests and pilot projects to validate simulation results in real-world scenarios would help address practical challenges and refine system designs.

4. **Enhanced Simulation Models**

Improving simulation models to include a broader range of environmental factors and real-world uncertainties will enhance the accuracy and reliability of predictions.

Overall, while the project has laid a strong foundation for understanding MG integration, continued research and development are essential to fully realize the potential of MGs in achieving sustainable and resilient energy systems.

5. ACKNOWLEDGMENTS

Our thanks to the experts who have contributed towards development of this research and execution of the MATLAB Simulink Model.

6. REFERENCES

[1.] Amir M, Patel S, Shah M. Advanced control strategies for microgrid operations: A review. Int J Electr Power Energy Syst. 2022;134:107368.

[2.] Alotaibi F, Ganaie MA, Ahmad S. Challenges and solutions for the widespread adoption of microgrids: A comprehensive review. Energy Rep. 2023;9:1235-1254.

[3.] Butt S, Masood T, Ahmed R. Enhancing energy security and reducing emissions with microgrids. J Clean Prod. 2021;320:128755.

[4.] Dileep GK. Technological advancements and challenges in microgrid integration. J Energy Eng. 2020;146(4):04020040.

[5.] Ganthia SK, Barik NC. Control strategies for microgrids with intermittent renewable energy sources. Energy Rep. 2022;8:334-349.

[6.] Hosseini SA, Li W, Zhu K. Role of power electronics in renewable energy integration. J Power Electron. 2021;21(3):1231-1243.

[7.] Ourahou H, Hannan MA, Rahim NA. Advanced control strategies for microgrid applications. Renew Sustain Energy Rev. 2020;127:109866.

[8.] Roslan R, Adinugroho W, Pereira E. Voltage and frequency regulation in microgrids with renewable energy sources. IEEE Trans Smart Grid. 2022;13(2):950-961.

[9.] Shirkhani M, Aminifar F, Mohammadi K. Grid-connected and islanded operation of microgrids: A review. Elect Power Syst Res. 2023;207:108088.

[10.] Strielkowski W, Dulikravich GS, Wu X. Optimization of energy storage systems in microgrids. Energy Convers Manag. 2020;207:112415.

[11.] Tan Y, Zhang J, Wang X. Advancements in microgrid control algorithms and communication systems. J Mod Power Syst Clean Energy. 2021;9(4):678-692.

[12.] Behzadi S, Mohebbi A, Babanezhad M, Gharehpetian GB. A review on the impact of renewable energy sources and storage systems on the reliability of power systems. Renew Energy. 2023;191:736-751.

[13.] Jia X, Liu H, Li Q, Jiang M. Review of energy storage technologies and their applications in renewable energy systems. Renew Sustain Energy Rev. 2023;153:111790.

[14.] Mieński S, Wasiak M, Kelm J. Control algorithms for improving power quality in PV-integrated microgrids. J Electr Eng Technol. 2023;18(2):763-775.

[15.] Nwaigwe SU, Mutabilwa DM, Dintwa K. Current sharing mechanisms in microgrids: A review. Elect Power Syst Res. 2019;172:197-208.

[16.] Romanov V, Leiss B. Energy storage solutions for renewable energy integration: A review. Renew Energy. 2022;187:1121-1135.

Case Studies and Regional Focus:

[17.] Ahmad S, Ganaie MA, Alotaibi F. Case studies on microgrid implementation: Insights from the United Kingdom. Energy Rep. 2022;8:2064-2079.

[18.] Panda S, Das D. Achieving renewable energy targets through microgrid implementation: The case of the United Kingdom. Energy Policy. 2021;156:112412.

[19.] Butt M, Jan MA, Malik SA. Challenges and advancements in microgrid integration in the UK. Energy Rep. 2021;7:1691-1704.

Challenges and Future Directions:

[20.] Bagherzadeh M, Molaei R, Faraji V. Benefits and challenges of microgrid implementation in modern power systems. Renewable Energy. 2019;141:1087-1098.

[21.] Garg M, Niazi KR. Renewable energy integration into the power grid: Challenges and solutions. Energy Rep. 2022;8:10112-10127.

[22.] Ganesan S, Gupta A, Jain R. Control strategies for integrating renewable energy sources in microgrids. Energy Rep. 2020;6:46-62.

[23.] Zhang L, Zhang Z, Li Y. Energy storage system management in microgrids: Challenges and solutions. Renewable Energy. 2023;208:1105-1116.

Technical Aspects and Optimization:

[24.] Ahmad T, Zhang D, Huang C, Zhang H, Dai N, Song Y, Chen H. Review and comparison of various optimization techniques for microgrid. Renewable Sustain Energy Rev. 2022;116:109424.

[25.] Ali N, Kazmi SZ, Khan MA, Abbas S. Advanced battery storage systems for renewable energy integration. Energy Storage Mater. 2023;58:1-14.

[26.] Pathan KA, Haider N, Khan MR. Droop control strategies for microgrids: A comparative study. Energy Convers Manage. 2021;227:113613.

[27.] Tiwari M, Phurailatpam T, Flynn D. State-of-charge optimization in energy storage systems for microgrids. Energy Rep. 2022;8:510-523.

[28.] Chukwunweike JN, Michael S, Mbamalu MI, Emeh C. Artificial intelligence and electrocardiography: A modern approach to heart rate monitoring. World J Adv Res Rev. 2024;23(01):1385–1414. doi:10.30574/wjarr.2024.23.1.2162. Available from: https://doi.org/10.30574/wjarr.2024.23.1.2162.

Economic and Environmental Impact:

[29.] Rosales-Asensio E, Rodríguez M, Gómez T. Cost and sustainability benefits of integrating microgrids into distribution networks. Energy Convers Manage. 2023;266:115415.

[30.] Worighi A, Khedher NB, Zhang L. Economic and environmental benefits of microgrids: A case study. Energy Rep. 2019;5:1183-1192.