iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 Issue: IV Month of publication: April 2026

DOI: https://doi.org/10.22214/ijraset.2026.80504

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue IV Apr 2026- Available at www.ijraset.com

Modelling and Simulation of Microgrid Dynamic Operation Modes

Sayali Sonawane[1], Dr. Girish K. Mahajan[2], Dr. Nitin M. Khandare[3]
[1]MTech Scholar Electrical Engineering, Department SSGB College of Engineering and Technology, Bhusawal, Maharashtra, India
[2, 3]Assistant Professor, Electrical Engineering, Department SSGB College of Engineering and Technology, Bhusawal, Maharashtra, India

Abstract: The integration of renewable energy sources into power distribution systems has become increasingly important due to the rising demand for reliable and sustainable electricity. Microgrids provide an effective approach for combining distributed energy resources with conventional power systems while maintaining system stability and reliability. This study presents the Modeling and simulation of a microgrid system developed in MATLAB and Simulink to examine its operational performance under different conditions. The proposed microgrid includes a solar photovoltaic (PV) generation system, a battery energy storage system (BESS), a diesel generator used as a backup source, a utility grid connection, and multiple electrical loads connected through a common AC bus. The model is designed to evaluate how the system responds to several operating situations, including normal grid-connected operation, fault conditions, islanded mode, load changes, and grid reconnection.

Special attention is given to maintaining voltage and frequency stability during disturbances. The battery energy storage system plays a key role in balancing power within the microgrid by storing excess energy and supplying power when renewable generation is insufficient. The simulation results demonstrate that the proposed microgrid configuration can maintain stable operation and ensure reliable power supply under varying operating conditions.

Keywords: Microgrid, Renewable Energy Integration, Solar Photovoltaic (PV), Battery Energy Storage System (BESS), Diesel Generator, MATLAB/Simulink, Islanded Operation, Grid-Connected Mode, Power System Stability, Distributed Energy Resources (DER).

I. INTRODUCTION

The increasing demand for dependable and environmentally sustainable electricity has encouraged the wider adoption of renewable energy sources in modern power systems. Technologies such as solar and wind energy are being integrated into distribution networks to reduce dependence on conventional fossil-fuel generation. However, the variable and unpredictable nature of these renewable sources introduces challenges related to power quality, system stability, and effective energy management. In recent years, microgrids have been recognized as a practical approach for addressing these issues by combining distributed energy resources, local loads, and energy storage systems within a localized electrical network.

A microgrid can function either in coordination with the main utility grid or independently when disturbances occur in the external network. This flexibility improves supply reliability and helps ensure uninterrupted electricity for critical facilities such as hospitals, research centres, and remote communities. In addition, microgrids allow consumers to participate more actively in energy generation and management, gradually transforming traditional passive distribution systems into more interactive and intelligent power networks. This study focuses on the modeling and simulation of a microgrid system to understand its operational characteristics under different conditions. Various simulation scenarios are analyzed to evaluate system behaviour, coordination between photovoltaic generation and battery energy storage, and the overall stability of the microgrid during transitions between operating modes. The results provide useful insights for improving microgrid design and operational strategies.

II. LITERATURE REVIEW

The continuous rise in global electricity consumption, along with growing environmental concerns linked to fossil-fuel-based power generation, has encouraged the development of cleaner and more sustainable energy solutions. Renewable energy technologies such as solar and wind have therefore gained considerable attention in modern power systems. However, integrating these energy sources into traditional electrical networks can be challenging because their power output depends on weather and environmental conditions. To address these limitations, the concept of microgrids has been introduced as an effective way to manage distributed energy resources within a localized power network. A microgrid is generally defined as a small-scale electrical system that includes distributed generation units, energy storage devices, and local loads operating within a specific geographical area. One of the key advantages of a microgrid is its operational flexibility. It can function in coordination with the main utility grid during normal conditions and can also operate independently, known as islanded mode, when disturbances or outages occur in the main grid. This capability improves reliability and ensures continuous power supply to critical loads.

Early studies on microgrid concepts were presented by Robert H. Lasseter, who described microgrids as integrated systems capable of coordinating distributed generators and loads as a single controllable unit. His work highlighted several benefits of decentralized energy generation, including reduced transmission losses, improved system reliability, and more efficient utilization of renewable resources. In addition, he emphasized the importance of advanced control strategies to maintain stable operation and ensure smooth transitions between grid-connected and islanded modes. Further research into microgrid operation and control was carried out by Nikos Hatziargyriou. His work examined how distributed generation and energy storage devices interact within a microgrid environment. Particular attention was given to maintaining stable voltage and frequency levels, especially during changes in operating conditions. These studies also stressed the importance of coordinated protection mechanisms and control systems to maintain safe and reliable microgrid operation. Another important development in microgrid research was proposed by Josep M. Guerrero, who introduced a hierarchical control framework for microgrid management. This approach divides system control into three layers: primary, secondary, and tertiary control. The primary level is responsible for immediate voltage and frequency regulation, the secondary level restores deviations that occur during disturbances, and the tertiary level manages power exchange between the microgrid and the utility grid. This structured control method has become widely used in modern microgrid designs.

The role of renewable energy within microgrids has also been widely explored by researchers such as Henrik Lund. His work focused on how renewable technologies can contribute to sustainable energy systems while reducing greenhouse gas emissions. Although renewable energy sources offer environmental advantages, their fluctuating output creates challenges for maintaining consistent power quality and system stability. For this reason, proper coordination between renewable generation units and energy storage technologies is necessary for reliable microgrid operation.

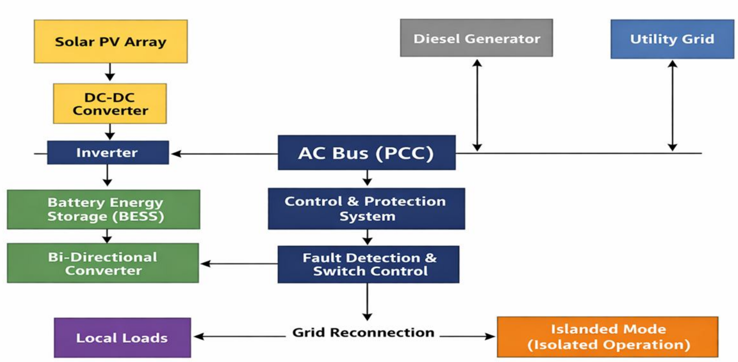
III. METHOEDOLOGY

A. *System Modeling Approach*

The main objective of this work is to design and simulate a microgrid system in order to study how it behaves under different operating conditions. The proposed system combines renewable energy generation, energy storage, and a conventional backup source so that a stable and reliable power supply can be maintained. To carry out this study, the microgrid model was developed and tested using MATLAB and Simulink. These simulation tools allow different operating situations to be examined and help evaluate the performance of each component in the system.

B. *Microgrid Architecture*

The microgrid designed for this study consists of several interconnected components, including a solar photovoltaic (PV) system, a battery energy storage system, a diesel generator, the utility grid, and different types of electrical loads. All these elements are connected through a common AC bus that serves as the main point for power distribution within the system. The solar PV system acts as the primary renewable energy source, while the battery storage system helps manage the balance between energy generation and consumption. The diesel generator is included to provide backup power when renewable generation and stored energy are not sufficient to meet the load demand.



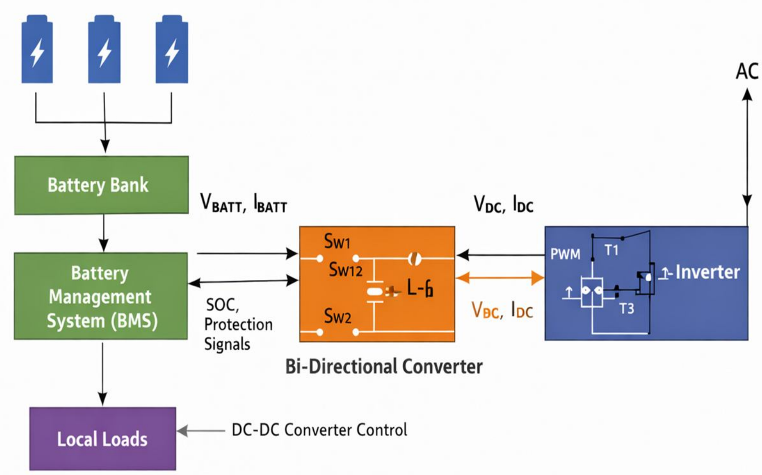
Block Grid System Modeling

C. Photovoltaic (PV) System

The PV subsystem is modeled to represent the conversion of solar energy into electrical power. Its output mainly depends on environmental factors such as solar irradiance and ambient temperature. A DC–DC converter is used to regulate the voltage generated by the PV array and improve energy transfer efficiency. Since the PV array produces DC power, an inverter is used to convert this power into AC so that it can be supplied to the AC bus and delivered to connected loads.

D. Battery Energy Storage System (BESS)

The battery energy storage system plays an important role in maintaining the balance between power generation and demand within the microgrid. When the PV system produces more power than required, the excess energy is stored in the battery. During periods of low solar generation or increased load demand, the stored energy can be released to support the system. The battery is connected through a bidirectional converter, which allows it to both charge and discharge depending on system requirements. In addition to energy storage, the battery system also assists in stabilizing voltage and frequency during sudden changes in load or generation.
The BESS in this project uses a 900 V DC bus, which is higher than the PV bus voltage (800 V) to provide margin for battery voltage variation during charge and discharge cycles. In a practical system, the battery voltage varies from approximately 3.0 V/cell (fully discharged) to 4.2 V/cell (fully charged), representing a 40% voltage variation. The 900 V bus voltage ensures adequate inverter modulation margin across the entire SOC range.



Battery Energy Storage System (BESS)

E. Diesel Generator Modeling

A diesel generator is included as a backup source to improve the reliability of the system. It is mainly used when renewable generation and stored energy are not able to meet the total load demand. The generator is connected to the AC bus and operates in coordination with the other power sources to maintain a continuous power supply.

F. Grid Connection and Load Modeling

The microgrid is connected to the main utility grid through a point of common coupling (PCC). Under normal conditions, the microgrid operates in grid-connected mode, allowing power to flow between the local system and the utility network. If disturbances occur in the main grid, the microgrid can isolate itself and continue operating independently in islanded mode. Different types of loads are included in the model to represent typical electricity consumption in residential, commercial, or industrial environments.

G. Simulation Scenarios

Several simulation cases were considered to understand how the microgrid behaves in different situations. These scenarios include normal grid-connected operation, disturbances in the grid, islanded operation, sudden load changes, and reconnection of the microgrid to the main grid after islanding. By analyzing these situations, it becomes possible to evaluate how well the system maintains stability and power balance.

H. Grid-connected operation

Where the microgrid operates in coordination with the main grid.

1) Fault conditions – where disturbances occur in the grid and system response is analysed.
2) Islanded operation – where the microgrid operates independently from the main grid.
3) Load variation scenarios – where sudden increases or decreases in load demand are introduced.
4) Grid reconnection – where the microgrid reconnects to the utility grid after islanded operation.

I. Performance Assessment

The performance of the microgrid is evaluated by monitoring electrical parameters such as voltage levels, current flow, system frequency, and power distribution across the network. Studying these parameters helps determine how effectively the system responds to disturbances and varying operating conditions. The simulation results provide useful information about the interaction between renewable energy sources, energy storage systems, and backup generation in maintaining reliable microgrid operation.

IV. MODEL CONSTRUCTION WORKFLOW

The programmatic construction follows a systematic workflow:

1) Step 1: Create a new blank Simulink model and add the power Gui block
2) Step 2: Add DC sources and capacitors for PV and BESS subsystems
3) Step 3: Add Universal Bridge inverters for PV and BESS
4) Step 4: Add per-phase RL filters for each inverter
5) Step 5: Add three-phase AC sources for grid and diesel generator
6) Step 6: Add per-phase circuit breakers (CB_Main, CB_DG, CB_Load)
7) Step 7: Add three-phase RLC loads (static and dynamic)
8) Step 8: Add Three-Phase Fault block
9) Step 9: Add Three-Phase V-I Measurement block at PCC
10) Step 10: Create SPWM subsystems (PWM_PV, PWM_BESS)
11) Step 11: Create protection/islanding detection subsystem
12) Step 12: Add scope blocks for visualization
13) Step 13: Connect all electrical and signal lines
14) Step 14: Configure simulation parameters and run.

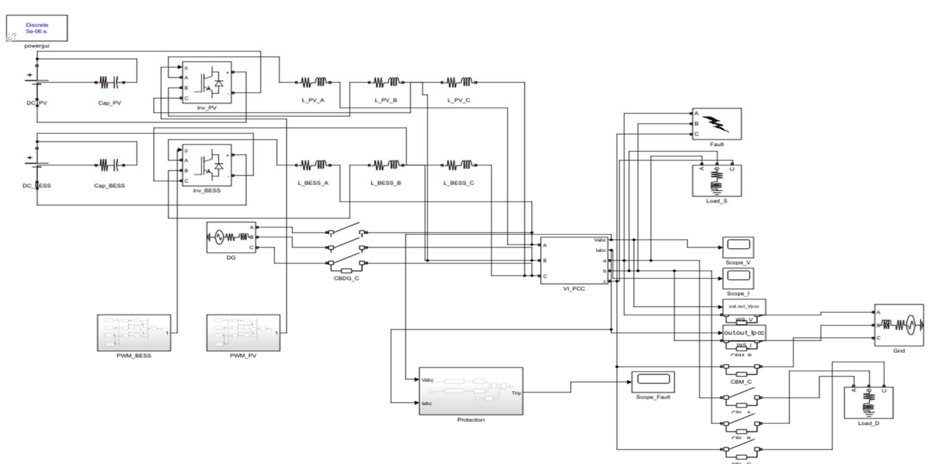


Fig.3 Complete Microgrid Simulink Model Layout

The microgrid model used in this work was developed in MATLAB R2022b using Simulink along with the Simscape Electrical toolbox. Simulink made it easy to build the overall system using a visual, block-based approach, while Simscape Electrical provided the necessary components to represent real electrical systems.The toolbox includes ready-to-use models such as three-phase sources, transformers, electrical machines, power electronic devices, and measurement blocks. Using these elements, the microgrid system could be modelled in a way that closely reflects practical operation. This setup allowed the behaviour of the system to be observed under different conditions, including normal operation as well as disturbances.

The system is designed with several important electrical considerations:

1) Voltage Level Compatibility: All AC sources and loads operate at 480 V line-to-line, 60 Hz, ensuring direct interconnection without transformers in the simulation model.
2) Grounding Strategy: The system uses a grounded-Y neutral configuration for the grid and diesel generator sources, providing a defined neutral reference and ground fault current path. The inverter-based DERs (PV and BESS) are connected with floating DC buses.
3) Per-Phase Breaker Configuration: Each circuit breaker is implemented as three individual single-phase breakers to allow per-phase control and to accurately model three-phase switching transients.
4) Snubber Design: Each breaker includes a 1 MΩ parallel resistance snubber to prevent numerical issues in the discrete-time simulation when breakers are open, providing a high-impedance current path that resolves algebraic loop constraints in Simscape Electrical.

V. MEASUREMENTS AND VISULIATION BOX

Three-Phase V-I Measurement: Provides per-phase voltage and current measurements at the PCC. The voltage output is the phase-to-ground voltage, and the current output is the line current. Both outputs are three-element vectors (phases A, B, C) that are routed to scope blocks for visualization and to the protection subsystem for fault detection.

Scope Blocks: Three scope blocks capture the simulation results:

Scope_V: Displays PCC voltage waveforms (3 phases) throughout the 0.5 s simulation

Scope_I: Displays PCC current waveforms (3 phases) throughout the 0.5 s simulation

Scope_Fault: Displays the protection trip signal (single binary signal).

VI. OVERVIEW OF SIMULATION RESULT

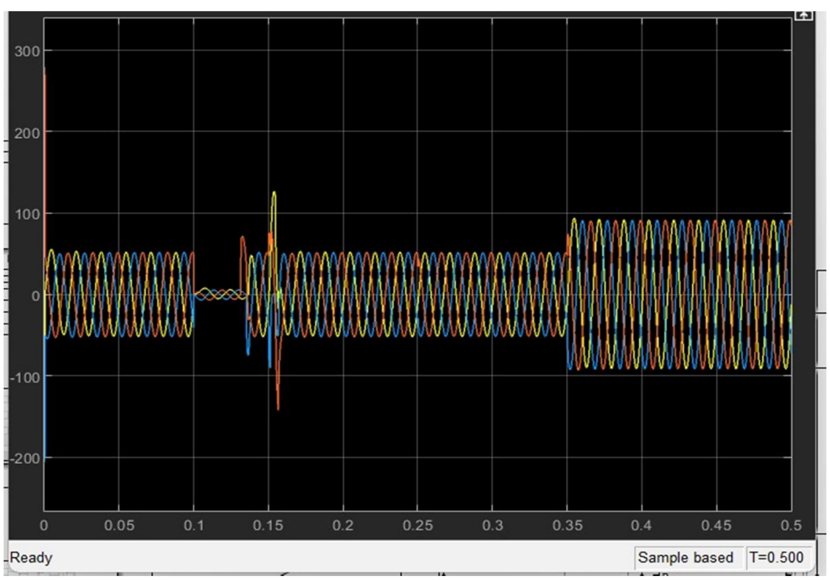


Fig.4 voltage scope

The simulation produces three sets of waveforms that collectively capture the complete dynamic behavior of the microgrid across all five operation modes:

detailed simulation results for all five dynamic operation modes of the microgrid system. The microgrid was simulated for 0.5 seconds using the discrete-time model described in the previous chapters. Three key waveforms were captured at the Point of Common Coupling (PCC): voltage (Scope_V), current (Scope_I), and the protection trip signal (Scope_Fault). Each mode is analyzed in detail with reference to the observed waveform characteristics, expected behavior based on circuit analysis, and implications for microgrid design.

The simulation was executed on a standard desktop computer (Intel Core i7, 16 GB RAM) using MATLAB R2022b. The total simulation time for the 0.5 s scenario with 5 µs time step (100,000 time steps) was approximately 15 seconds, demonstrating the computational efficiency of the discrete-time SPS modeling approach

Figure 4. shows the PCC voltage waveform (three-phase line-to-neutral), which is the primary indicator of power quality and system stability. The voltage waveform clearly shows the five distinct modes with characteristic amplitude and waveform quality changes at each transition point.

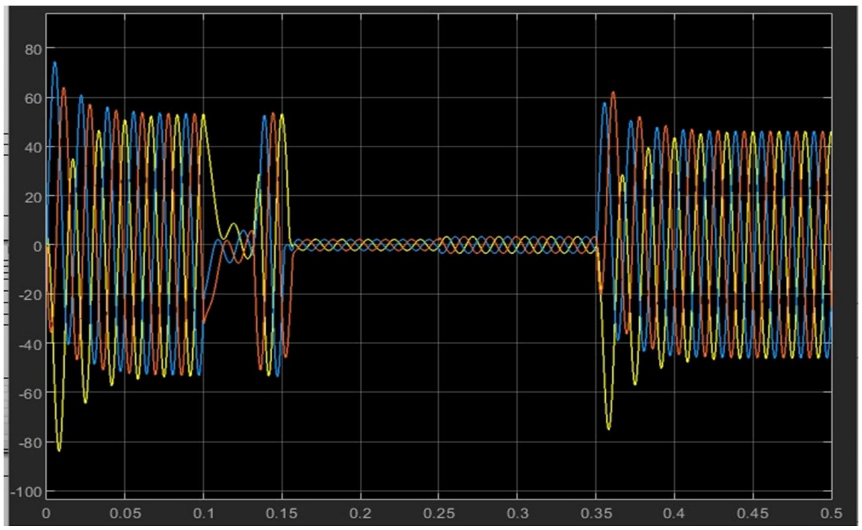


Fig.5 Current Scope

Figure 5 shows the PCC current waveform (three-phase line current), which reflects the power flow through the microgrid and responds to changes in load and source configuration. The current waveform provides complementary information to the voltage, showing how the power balance shifts between modes.

PCC current during grid-connected mode shows balanced three-phase sinusoidal waveforms with a peak amplitude of approximately ±60 A. The current includes contributions from all connected sources (grid, PV inverter, BESS inverter) flowing to the 10 kW static load. The relatively high current level (compared to the load-only current of ~17 A peak) indicates significant circulating current between the multiple sources due to small differences in their voltage magnitudes and phase angles.

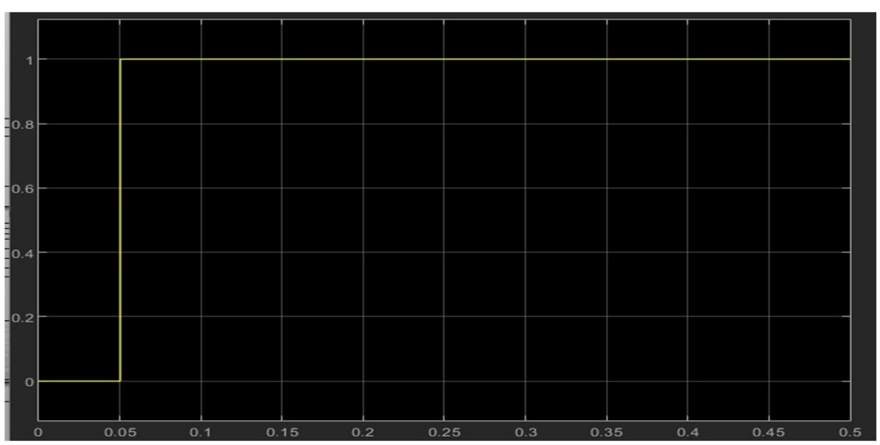


Fig 6. Fault Detection

Figure 6 shows the protection trip signal, a binary signal (0 or 1) that indicates whether the protection system has detected a fault condition. This signal demonstrates the proper operation of the passive islanding detection logic.

VII. CONCLUSION

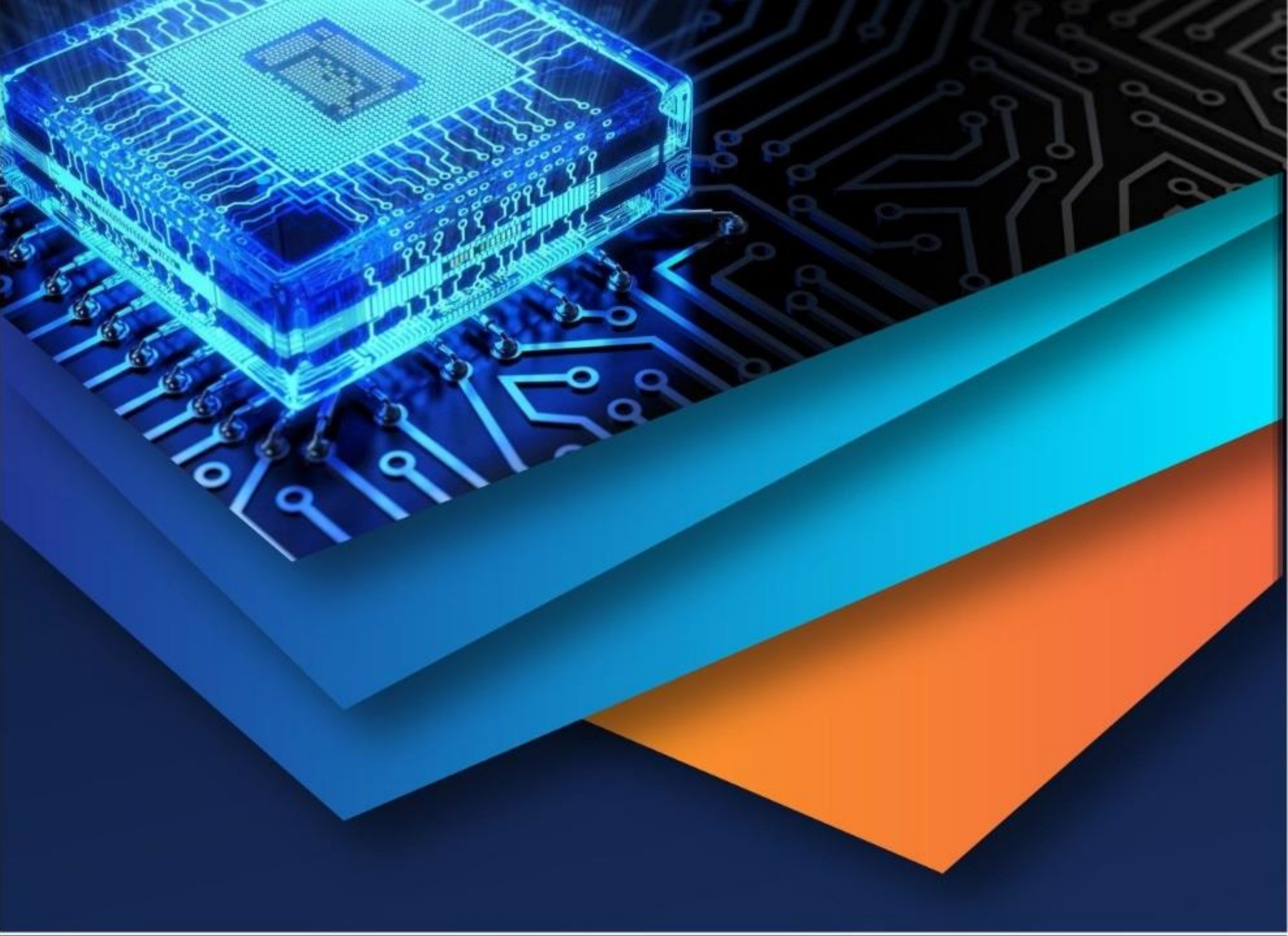
In this work, a detailed microgrid model was developed and analysed to study its behaviour under different operating conditions. The system integrates multiple distributed energy resources, including a photovoltaic source, battery energy storage, and a diesel generator, all connected to a common AC bus. The model was implemented in MATLAB R2022b using Simulink and Simscape Electrical, allowing detailed representation of power electronic interfaces and system dynamics.

The simulation results confirm that the microgrid is capable of operating reliably in both grid-connected and islanded modes. During normal operation, the utility grid maintains system voltage and frequency, while during islanded conditions, the local sources collectively supply the load without instability. The response of the system under fault conditions and load variations was also examined, showing expected transient behaviour such as voltage dips and current surges, followed by recovery once the disturbance is cleared.

The use of SPWM-controlled inverters enabled proper conversion of DC sources to AC with acceptable waveform quality, while RL filters helped in reducing switching harmonics. The implemented protection logic based on voltage and current thresholds was able to detect abnormal conditions within a short time and respond accordingly, ensuring system safety. Although the model is based on simplified control assumptions, the results demonstrate key operational characteristics of a practical microgrid, including mode transition capability, disturbance response, and coordination between multiple sources. This study provides a useful simulation framework that can be further extended with advanced control strategies, synchronization methods, and real-time validation for more realistic applications.

REFERENCES

[1] R. H. Lasseter, "MicroGrids," 2002 IEEE Power Engineering Society Winter Meeting, Conference Proceedings, vol. 1, pp. 305-308, 2002.
[2] N. Hatziargyriou, H. Asano, R. Iravani, and C. Marnay, "Microgrids," IEEE Power and Energy Magazine, vol. 5, no. 4, pp. 78-94, Jul.-Aug. 2007.
[3] S. Parhizi, H. Lotfi, A. Khodaei, and S. Bahramirad, "State of the Art in Research on Microgrids: A Review," IEEE Access, vol. 3, pp. 890-925, 2015.
[4] M. G. Villalva, J. R. Gazoli, and E. R. Filho, "Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays," IEEE Trans. Power Electronics, vol. 24, no. 5, pp. 1198-1208, May 2009.
[5] F. Diaz-Gonzalez, A. Sumper, O. Gomis-Bellmunt, and R. Villafafila-Robles, "A review of energy storage technologies for wind power applications," Renewable and Sustainable Energy Reviews, vol. 16, no. 4, pp. 2154-2171, 2012.
[6] F. Katiraei and M. R. Iravani, "Power Management Strategies for a Microgrid With Multiple Distributed Generation Units," IEEE Trans. Power Systems, vol. 21, no. 4, pp. 1821-1831, Nov. 2006.
[7] P. Piagi and R. H. Lasseter, "Autonomous Control of Microgrids," 2006 IEEE Power Engineering Society General Meeting, pp. 1-8, 2006.
[8] F. Katiraei, R. Iravani, N. Hatziargyriou, and A. Dimeas, "Microgrids management," IEEE Power and Energy Magazine, vol. 6, no. 3, pp. 54-65, May-Jun. 2008.
[9] P. Mahat, Z. Chen, and B. Bak-Jensen, "Review of islanding detection methods for distributed generation," 2008 Third Int. Conf. Electric Utility Deregulation and Restructuring and Power Technologies, pp. 2743-2748, 2008.
[10] R. K. Subroto et al., "Modeling and Simulation of Microgrid Transient Behavior during Mode Transitions," 2019 IEEE Int. Conf., pp. 1-4, 2019.
[11] IEEE Standard 1547-2018, "IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces," 2018.
[12] IEEE Standard 519-2014, "IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems," 2014.
[13] D. E. Olivares et al., "Trends in Microgrid Control," IEEE Trans. Smart Grid, vol. 5, no. 4, pp. 1905-1919, Jul. 2014.
[14] J. J. Justo, F. Mwasilu, J. Lee, and J.-W. Jung, "AC-microgrids versus DC-microgrids with distributed energy resources: A review," Renewable and Sustainable Energy Reviews, vol. 24, pp. 387-405, 2013.
[15] "Battery Degradation-Aware Energy Management in Microgrids," Batteries (MDPI), 2024.
[16] IEEE,"Recent Developments in Microgrid Protection Systems," IEEE Power and Energy Society, 2024



10.22214/IJRASET

45.98

IMPACT FACTOR:
7.129

IMPACT FACTOR:
7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY