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ADAPTIVE POWER COORDINATION FOR RENEWABLE-INTEGRATED GRID MICROGRIDS USING INTELLIGENT OPTIMIZATION

[1]Dr.L.Kishore,[2]Mr.CH.Krishna Prasad,[3]Mogarapu Anil Kumar
[1]Ph.D., Principal, Department of Electrical and Electronics Engineering, Sreekavitha Engineering College, Khammam-507122
[1]Email: kishorephd724@gmail.com
[2]Head of the Department, Department of Electrical and Electronics Engineering, Srichaitanya Institute of Technology&Research,Khammam-507210
[2]Email: scitkmm.eeehod@gmail.com
[3]Assistant professor, Department of Electrical and Electronics Engineering, Sri chaitanya institute of technology and research,Khammam-Hyderabad Road, Ponnekal (V), Khammam Rural, Khammam, Telangana - 507170
[3]Email: mogarapuanil@gmail.com

ABSTRACT

Energy management in grid-connected microgrids is essential for achieving efficient, reliable, and economical operation of distributed energy resources. This study presents an intelligent energy management approach for a grid-connected microgrid integrating renewable energy sources, energy storage systems, local loads, and the utility grid. The proposed framework uses intelligent decision-making techniques to continuously monitor power generation, energy demand, battery state of charge, electricity prices, and grid conditions. Based on these parameters, the system determines suitable power flow and energy scheduling strategies to improve renewable energy utilization while reducing energy costs and unnecessary power exchange with the main grid. The intelligent controller also supports effective battery charging and discharging and maintains the balance between generation and consumption. The proposed approach can enhance microgrid stability, operational efficiency, and reliability under varying load and renewable generation conditions. The framework provides a flexible solution for modern microgrids and can contribute to reduced energy consumption, improved renewable integration, and more sustainable power management.

Keywords: Grid-Connected Microgrid, Energy Management, Intelligent Energy Management, Renewable Energy, Energy Storage System, Power Management, Load Scheduling, Battery Management, Smart Grid, Power Optimization, Distributed Energy Resources, Renewable Energy Integration.

I.INTRODUCTION

The increasing demand for electrical energy and the growing integration of renewable energy sources have created a need for more efficient and flexible power management systems. Microgrids have emerged as an important solution because they can integrate distributed energy resources such as solar photovoltaic systems, wind energy, battery storage, and local loads within a controlled network. A grid-connected microgrid can exchange power with the main utility grid while also managing its local generation and consumption. This provides greater flexibility, improves energy utilization, and supports the reliable operation of modern power systems.

However, managing energy in a grid-connected microgrid is challenging because renewable energy generation is variable and load demand changes continuously. Improper scheduling of renewable sources, batteries, and grid power can increase operating costs and reduce system efficiency. Energy storage systems also need to be managed carefully to avoid

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unnecessary charging and discharging and to maintain an appropriate state of charge. Therefore, an effective energy management strategy is required to coordinate different energy sources and loads according to changing operating conditions.

Intelligent energy management techniques can provide an effective solution to these challenges by using real-time system information and intelligent decision-making. Such techniques can analyze parameters including power generation, load demand, battery state of charge, electricity prices, and grid conditions to determine suitable energy flow. The system can prioritize renewable energy, optimize battery operation, and decide when electricity should be imported from or exported to the utility grid. This can help reduce energy costs while improving the overall utilization of available resources.

The proposed work focuses on the development of an intelligent energy management framework for a grid-connected microgrid. The framework coordinates renewable energy sources, energy storage, local loads, and utility-grid interaction to achieve efficient power management. By dynamically adapting to variations in generation and demand, the proposed approach aims to improve energy efficiency, reduce unnecessary grid dependency, enhance operational reliability, and promote greater utilization of renewable energy.

II.LITERATURE SURVEY

García Vera et al. (2019) reviewed various energy management techniques for microgrids containing renewable energy sources. Their study focused on the challenges associated with integrating solar and wind power into microgrids because of their intermittent nature. Different optimization approaches were analyzed for grid-connected and islanded microgrids, with particular attention to energy storage systems. The authors concluded that effective energy management and optimization techniques can improve renewable energy utilization, reduce operating costs, and enhance the overall performance of microgrids.

Rangu et al. (2020) presented a comprehensive review of power management strategies for distributed energy resources in microgrids. The study examined the effects of fluctuating renewable generation and changing load demand on microgrid operation. Various power management methods were discussed for improving reliability, flexibility, and energy efficiency. The authors emphasized that advanced management strategies are required to coordinate renewable sources, storage units, and loads effectively under different operating conditions.

Ramli et al. (2019) investigated energy management in microgrids that include intermittent renewable energy sources and energy storage systems. Their work focused on maintaining a suitable balance between energy generation, storage, and consumer demand. Optimization techniques were used to determine appropriate energy scheduling decisions. The results indicated that coordinated management of renewable resources and batteries can improve the efficiency and economic performance of a microgrid.

Olivares et al. (2019) studied different microgrid control methods aimed at achieving sustainable energy management. The authors discussed the integration of renewable energy sources, energy storage systems, and local loads within microgrids. Their research highlighted the difficulties caused by variable renewable generation and changing operating conditions. The study showed that advanced control and energy management strategies are important for maintaining system reliability, power quality, and efficient energy utilization.

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Di Somma et al. (2020) reviewed centralized energy management systems developed for microgrids. Their study compared different optimization methods based on objectives such as operating cost reduction, renewable energy utilization, and efficient scheduling of distributed resources. The authors also considered factors such as uncertainty, optimization time horizon, and system constraints. Their findings showed that centralized energy management can effectively coordinate microgrid components, although computational complexity can become a limitation for real-time applications.

Essayeh et al. (2021) conducted a systematic review of energy management strategies for smart and green microgrids. The study examined different microgrid configurations, energy management techniques, and optimization approaches. The authors explained that intelligent management can improve the coordination between renewable energy generation, energy storage, and electrical loads. They also identified several challenges related to uncertainty, scalability, and real-time decision-making, suggesting the need for more adaptive and intelligent energy management frameworks.

Touma et al. (2021) reviewed energy management systems with particular emphasis on control strategies and electricity pricing mechanisms. The study analyzed how energy prices, consumer demand, distributed generation, and storage systems influence microgrid scheduling. The authors reported that appropriate pricing and control strategies can encourage efficient energy consumption and reduce the operating cost of microgrids. Their work also highlighted the importance of intelligent decision-making for future smart-grid-based microgrid applications.

Zahraoui et al. (2021) provided a comprehensive review of energy management systems used in microgrids. Their research examined different EMS architectures, control techniques, optimization algorithms, and operational objectives. The authors emphasized that effective coordination between distributed energy resources, battery storage, local loads, and the utility grid is essential for reliable microgrid operation. The study also identified intelligent and adaptive energy management as an important direction for improving renewable energy integration and system efficiency.

Di Giorgio et al. (2020) investigated the use of computational intelligence techniques for microgrid energy management. Their work considered intelligent approaches such as neural networks, fuzzy logic, and other computational methods for managing energy flow. These techniques were compared with conventional energy management approaches, particularly for real-time scheduling. The study demonstrated that computational intelligence can provide effective solutions for managing complex microgrid conditions and improving renewable energy utilization.

III.EXISTING SYSTEM

The existing energy management systems for grid-connected microgrids mainly rely on conventional control strategies and mathematical optimization techniques to coordinate renewable energy sources, energy storage systems, local loads, and power exchange with the utility grid. These systems generally monitor the amount of power generated by renewable sources, the current load demand, battery state of charge, and grid power availability. Based on these parameters, predefined control rules are used to determine whether energy should be supplied from renewable sources, stored in batteries, or purchased from the main grid.

In many existing systems, optimization techniques such as linear programming, mixed-integer linear programming, dynamic

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programming, and particle swarm optimization are used to schedule energy resources. The primary objectives are usually to minimize electricity costs, reduce peak power demand, improve renewable energy utilization, and maintain the balance between generation and consumption. Although these approaches can provide effective scheduling results, they often depend on accurate mathematical models and predefined system parameters.

Traditional rule-based systems are relatively simple to implement and can respond to basic operating conditions. However, they have limited adaptability when there are sudden changes in renewable energy generation, load demand, electricity prices, or battery conditions. Since the rules are generally predefined, the system may not be able to make optimal decisions under complex or unexpected operating conditions.

Another limitation of existing systems is the difficulty of handling the intermittent nature of renewable energy sources such as solar and wind power. Variations in weather conditions can cause significant changes in power generation, which may lead to increased dependence on the utility grid. Similarly, improper battery scheduling can result in unnecessary charging and discharging, reducing the effective utilization and lifetime of the energy storage system.

Therefore, while existing energy management systems provide a foundation for coordinating microgrid resources, they have limitations in terms of adaptability, real-time decision-making, uncertainty handling, and intelligent resource coordination. These limitations create a need for an intelligent energy management approach that can learn from changing operating conditions and dynamically determine the most suitable energy scheduling strategy for a grid-connected microgrid.

IV.PROPOSED SYSTEM

The proposed system presents an intelligent energy management framework for a grid-connected microgrid that is designed to improve energy efficiency, reduce operating costs, and maximize the utilization of renewable energy. The system integrates renewable energy sources such as solar and wind, an energy storage system, local electrical loads, and the main utility grid. Real-time information about power generation, load demand, battery state of charge, electricity price, and grid conditions is collected and provided to the intelligent energy management unit.

The intelligent controller analyzes the available operating conditions and determines the most appropriate energy flow within the microgrid. When renewable energy generation is sufficient, the system gives priority to supplying the local loads using renewable power. Excess energy can be directed toward battery charging or exported to the utility grid. When renewable generation is insufficient, the stored battery energy can be used to satisfy the load demand. If the battery reaches its operating limits or cannot provide sufficient power, electricity can be imported from the main grid.

The proposed approach continuously adapts the energy scheduling decisions according to variations in renewable generation and load demand. Unlike conventional rule-based systems, the intelligent management mechanism can support improved decision-making under changing operating conditions. Battery charging and discharging are also coordinated to maintain an appropriate state of charge and avoid unnecessary battery operation. This helps improve the effective utilization of the storage system while maintaining the balance between energy generation and consumption.

The major objective of the proposed system is to minimize energy costs, reduce

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unnecessary grid dependency, increase renewable energy utilization, and improve the reliability of the microgrid. The system can also reduce power wastage by efficiently managing surplus renewable energy. By coordinating all major microgrid components through an intelligent controller, the proposed framework provides a flexible and efficient solution for modern grid-connected microgrid applications.

Overall, the proposed system aims to overcome the limitations of conventional energy management approaches by providing adaptive, intelligent, and efficient energy scheduling. The performance of the proposed system can be evaluated using parameters such as operating cost, renewable energy utilization, grid power consumption, battery utilization, energy efficiency, and system reliability.

V.SYSTEM ARCHITECTURE

The system architecture represents an intelligent energy management system for a grid-connected microgrid. The architecture consists of renewable energy sources, battery storage, local loads, the utility grid, real-time data inputs, an intelligent energy management unit, and the final control and optimization outputs. All these components work together to maintain a balance between energy generation and consumption while improving the overall efficiency of the microgrid.

The Solar PV and Wind Turbine act as the primary renewable energy sources in the microgrid. Solar panels generate electrical power from sunlight, while wind turbines produce power based on wind availability. Their power outputs are continuously monitored and supplied to the intelligent energy management system. Since renewable generation varies according to environmental conditions, real-time monitoring helps the controller make suitable decisions regarding the utilization of available renewable energy.

The Battery Storage System is used to store excess electrical energy and provide power when renewable generation is insufficient. The battery's State of Charge (SOC) is continuously monitored by the system. When renewable generation is higher than the local demand, the excess energy can be used to charge the battery. During periods of low renewable generation or increased demand, the stored energy can be discharged to support the local loads. This improves renewable energy utilization and reduces unnecessary dependence on the utility grid.

The Local Loads represent the electrical consumers connected to the microgrid. Their power demand is continuously measured and provided to the energy management system. The controller compares the load requirement with the available renewable generation and battery energy. Based on this comparison, it determines whether the load should be supplied by renewable sources, the battery, or the utility grid.

The Inputs (Real-Time Data) block provides important information required for intelligent decision-making. It includes renewable energy generation, load demand, battery status, electricity price, and grid conditions. These parameters allow the system to understand the current operating state of the microgrid and select an appropriate energy management strategy. Continuous data collection enables the system to respond to changes in generation and consumption.

The central component is the Intelligent Energy Management System (IEMS). It first performs data acquisition and monitoring, where information from renewable sources, batteries, loads, and the grid is collected. The system then performs prediction and analysis to estimate future renewable generation, load demand, and electricity prices. This information helps the controller

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anticipate upcoming energy requirements rather than depending only on the current operating condition.

The Intelligent Decision-Making module uses techniques such as optimization, machine learning, or fuzzy logic to determine the most suitable energy management decision. It evaluates different energy sources and selects an efficient power-flow strategy. The Energy Scheduling and Control module then converts these decisions into an operating schedule for renewable sources, battery charging/discharging, local loads, and grid interaction.

The Utility Grid provides additional power whenever the microgrid cannot satisfy its local demand using renewable generation and stored energy. Conversely, when excess renewable energy is available, the microgrid can export power to the utility grid. Therefore, the architecture supports bidirectional power exchange between the microgrid and the main grid. This flexibility helps maintain energy balance under different operating conditions.

The Control Signals generated by the intelligent energy management system are provided to different operating components. These signals can control inverter operation, battery charging and discharging, load management, and grid power scheduling. Through these control actions, the system dynamically adjusts the power flow according to the selected energy management strategy.

Finally, the architecture aims to achieve four major outputs or goals: minimizing energy cost, maximizing renewable energy utilization, reducing grid dependency, and improving reliability and efficiency. By coordinating renewable generation, battery storage, local loads, and utility-grid power through intelligent decision-making, the proposed architecture provides an adaptive approach for efficient operation of a grid-connected microgrid.

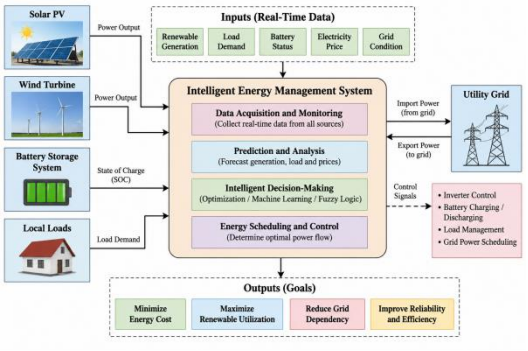


Fig 5.1 System Architecture

VI.IMPLEMENTATION



Fig 6.1 Home Page



Fig 6.2 Real Time Monitoring



Fig 6.3 Energy Management

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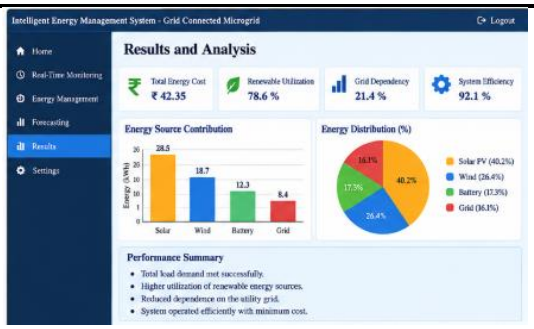


Fig 6.4 Results and Analysis

VII.CONCLUSION

The proposed intelligent energy management system provides an effective approach for managing the energy flow in a grid-connected microgrid. By coordinating renewable energy sources, battery storage, local loads, and the utility grid, the system can maintain a suitable balance between energy generation and consumption. The use of real-time information about renewable generation, load demand, battery status, electricity prices, and grid conditions enables the system to make appropriate energy management decisions under changing operating conditions.

The intelligent decision-making mechanism helps maximize the utilization of renewable energy while reducing unnecessary dependence on the utility grid. Excess renewable energy can be stored in the battery or exported to the grid, whereas stored energy can be utilized when renewable generation is insufficient. This coordinated operation can reduce energy costs, improve battery utilization, and support reliable power supply to local loads.

Overall, the proposed system demonstrates the potential of intelligent techniques for improving the efficiency, reliability, and sustainability of grid-connected microgrids. The framework can be further enhanced by incorporating advanced machine learning and deep learning models for more accurate renewable generation and load forecasting. Future developments can also include real-time electricity pricing, demand response, electric vehicle integration, and advanced battery optimization, making the system more adaptive and suitable for future smart-grid applications.

VIII.FUTURE SCOPE

The proposed intelligent energy management system has significant scope for further development and practical implementation. In the future, advanced machine learning and deep learning algorithms can be integrated to improve the prediction of solar and wind power generation, load demand, and electricity prices. More accurate forecasting can help the system make better energy scheduling decisions and respond effectively to sudden changes in generation and consumption.

The system can also be extended by incorporating electric vehicles (EVs) as controllable energy resources. EV batteries can be charged during periods of low electricity prices or high renewable generation and can potentially supply energy to the microgrid during peak-demand periods. Similarly, advanced battery management techniques can be introduced to improve battery life, charging efficiency, and state-of-charge estimation.

Future work can also focus on real-time demand response and dynamic electricity pricing. The intelligent controller can automatically adjust flexible loads according to electricity prices and grid conditions, helping consumers reduce energy costs and minimizing peak demand. Integration with smart meters and IoT-based monitoring devices can further enable continuous collection of real-time operational data.

Another important direction is the development of hybrid intelligent optimization models, combining machine learning, fuzzy logic, and optimization algorithms to improve decision-making under uncertain conditions. Cloud and edge computing can also be incorporated to support large-scale microgrid monitoring

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and faster real-time control. These improvements can make the proposed framework more scalable, adaptive, reliable, and suitable for future smart-grid and sustainable energy applications.

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