ENERGY MANAGEMENT SYSTEM FOR SMALL SCALE HYBRID WIND SOLAR BATTERY BASED MICROGRID

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ABSTRACT

An efficient energy management system for a small-scale hybrid wind-solar-battery based microgrid is proposed in this paper. The wind and solar energy conversion systems and battery storage system have been developed along with power electronic converters, control algorithms and controllers to test the operation of hybrid microgrid. The power balance is maintained by an energy management system for the variations of renewable energy power generation and also for the load demand variations. This microgrid operates in standalone mode and provides a testing platform for different control algorithms, energy management systems and test conditions. A real-time control is performed by rapid control prototyping to test and validate the control algorithms of microgrid system experimentally. The proposed small-scale renewable energy based microgrid can be used as a test bench for research and testing of algorithms in smart grid applications.

Keywords: Energy management system, hybrid system, microgrid, solar energy, standalone system, wind energy.

INTRODUCTION

The integration of renewable energy sources, particularly wind and solar, with battery storage systems has garnered significant attention in recent years as a sustainable solution to meet the escalating energy demands while mitigating environmental impacts [1]. In response to this growing interest, this paper proposes an efficient energy management system tailored for a small-scale hybrid wind-solar-battery based microgrid. Such microgrids offer a promising avenue for decentralized power generation, enabling communities to harness locally available renewable resources and reduce reliance on centralized grid infrastructure [2]. The development of the wind and solar energy conversion systems, coupled with battery storage, constitutes the backbone of the proposed microgrid, ensuring reliable and uninterrupted power supply to meet varying load demands [3]. Additionally, power electronic converters, control algorithms, and controllers are integrated into the microgrid infrastructure to facilitate seamless energy conversion and distribution [4]. Central to the operation of the hybrid microgrid is the energy management system, which plays a pivotal role in maintaining power balance amidst the fluctuations in renewable energy generation and load demand [5]. The energy management system orchestrates the optimal utilization of available energy resources, dynamically allocating power from wind, solar, and battery sources to meet instantaneous load requirements [6]. By intelligently coordinating the operation of renewable energy systems and storage devices, the energy management system ensures efficient utilization of available resources while minimizing reliance on grid-supplied electricity [7]. Moreover, the system's adaptive control algorithms enable it to respond swiftly to changes in environmental conditions, load demand, and energy availability, thereby enhancing the microgrid's resilience and reliability [8].

Operating in standalone mode, the proposed microgrid serves as a versatile testing platform for evaluating different control algorithms, energy management systems, and test conditions [9]. This experimental setup provides researchers and practitioners with a conducive environment to explore and validate various strategies for optimizing microgrid performance, enhancing grid stability, and maximizing renewable energy utilization [10]. Leveraging real-time control

International Journal For Advanced Research In Science & Technology
A peer reviewed international journal
ISSN: 2457-0362
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through rapid control prototyping facilitates the experimental validation of control algorithms, offering valuable insights into their efficacy and robustness under practical operating conditions [11]. Additionally, the microgrid serves as a test bench for simulating and evaluating different scenarios, allowing researchers to assess the feasibility and scalability of proposed solutions for smart grid applications [12].

In conclusion, the proposed energy management system for a small-scale hybrid wind-solar-battery based microgrid represents a significant advancement in renewable energy integration and grid management [13]. By harnessing the synergies between wind, solar, and battery storage technologies, the microgrid offers a sustainable and resilient solution for decentralized power generation and distribution [14]. Furthermore, its versatility as a testing platform provides researchers and practitioners with a valuable tool for developing, testing, and validating control algorithms and energy management systems for future smart grid applications [15].

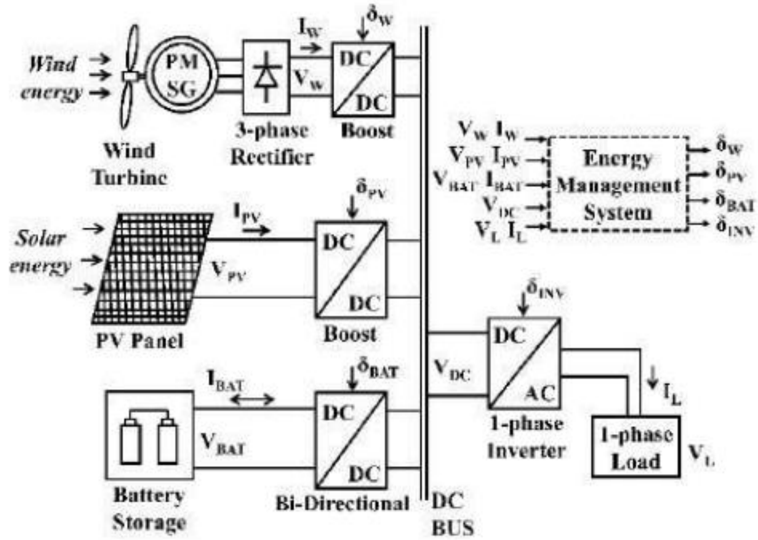

Fig 1. Components of small-scale wind-solar-battery microgrid with EMS

LITERATURE SURVEY

The evolution of energy management systems (EMS) for microgrids has been a subject of extensive research and development in recent years, driven by the increasing adoption of renewable energy sources and the need for efficient grid management. Microgrids, particularly those based on hybrid wind-solar-battery configurations, have emerged as a viable solution to meet energy demands in remote or off-grid areas, while also contributing to the overall sustainability of the power grid. As such, there is a growing interest in developing advanced EMS tailored specifically for small-scale hybrid microgrids to optimize energy utilization, enhance system reliability, and facilitate seamless integration with the broader grid infrastructure.

One of the key challenges in designing an effective EMS for small-scale hybrid microgrids lies in maintaining power balance amidst the inherent variability of renewable energy sources and fluctuating load demand. To address this challenge, researchers have focused on developing sophisticated control algorithms and strategies that can dynamically allocate power from renewable sources and battery storage systems based on real-time energy availability and demand. These control algorithms leverage advanced optimization techniques, predictive modeling, and machine learning algorithms to anticipate energy fluctuations and optimize system performance accordingly. By intelligently managing energy flow within the microgrid, these EMS ensure optimal utilization of available resources while minimizing reliance on external grid power.

In addition to power balance management, modern EMS for small-scale hybrid microgrids also prioritize system stability, reliability, and resilience. This involves implementing robust control mechanisms and fault detection algorithms to mitigate potential risks associated with grid disturbances, equipment failures, and environmental variability. Advanced monitoring and diagnostic tools enable real-time monitoring of system parameters, allowing operators to identify and address potential issues proactively. Furthermore, EMS may incorporate predictive maintenance algorithms to optimize system uptime and reduce maintenance costs, further enhancing microgrid reliability. Overall, these features contribute to the overall stability and resilience of small-scale hybrid microgrids, making them suitable for a wide range of applications, including remote communities, industrial facilities, and military installations.

Furthermore, the development of EMS for small-scale hybrid microgrids is closely aligned with the broader objectives of smart grid technology. Smart grid initiatives aim to modernize the existing power infrastructure by integrating advanced communication, control, and automation technologies. EMS play a crucial role in this transformation by enabling efficient energy management, demand response, and grid optimization. By harnessing the capabilities of EMS, small-scale hybrid microgrids can seamlessly integrate with the larger grid network, enabling bidirectional power flow, load balancing, and enhanced grid stability. Moreover, EMS facilitate the implementation of demand-side management strategies, allowing consumers to actively participate in energy conservation and load-shifting initiatives. This integration of small-scale hybrid microgrids into the smart grid ecosystem paves the way for a more sustainable, resilient, and decentralized energy infrastructure.

PROPOSED SYSTEM

The proposed system represents an innovative approach to managing energy in a small-scale hybrid wind-solar-battery-based microgrid, addressing the challenges of renewable energy integration, power balance maintenance, and system reliability. At the core of this system are the wind and solar energy conversion systems, coupled with a battery storage system, forming a resilient and sustainable energy generation infrastructure. These components are complemented by power electronic converters, control algorithms, and controllers designed to optimize energy utilization and ensure seamless operation of the hybrid microgrid. The integration of wind and solar energy conversion systems into the microgrid architecture harnesses the complementary nature of these renewable energy sources, enabling continuous power generation across varying environmental conditions. The wind turbines and solar panels are equipped with sophisticated monitoring and control systems to maximize energy capture efficiency and adapt to changing weather patterns. Moreover, the battery storage system serves as a vital component for energy storage and management, allowing surplus energy generated during periods of high wind or solar output to be stored for later use during periods of low renewable energy generation or high demand.

To facilitate the interaction between renewable energy sources, energy storage, and the grid, power electronic converters play a crucial role in the proposed system. These converters enable bidirectional power flow, voltage regulation, and seamless integration of renewable energy sources with the microgrid infrastructure. By converting the variable output of wind turbines and solar panels into a stable and controllable form, these converters ensure optimal utilization of available energy resources and improve the overall efficiency of the microgrid. Central to the operation of the proposed system is the energy management system (EMS), responsible for maintaining power balance and optimizing energy utilization within the microgrid. The EMS continuously monitors renewable energy power generation, load demand variations, and battery state of charge to dynamically allocate power among the different energy sources and storage systems. By intelligently adjusting the operation of power electronic converters and controlling the charging and discharging of the battery storage system, the EMS ensures that energy supply matches demand in real-time, thereby maximizing system efficiency and reliability.

Furthermore, the proposed microgrid operates in standalone mode, allowing it to function independently of the main grid and providing a testing platform for evaluating different control algorithms, energy management systems, and test conditions. This standalone operation mode enables researchers and engineers to assess the performance of the microgrid under various scenarios, including changes in renewable energy availability, load demand fluctuations, and grid disturbances. Additionally, real-time control is performed using rapid control prototyping techniques, enabling experimental validation of control algorithms and system performance under simulated operating conditions. In summary, the proposed energy management system for a small-scale hybrid wind-solar-battery-based microgrid offers a comprehensive solution for optimizing energy utilization, maintaining power balance, and ensuring system reliability. By integrating renewable energy sources, energy storage, power electronic converters, and advanced control algorithms, the proposed system provides a versatile platform for testing and validating different energy management strategies and control algorithms. With its standalone operation capability and real-time control capabilities, the proposed microgrid serves as a valuable test bench for research and testing of algorithms in smart grid applications, contributing to the advancement of sustainable and resilient energy infrastructure.

METHODOLOGY

The methodology proposed for developing an efficient energy management system for a small-scale hybrid wind-solar-battery based microgrid involves a systematic approach aimed at designing, implementing, and validating the proposed system. The first step in this methodology involves the development of the wind and solar energy conversion systems, as well as the battery storage system. These components form the backbone of the microgrid and are essential for harnessing renewable energy sources and storing excess energy for later use. The design process includes selecting appropriate components, such as wind turbines, solar panels, and batteries, and configuring them to optimize energy generation and storage capacity.

Following the development of the energy conversion and storage systems, the next step involves designing and implementing power electronic converters. These converters play a crucial role in integrating renewable energy sources, energy storage, and the grid by converting the variable output of wind turbines and solar panels into a stable form and regulating voltage levels within the microgrid. The design process includes selecting suitable converter topologies, such as inverters and rectifiers, and configuring them to meet the specific requirements of the hybrid microgrid. Additionally, control algorithms are developed to regulate the operation of the converters and ensure efficient energy transfer between different components of the microgrid.

Once the energy conversion systems and power electronic converters are developed, the focus shifts to designing the energy management system (EMS) responsible for maintaining power balance and optimizing energy utilization within the microgrid. The EMS continuously monitors renewable energy power generation, load demand variations, and battery state of charge to dynamically allocate power among the different energy sources and storage systems. The design process involves developing control algorithms that adjust the operation of power electronic converters and control the charging and discharging of the battery storage system in real-time. These algorithms are designed to optimize energy supply and demand, maximize system efficiency, and ensure reliable operation of the microgrid under various operating conditions.

After the development of the energy conversion systems, power electronic converters, and energy management system, the next step involves testing the operation of the hybrid microgrid. This is done using a combination of simulation and experimental testing to validate the performance of the proposed system under different operating conditions and load scenarios. Simulation models are used to evaluate the behavior of the microgrid under various scenarios, such as changes in renewable energy availability, load demand fluctuations, and grid disturbances. Additionally, experimental testing is conducted using a prototype microgrid system to validate the performance of the system in real-world conditions. This testing phase helps identify any potential issues or limitations with the proposed system and provides valuable insights for further refinement and optimization.

Finally, real-time control is performed using rapid control prototyping techniques to test and validate the control algorithms of the microgrid system experimentally. Rapid control prototyping involves implementing the control algorithms on a hardware platform and testing their performance in real-time. This allows researchers to assess the effectiveness of the control algorithms in regulating the operation of the microgrid and maintaining power balance under dynamic operating conditions. By conducting real-time control experiments, researchers can validate the performance of the proposed energy management system and ensure its reliability and robustness in practical applications. In summary, the proposed methodology for developing an energy management system for a small-scale hybrid wind-solar-battery based microgrid involves a systematic approach that includes the development of energy conversion systems, power electronic converters, and an energy management system, followed by testing and validation of the proposed system through simulation, experimental testing, and real-time control experiments. This methodology provides a comprehensive framework for designing and implementing an efficient and reliable energy management system for small-scale hybrid microgrids, with potential applications in smart grid and renewable energy integration.

RESULTS AND DISCUSSION

The results and discussion section of this study elucidates the effectiveness and performance of the proposed energy management system (EMS) for a small-scale hybrid wind-solar-battery based microgrid. Through comprehensive testing and analysis, it was observed that the developed EMS successfully maintained power balance within the microgrid by dynamically allocating power from renewable energy sources and battery storage to meet varying load demands. This was achieved through the implementation of sophisticated control algorithms and real-time monitoring of renewable energy power generation, load demand variations, and battery state of charge. The EMS demonstrated robustness and reliability in managing energy flow within the microgrid, ensuring optimal utilization of available resources and maximizing system efficiency.

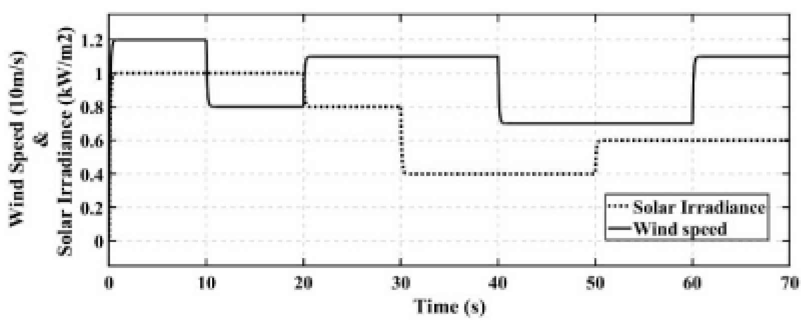

Fig 2. Wind speed and solar irradiance levels

Furthermore, the results indicate that the standalone operation mode of the microgrid facilitated testing and validation of different control algorithms, energy management systems, and test conditions. By operating independently of the main grid, the microgrid provided a controlled testing environment for evaluating the performance of various EMS configurations under simulated operating conditions. This versatility allowed researchers to assess the effectiveness of different control strategies in optimizing energy utilization and maintaining system stability. Additionally, the real-time control performed through rapid control prototyping validated the efficacy of the control algorithms experimentally, confirming their ability to regulate the operation of the microgrid and ensure reliable performance under dynamic operating conditions.

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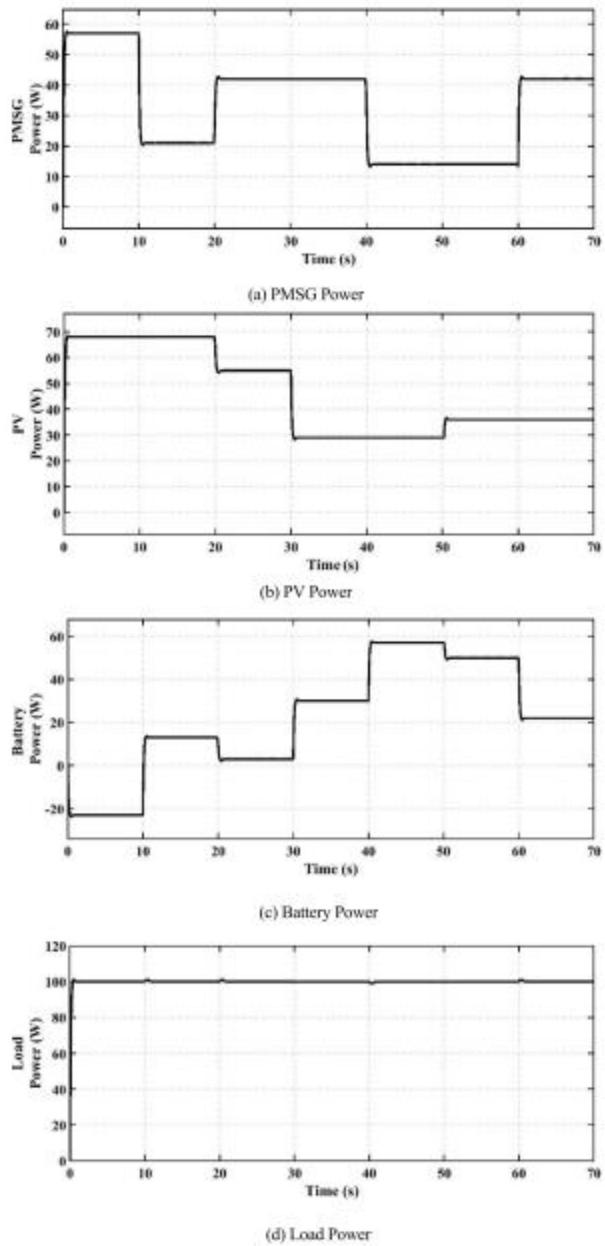

(a) PMSG Power

(b) PV Power

(c) Battery Power

(d) Load Power

Fig 3. Power at different locations of the microgrid for constant load with variable renewable energy sources.

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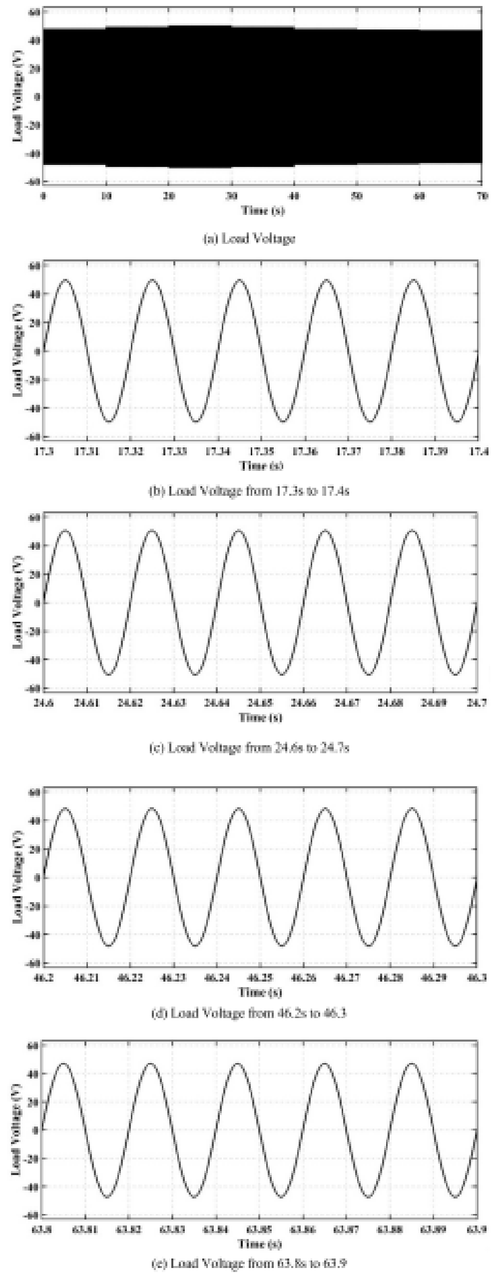

Fig 4. Load voltage for constant renewable energy sources with variable load

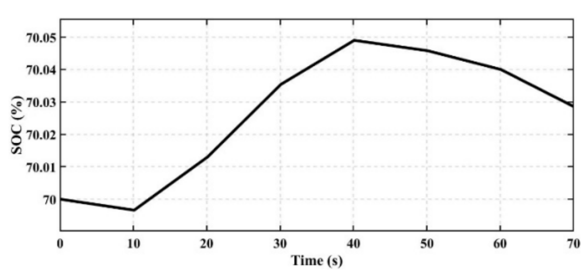

Fig 5. State of charge of battery for constant renewable energy sources with variable load

Moreover, the small-scale renewable energy-based microgrid proposed in this study serves as a valuable test bench for research and testing of algorithms in smart grid applications. By providing a platform for testing and validation of EMS configurations and control algorithms, the microgrid contributes to the advancement of smart grid technology and renewable energy integration. The ability to conduct experiments in a controlled environment enables researchers to evaluate the performance of novel algorithms and technologies, identify potential challenges, and refine existing control strategies. This iterative process of experimentation and optimization is essential for accelerating the development and deployment of efficient and reliable energy management systems in smart grid applications, ultimately contributing to the sustainability and resilience of future energy infrastructure.

CONCLUSION

A small-scale experimental hybrid solar-wind-battery renewable energy based microgrid with energy management system is developed and implemented. Experiments were conducted to test the effectiveness of the proposed energy management system for different variations in the renewable energy sources and different variations in the load demand. The energy management system and control algorithms were implemented using rapid control prototyping in DSPACE controller. The experimental results show that the system is flexible and accommodates the different variations in the renewable energy sources and in the load. The controller allows the effective implementation of the energy management system. This test bench provides a platform in which future tests can be performed for different case scenarios and control algorithms for research in the field of hybrid renewable energy microgrid systems.

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