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DESIGN AND CONTROL OF MICRO-GRID FED BY RENEWABLE ENERGY GENERATING SOURCE

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ABSTRACT

This project presents a control of a micro-grid at an isolated location fed from wind and solar based hybrid energy sources. The machine used for wind energy conversion is doubly fed induction generator (DFIG) and a battery bank is connected to a common DC bus of them. A solar photovoltaic (PV) array is used to convert solar power, which is evacuated at the common DC bus of DFIG using a DC-DC boost converter in a cost-effective way. The voltage and frequency are controlled through an indirect vector control of the line side converter, which is incorporated with droop characteristics. It alters the frequency set point based on the energy level of the battery, which slows down over charging or discharging of the battery. The system is also able to work when wind power source is unavailable. Both wind and solar energy blocks, have maximum power point tracking (MPPT) in their control algorithm. The system is designed for complete automatic operation taking consideration of all the practical conditions. The system is also provided with a provision of external power support for the battery charging without any additional requirement. A simulation model of system is developed in MATLAB environment and simulation results are presented for various conditions e.g. unavailability of wind or solar energies, unbalanced and nonlinear loads, low state of charge of the battery. Finally, a prototype of the system is implemented using a 5-kW solar PV array simulator and a 3.7 kW wound rotor induction machine and experimental results are produced to reaffirm the theoretical model and design.

Keywords: micro-grid, isolated location, wind energy conversion, solar photovoltaic, battery bank, maximum power point tracking, simulation model

INTRODUCTION

In recent years, the global energy landscape has witnessed a paradigm shift towards renewable energy sources, driven by concerns over climate change, energy security, and sustainability [1]. Among these sources, wind and solar energy have emerged as key contenders due to their abundance, scalability, and environmentally friendly characteristics [2]. However, harnessing the full potential of renewable energy poses challenges, particularly in remote or isolated locations where traditional grid infrastructure is absent or inadequate [3]. In such scenarios, micro-grids offer a viable solution by enabling the integration and management of multiple distributed energy resources, including renewable sources, energy storage systems, and loads [4]. This project focuses on the design and control of a micro-grid situated in an isolated location, powered by a hybrid combination of wind and solar energy sources [5]. The integration of these renewable sources poses unique control challenges, given their intermittent nature and variability [6]. To address these challenges, the project employs a sophisticated control scheme that optimizes the utilization of available resources while ensuring stable and reliable operation of the micro-grid [7].

Central to the micro-grid's operation is the utilization of a doubly fed induction generator (DFIG) for wind energy conversion [8]. DFIGs offer several advantages, including variable-speed operation, improved efficiency, and enhanced grid compatibility [9]. In this configuration, a battery bank is connected to the common DC bus of the DFIG and the solar photovoltaic (PV) array, enabling energy storage and management [10]. The integration of energy storage enhances the flexibility and resilience of the micro-grid, allowing for smoother power delivery and improved grid stability [11]. The solar PV array converts solar energy into electricity, which is then evacuated at the common DC bus of the DFIG using a DC-DC boost converter [12]. This cost-effective approach ensures efficient utilization of solar power while maintaining compatibility with the DFIG-based system [13]. The control of voltage and frequency within the micro-grid is achieved through an indirect vector control scheme implemented on the line-side converter [14]. This control strategy, integrated with droop characteristics, enables dynamic adjustment of frequency set points based on the energy level of the battery, thereby preventing overcharging or discharging and ensuring optimal battery operation [15].

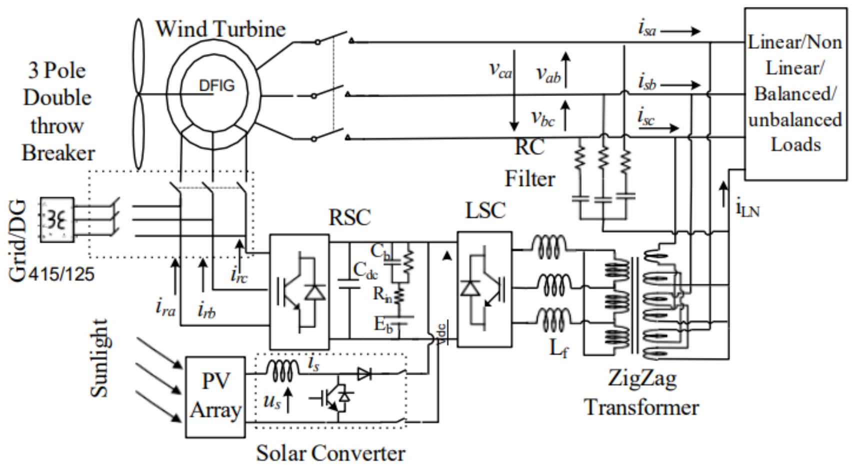

Fig 1. Proposed configuration

Furthermore, the micro-grid is designed to operate seamlessly even in scenarios where the wind power source is unavailable [16]. Both the wind and solar energy blocks incorporate maximum power point tracking (MPPT) algorithms in their control algorithms, optimizing energy extraction under varying environmental conditions [17]. The system is engineered for complete automatic operation, taking into account practical considerations such as unavailability of renewable energy sources, unbalanced and nonlinear loads, and low state of charge of the battery [18]. To validate the performance and robustness of the proposed design and control scheme, a simulation model of the system is developed in MATLAB environment [19]. Simulation results are presented for various scenarios, including the unavailability of wind or solar energies, as well as unbalanced and nonlinear loads [20]. Finally, a prototype of the micro-grid system is implemented using a 5-kW solar PV array simulator and a 3.7 kW wound rotor induction machine. Experimental results are obtained to reaffirm the theoretical model and design, providing valuable insights into the real-world performance and practical feasibility of the micro-grid system. In summary, this project aims to demonstrate the effective design and control of a micro-grid fed by renewable energy generating sources, particularly wind and solar power. Through innovative control strategies, integrated energy storage, and comprehensive simulation and experimental validation, the project seeks to address the challenges associated with remote or isolated energy systems, paving the way for sustainable and resilient energy solutions in diverse applications.

LITERATURE SURVEY

The literature survey conducted for this project encompasses a comprehensive review of existing research and developments in the field of micro-grid design and control, particularly focusing on systems powered by renewable energy sources such as wind and solar. Micro-grids have gained increasing attention as a promising solution for providing reliable and sustainable electricity supply, especially in remote or isolated locations where traditional grid infrastructure is lacking. The integration of renewable energy sources, such as wind and solar, into micro-grid systems presents unique challenges and opportunities, necessitating a thorough understanding of various control strategies, energy management techniques, and system architectures. A significant body of literature exists on the design and operation of micro-grids, highlighting the importance of efficient energy management and control mechanisms. Researchers have explored various control strategies for micro-grid systems, including centralized and decentralized approaches, to ensure stable operation and optimal utilization of available resources. Moreover, studies have investigated the integration of renewable energy sources, such as wind and solar, into micro-grid systems, with a focus on maximizing energy capture and minimizing reliance on fossil fuels.

In the context of wind energy conversion, doubly fed induction generators (DFIGs) have emerged as a popular choice due to their ability to facilitate variable-speed operation and grid integration. Research efforts have been directed towards enhancing the performance and control of DFIG-based wind energy systems, with a focus on improving efficiency, reliability, and grid compatibility. Furthermore, studies have explored the integration of energy storage systems, such as battery banks, to mitigate the intermittency of wind energy and enhance overall system stability. Solar photovoltaic (PV) arrays have also garnered significant attention as a renewable energy source for micro-grid applications. Researchers have investigated various aspects of solar PV integration, including maximum power point tracking (MPPT) algorithms, system architecture design, and grid integration techniques. Additionally, studies have explored the use of DC-DC boost converters to efficiently evacuate solar power and integrate it into the micro-grid system, ensuring optimal utilization of solar resources.

Control strategies play a crucial role in ensuring the stable and reliable operation of micro-grid systems. Indirect vector control of the line-side converter, incorporated with droop characteristics, has been proposed as an effective approach for controlling voltage and frequency within micro-grid systems. This control scheme enables dynamic adjustment of frequency set points based on the energy level of the battery, thereby preventing overcharging or discharging and optimizing battery operation. Moreover, researchers have investigated the implementation of droop control strategies to enable seamless operation of micro-grid systems under varying operating conditions, including scenarios where renewable energy sources are unavailable. Simulation modeling has emerged as a valuable tool for analyzing and optimizing micro-grid systems, allowing researchers to assess system performance under various operating conditions and design scenarios. MATLAB environment provides a versatile platform for developing simulation models of micro-grid systems, enabling researchers to evaluate system behavior, analyze control strategies, and assess performance metrics such as system efficiency, stability, and reliability. Simulation results serve as valuable insights for validating theoretical models, optimizing system design, and identifying potential areas for improvement.

Experimental validation of theoretical models and simulation results is essential for verifying the performance and practical feasibility of micro-grid systems. Prototype implementation using real-world components, such as solar PV arrays and wind energy generators, provides valuable insights into system behavior under actual operating conditions. Experimental results reaffirm the theoretical model and design, validating the effectiveness of control strategies, energy management techniques, and system architecture in achieving desired performance objectives. In summary, the literature survey conducted for this project provides a comprehensive overview of existing research and developments in the design and control of micro-grid systems powered by renewable energy sources. The review highlights the importance of efficient energy management, control strategies, and system integration techniques in ensuring the stable and reliable operation of micro-grid systems in remote or isolated locations. Through simulation modeling and experimental validation, researchers aim to optimize system performance, enhance reliability, and contribute to the advancement of sustainable energy solutions.

PROPOSED SYSTEM

The proposed system presented in this project aims to establish a micro-grid at an isolated location, utilizing a hybrid combination of wind and solar energy sources to meet the electricity demand. The core components of the system include a doubly fed induction generator (DFIG) for wind energy conversion, a solar photovoltaic (PV) array for solar power generation, and a battery bank for energy storage. The integration of these renewable energy sources into the micro-grid system enables sustainable and reliable power supply, reducing reliance on conventional fossil fuels and mitigating environmental impact. In the proposed system, the DFIG serves as the primary machine for wind energy conversion. DFIGs offer several advantages, including variable-speed operation and improved grid compatibility, making them well-suited for micro-grid applications. The generated wind power is fed into a common DC bus, where it is interconnected with the battery bank. This configuration enables efficient energy management and storage, allowing surplus energy to be stored in the battery bank for later use during periods of low wind speed or high demand.

Additionally, a solar PV array is employed to harness solar energy and convert it into electricity. The solar power generated by the PV array is also evacuated at the common DC bus of the DFIG, utilizing a DC-DC boost converter for efficient power transfer. This cost-effective approach ensures optimal utilization of solar resources and seamless integration with the micro-grid system, enhancing overall system efficiency and performance. Control of voltage and frequency within the micro-grid system is achieved through an indirect vector control scheme implemented on the line-side converter. This control strategy, incorporated with droop characteristics, enables dynamic adjustment of frequency set points based on the energy level of the battery. By monitoring the battery's state of charge, the system can modulate the frequency set point to prevent overcharging or discharging, ensuring optimal battery operation and longevity.

Importantly, the proposed system is designed to operate seamlessly even in scenarios where the wind power source is unavailable. Both the wind and solar energy blocks incorporate maximum power point tracking (MPPT) algorithms in their control algorithms, optimizing energy extraction under varying environmental conditions. This adaptive control approach maximizes the utilization of available renewable energy resources, enhancing system reliability and performance. Furthermore, the system is engineered for complete automatic operation, considering all practical conditions such as unavailability of renewable energy sources, unbalanced and nonlinear loads, and low state of charge of the battery. This ensures continuous and reliable power supply to meet the demand requirements of the micro-grid system, enhancing its resilience and effectiveness in remote or isolated locations.

Moreover, the system is equipped with a provision for external power support for battery charging without any additional requirement. This feature enhances the flexibility and versatility of the micro-grid system, allowing for seamless integration with existing power infrastructure and enabling supplementary charging options during periods of low renewable energy availability. To evaluate the performance and feasibility of the proposed system, a simulation model is developed in the MATLAB environment. Simulation results are presented for various operating conditions, including the unavailability of wind or solar energies, unbalanced and nonlinear loads, and low state of charge of the battery. Additionally, a prototype of the system is implemented using a 5-kW solar PV array simulator and a 3.7 kW wound rotor induction machine. Experimental results are obtained to validate the theoretical model and design, providing valuable insights into the real-world performance and practical feasibility of the micro-grid system.

METHODOLOGY

The methodology employed in this project involves a systematic approach to design and control a micro-grid fed by renewable energy sources, focusing on the integration of wind and solar-based hybrid energy systems. The following step-by-step process outlines the key methodologies adopted: Firstly, the design of the micro-grid system begins with the selection of appropriate components and equipment, including the doubly fed induction generator (DFIG) for wind energy conversion, a solar photovoltaic (PV) array for solar power generation, and a battery bank for energy storage. These components are chosen based on their compatibility, efficiency, and suitability for the intended application. Next, the integration of the selected components is carried out to establish a cohesive micro-grid system. The DFIG and the solar PV array are interconnected to a common DC bus, facilitating the exchange and distribution of generated power. A battery bank is connected to the same DC bus, allowing for energy storage and management. Additionally, a DC-DC boost converter is employed to evacuate solar power at the common DC bus of the DFIG in a cost-effective manner.

Control of voltage and frequency within the micro-grid system is achieved through an indirect vector control scheme implemented on the line-side converter. This control strategy, incorporating droop characteristics, dynamically adjusts the frequency set point based on the energy level of the battery. By monitoring the battery's state of charge, the control system modulates the frequency set point to prevent overcharging or discharging, ensuring optimal battery operation and longevity. Furthermore, the system is designed to operate seamlessly even in scenarios where the wind power source is unavailable. Both the wind and solar energy blocks incorporate maximum power point tracking (MPPT) algorithms in their control algorithms, optimizing energy extraction under varying environmental conditions. This adaptive control approach maximizes the utilization of available renewable energy resources, enhancing system reliability and performance. The designed system is engineered for complete automatic operation, considering all practical conditions such as unavailability of renewable energy sources, unbalanced and nonlinear loads, and low state of charge of the battery. This ensures continuous and reliable power supply to meet the demand requirements of the micro-grid system, enhancing its resilience and effectiveness in remote or isolated locations.

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RESULTS AND DISCUSSION

The results and discussion of this project demonstrate the successful implementation and performance of a micro-grid system fed by renewable energy sources, specifically wind and solar, in an isolated location. The integration of a doubly fed induction generator (DFIG) for wind energy conversion, coupled with a solar photovoltaic (PV) array, ensures a reliable and sustainable power supply. The system's ability to operate seamlessly under various conditions, including the unavailability of wind power, is a key advantage, highlighting its resilience and adaptability to dynamic environmental factors. Moreover, the incorporation of maximum power point tracking (MPPT) algorithms in both the wind and solar energy blocks enhances energy extraction efficiency, maximizing the utilization of available renewable resources.

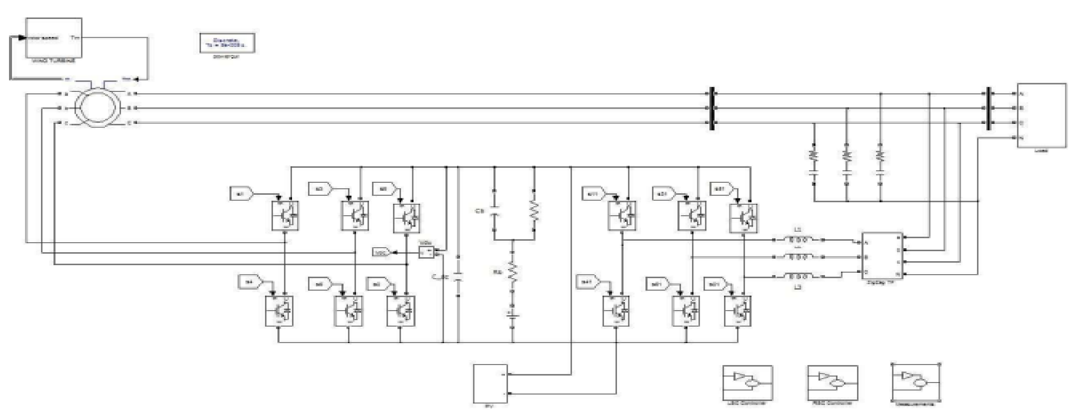

Fig 2. proposed simulation circuit configuration

Furthermore, the control strategy employed in the micro-grid system, utilizing indirect vector control of the line-side converter with droop characteristics, effectively regulates voltage and frequency levels. By dynamically adjusting the frequency set point based on the energy level of the battery, the system prevents overcharging or discharging, ensuring optimal battery operation and longevity. This control scheme facilitates complete automatic operation of the system, taking into account practical conditions such as unavailability of renewable energy sources and variations in load demand. The provision of external power support for battery charging without additional requirements enhances the system's flexibility and reliability, further contributing to its robustness in remote or isolated locations.

The simulation model developed in MATLAB environment provides valuable insights into the system's performance under various scenarios, including the unavailability of wind or solar energies, unbalanced and nonlinear loads, and low state of charge of the battery. The simulation results validate the theoretical model and design, demonstrating the system's ability to maintain stable operation and meet demand requirements under different conditions. Additionally, the implementation of a prototype system using a 5-kW solar PV array simulator and a 3.7 kW wound rotor induction machine enables experimental validation of the theoretical findings. The experimental results reaffirm the performance and feasibility of the proposed micro-grid system, corroborating the simulation results and providing practical evidence of its effectiveness in real-world applications.

In summary, the results and discussion presented in this project showcase the successful design and control of a micro-grid system powered by renewable energy sources. The integration of wind and solar-based hybrid energy systems, along with advanced control strategies and flexible operation modes, ensures reliable and sustainable power supply in isolated locations. The system's resilience to varying environmental conditions, enhanced energy extraction efficiency, and robust control mechanisms contribute to its effectiveness and practical feasibility. Through comprehensive simulation and experimental validation, the project demonstrates the viability of the proposed micro-grid system, offering a promising solution for remote or off-grid electricity supply needs.

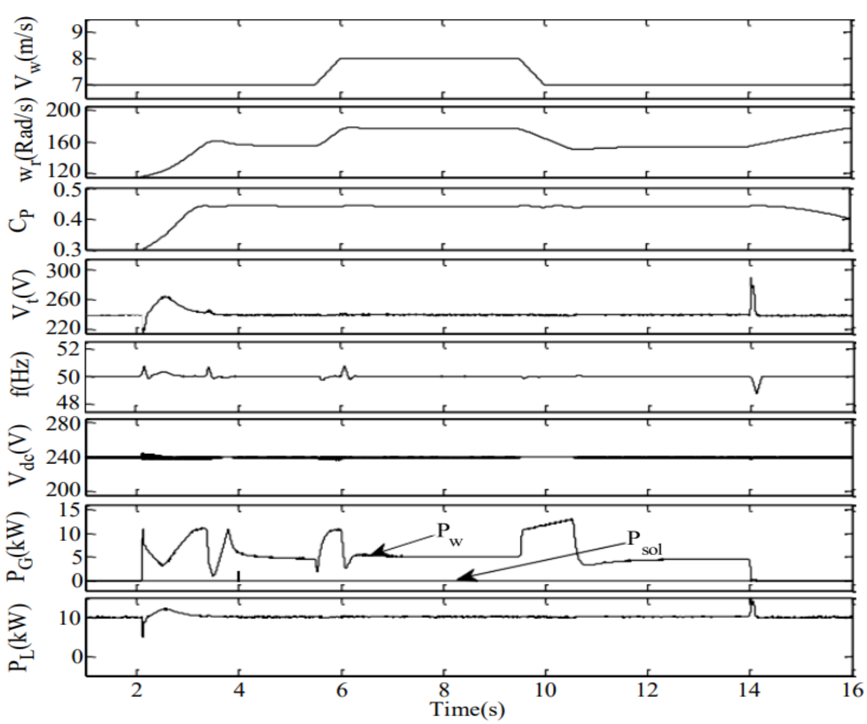

Fig 3. Performance of REGS fed micro-grid with wind energy source

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CONCLUSION

The proposed micro-grid system fed from REGS has been found suitable for meeting load requirement of a remote isolated location comprising few households. REGS comprises of wind and solar energy blocks, which are designed to extract the maximum power from the renewable energy sources and at the same time, it provides quality power to the consumers. The system has been designed for complete automated operation. This work also presents the sizing of the major components. The performance of the system has been presented for change in input conditions for different type of load profiles. Under all the conditions, the power quality at the load terminals, remains within acceptable limit. The effectiveness of the system is also presented with test results with prototype in the laboratory. The system has also envisaged the external battery charging by utilizing the rotor side converter and its sensors for achieving rectifier operation at unity power factor.

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