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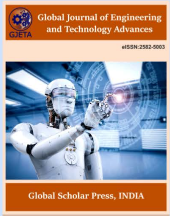

(Research Article)

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Design and simulation of hybrid renewable energy system integration of micro grids using Simulink

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Abstract

This research explores the novel design and simulation of a hybrid renewable energy system integrating photovoltaic (PV) panels, wind turbines, and a diesel generator backup to address the energy demands of an independent hostel in Nottingham, United Kingdom. The system prioritizes minimizing long-term costs and emissions while maintaining energy reliability. A detailed load profile was developed to optimize battery performance, reduce reliance on diesel, and extend battery lifespan, thereby lowering operational costs. Voltage source control and load profile modeling were implemented and evaluated using MATLAB R2023b. Simulation outcomes demonstrated a significant reduction in the diesel generator's runtime, leading to lower emissions. Additionally, the integrated energy management system ensures safe battery operations, enhancing system efficiency, sustainability, and overall performance. This research underscores the potential of optimizing renewable energy integration within microgrids using Simulink.

Keywords: Microgrids; Renewable Energy; Solar; Wind; Optimization; Net Zero; MATLAB; Carbon emissions; Photovoltaic

1. Introduction

To address the growing need for energy systems that are environmentally sustainable and resilient, innovative strategies for power generation and distribution are increasingly crucial. Microgrids, which are self-contained power networks incorporating distributed energy resources (DERs), offer a promising solution by seamlessly integrating renewable energy sources (RES) such as solar and wind into the main power system [1]. This shift towards microgrids signifies a significant evolution in the energy sector, emphasizing decentralization and resilience as key components of modern power [2]. The literature review encompassing several research articles, underscores the necessity of integrating renewable energy sources into microgrids to improve sustainability and mitigate carbon emissions. Research [3]; [4]; [5]. Underscore the necessity of creating control methodologies that facilitate optimal power transfer and ensure system stability. This research project investigates the utilization of Simulink, a powerful simulation tool, to improve the integration of renewable energy sources (RES) in microgrids. The objective of the project is to enhance microgrid performance, elevate power quality, and maximize the consumption of renewable energy through the development and simulation of control systems. Future energy requirements often include renewable electrical power sources as a viable solution [6]; [7]; [8]. The growing dependence on non-renewable resources has negatively impacted the world, resulting in elevated global temperatures, intensified weather phenomena, and the degradation of natural habitats. Recent advancements in capture and storage technologies, along with the worldwide initiative to attain net zero emissions [9]; [10]; [11], have resulted in an increase in renewable and green energy output. These advancements encompass both little attempts, such as domestic solar panels, and major projects, such as offshore wind farms. A microgrid is an autonomous energy system intended to supply electricity to a designated location, such as a university

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campus, hostel, hospital, commercial sector, or residential community. The system consists of many sources of decentralized energy, including solar panels, wind turbines, and generators that produce electricity. Furthermore, contemporary microgrids incorporate energy storage technology, including batteries. Some also provide electric vehicle charging stations [12]. Defines a microgrid by its locality, facilitating energy production for proximate consumers; its degree of autonomy, enabling potential detachment from the central grid for independent operation; and its intelligence level, allowing for the integration of a microgrid controller to assist in managing diverse energy sources [12].

2. Methodology

This section explores the methodologies and innovative strategies utilized in this research, focusing on the development of an energy management system for hybrid microgrids. It introduces a novel approach to modeling, control, and simulation of a hybrid microgrid energy management system designed for autonomous operation. The research progresses through the following key stages:

2.1. Data collection

The solar radiation (W/m^2) and wind speed (m/s) data utilized in this research were obtained from the National Aeronautics and Space Administration (NASA) website. The dataset spans a 48-hour period, specifically covering Monday, January 15, 2024, and Wednesday, January 17, 2024.

2.2. Design Project's Dynamic Load (Kw) Profile

The energy load (kW) data for a hostel was collected through a questionnaire over a 7-day period, from Monday, January 15, 2024, to Sunday, January 21, 2024. The raw energy consumption data was analyzed and converted into mean hourly values using the arithmetic mean method which was subsequently incorporated into the modeled 3-phase load.

2.3. Simulation of Selected Renewable Energy Sources with Corresponding Converters in MATLAB Simulink

The renewable energy sources selected for this study are solar and wind. Prior to modeling, a site visit was conducted at the project case study location, a hostel, to assess the feasibility of the energy sources. Solar radiation and wind speed data were verified as accessible through NASA, ensuring the availability of accurate input data. This information was instrumental in determining the appropriate parameters for developing the simulation models.

2.4. Microgrid Load Allocation Strategy

A coding technique for load-following dispatch in a microgrid was developed, the technique was regulated the hybrid power system to supply power to the load while simultaneously charging the battery. When solar and wind energy is insufficient to meet the load, the load-following dispatch approach will activate the battery and persist in system monitoring. When the battery reaches 20%, it will deactivate, and the diesel generator will activate to assume the load.

2.5. Modeling of Solar Photovoltaic Turbine

The photovoltaic array is a key component in Simulink models for solar PV systems, replicating the photovoltaic effect to convert sunlight into power. These models account for factors like radiation, temperature, and the I-V characteristics of solar cells. An MPPT (Maximum Power Point Tracking) algorithm, implemented using methods such as perturb and observe or incremental conductance, optimizes the PV array's output under varying solar conditions. The generated DC power is converted to AC by an inverter using power electronic components like IGBTs, PWM controllers, and filters, ensuring a smooth AC output. This completes the simulation of a fully operational solar PV system.

2.6. Modeling of Wind Turbine

The wind turbine is developed for an onshore wind farm, currently acknowledged as a more economical substitute for gas in powering plants. This encompasses the expenses related to managing wind variability. The hostel is situated 100 meters above mean sea level. We have selected horizontal-axis wind turbines for this project because of their durability and efficiency. The towers possess a robust foundation, facilitating the installation of the rotor shaft at the apex to capture elevated wind currents.

2.7. Modeling of Battery

The Simulink modeling of a battery commences with the selection of blocks from Simulink's library that depict its electrical and thermal characteristics, encompassing resistors, capacitors, voltage sources, and battery-specific components. The simulation configuration was established by modifying time intervals, solver parameters, and beginning conditions to guarantee precision across various scenarios. Validation ensues, wherein simulations are conducted under diverse charging and discharging settings to verify conformity with experimental data or product standards. The verified battery model is ultimately incorporated into larger system models, facilitating interaction with other components in intricate simulations.

2.8. Modeling of Diesel Generator

The Simulink modeling of diesel generators fulfills various significant applications. Engineers utilize these models to create and evaluate control methods, guaranteeing the generator functions efficiently beneath diverse loads. Engineers integrate these models with renewable energy sources in hybrid power systems to analyze their interactions and enhance system performance. Moreover, Simulink models serve as effective educational instruments, aiding researchers in comprehending the dynamics of diesel generators and the methodologies employed for their control within power systems. Simulink offers a comprehensive platform for the modeling, DG simulation and analysis thereby enhancing the efficiency and reliability of power systems.

2.9. Integration of the Modelled System

Figure 1 demonstrates the connection of the energy systems and the load via the bus bar and port in MATLAB Simulink 2023b.

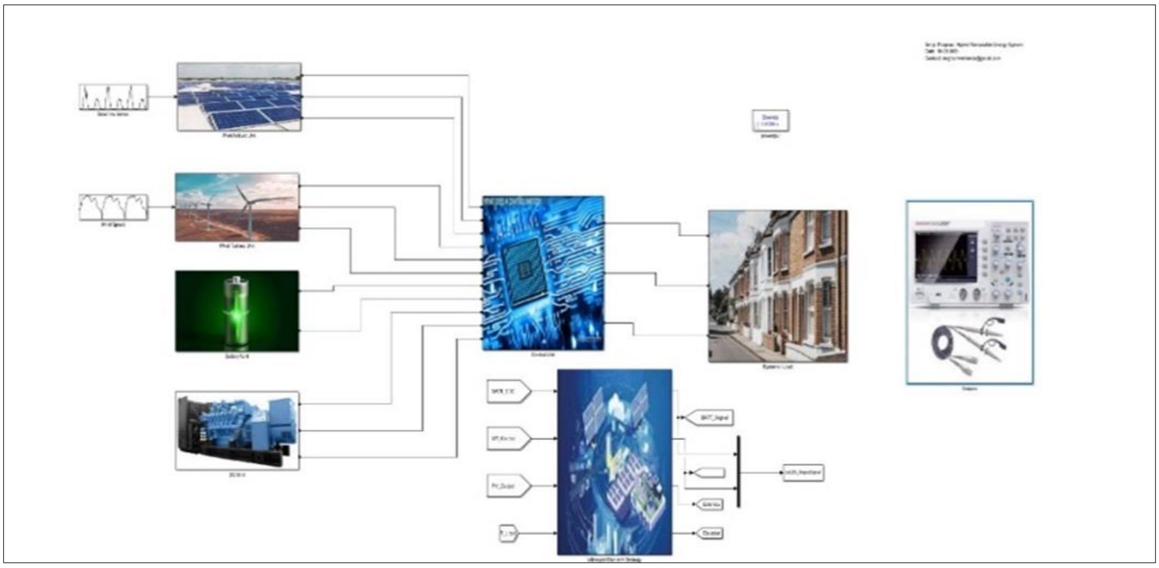

Figure 1 Integration of the modelled system

3. Results

The system's performance was evaluated by measuring response time and power consumption under different loads, with hourly assessments carried out over a 48-hour duration in a specified month. The data was gathered using scopes and shown on a graph. The load profile for 48 hours was provided to model the system's response, along with the associated power profile shared by all energy systems.

3.1. Solar radiation (kW/m2) and Power Output (kW/m2)

The solar radiation data in W/m^2 indicates that solar irradiation commenced at 05:00 and ceased at 18:00 everyday; the minimum recorded irradiance was 0 kW/m^2, while the maximum was 701.77 kW/m^2. The sun radiation measured on day one exceeds that on day two. The solar power output is derived from the Simulink simulation after inputting the data as illustrated in Figures 2 a & b, which depicts the solar irradiance and solar power output curve.

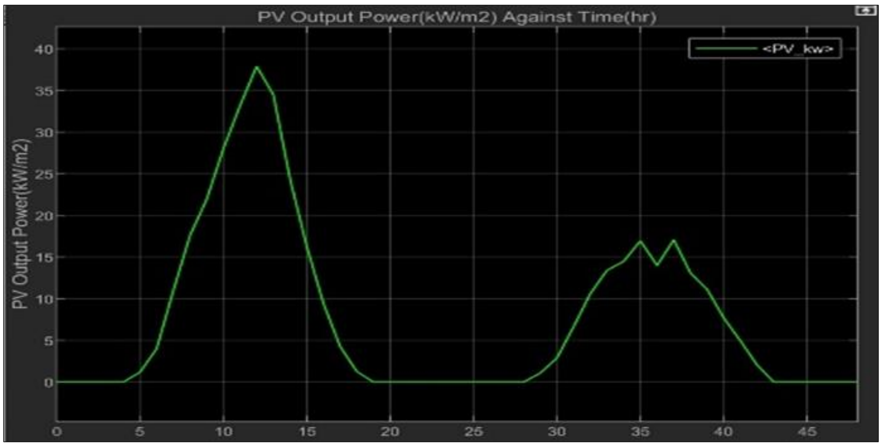

Figure 2 a PV Power Output (kW/m²) Profile

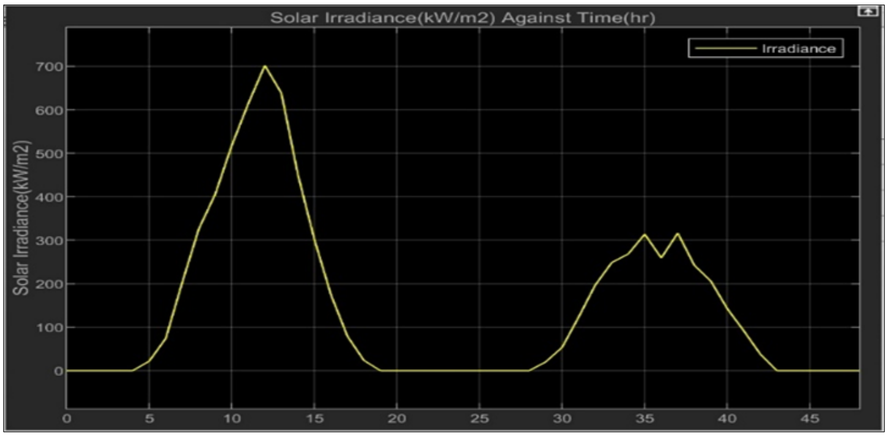

Figure 2 b PV Radiation (kW/m²) Profile

3.2. Wind Speed (m/s) and Power Output (Kw)

The wind speed data, measured in meters per second (m/s), reveals the following insights: wind speed was recorded hourly from 00:00 to 23:00 daily, with a minimum value of 3.98 m/s and a maximum of 13.08 m/s. Additionally, wind speeds on day one was higher compared to those on day two. The wind power output was obtained through Simulink simulations, using the wind speed data. The results are illustrated in Figures 3 a & b, which depicts the relationship between wind speed and wind power output.

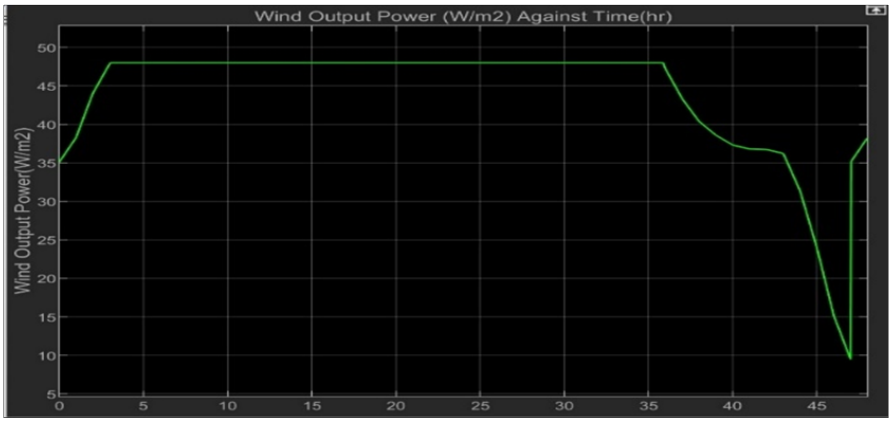

Figure 3 a Wind Power (m/s) Profile

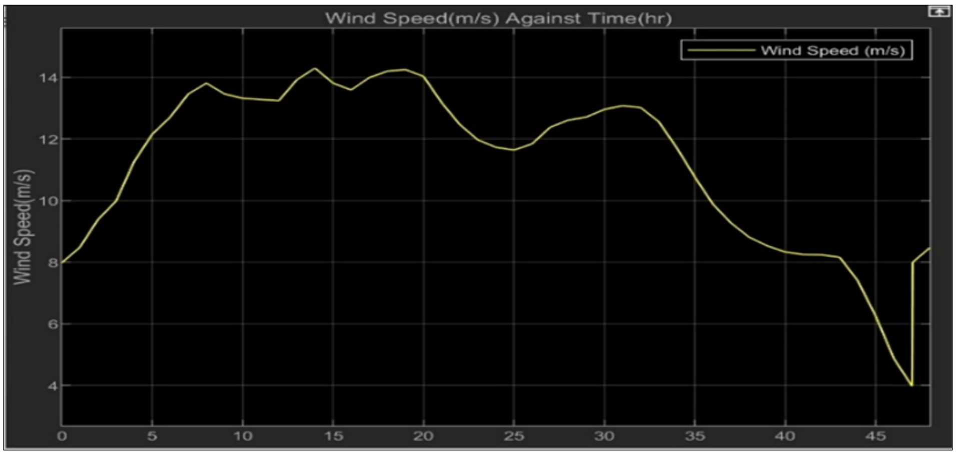

Figure 3 b Wind Speed Output (KW) Profile

3.3. Load Demand (kw) Profile

The load profile for the period of seven days, from Monday, April 15, 2024, to Sunday, April 21, 2024, was employed to simulate the system's performance, as illustrated in the composite plot in Figure 4, from which the following conclusions can be drawn: The load was documented from 00:00 to 23:00 every day; the minimum load recorded was 12.23 kW, while the maximum was 50.75 kW; the energy recorded on day one exceeded that of day two. The load profile is the outcome obtained from Simulink after inputting the data into the simulation. The curve represents the dynamic load profile.

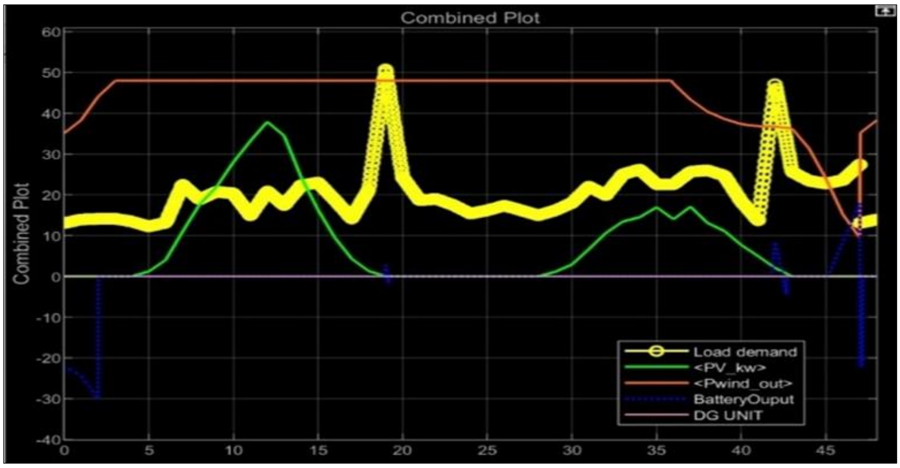

Figure 4 Combine Plot Profile

4. Discussion

Isolating independent microgrids from the primary grid mitigates the inertia challenge in power systems. Hybrid freestanding microgrids, consisting of wind, photovoltaic, and energy storage systems, provide effective solutions for independent electricity generation. Nevertheless, these systems are susceptible to supply interruptions caused by fluctuating weather conditions, a significant obstacle to dependable green energy. Furthermore, the quick release of stored energy diminishes the lifespan of storage systems and increases maintenance expenses. Attaining zero emissions is difficult among rising electricity requirements. Utilizing a suitable backup, such as a diesel generator, and executing efficient energy management can improve reliability and diminish maintenance expenses, ensuring uninterrupted power and prolonging the storage system longevity. This work introduces a model for an independent site that integrates photovoltaic systems, wind energy, a diesel generator, and an energy storage system, considering the provided data. The aim is to decrease emissions and curtail expenses. A hostel in Nottingham was employed as the subject of analysis. Figures 2 a & b depict the correlation between solar radiation (W/m^2) and photovoltaic power output (kW). The photovoltaic system commences energy generation upon reaching an irradiation of 2 W/m^2. Moreover, the output of the photovoltaic system escalates with an increase in solar radiation. Nevertheless, when the irradiance ranges from 0.044 to 0.065, particularly at 16.5 W/m^2 or higher, it is evident that the photovoltaic power rises despite the reduction in irradiance. This indicates a substantial correlation between irradiance and electricity generation. Figures 3 a & b indicate that wind power generation varies from a peak of 48 kW to a trough of 10 kW. Wind energy exhibits superior efficiency relative to solar energy in this region, as it constantly produces output throughout the day. Furthermore, the quantity of wind power generated in kilowatts is directly proportional to the wind speed, the battery power output diminishes as wind energy initially escalates. The battery power output remains stable within a range of 0.2 kW to 1.5 kW throughout the day. MATLAB Simulink offers seamless integration with MATLAB, granting access to extensive libraries and enhancing data analysis and algorithm development. Its user-friendly graphical interface simplifies system modeling, while comprehensive pre-built libraries reduce the need for custom coding. It supports real-time simulation and code generation, essential for embedded system development, and employs a model-based design approach that accelerates development and improves performance. Additionally, it allows for customization and third-party toolbox integration, facilitates efficient debugging with interactive tools, supports automated code generation in multiple languages for optimized deployment, enables multidomain simulation for complex projects, and provides robust community support and documentation for user guidance. The disadvantages encompass its elevated cost, rendering it less accessible for smaller organizations; a significant learning curve for individuals unacquainted with MATLAB; potential performance complications with extensive models; restricted flexibility owing to its profound MATLAB integration; licensing limitations that may impede collaboration; a less intuitive interface for non-engineering applications; diminished debugging and simulation speeds with intricate models; and potential hardware compatibility challenges necessitating supplementary configuration. The advantages and disadvantages suggest that MATLAB Simulink, although a robust tool for particular applications, is contingent upon aspects such as budget, hardware prerequisites, and the project's specific requirements, rendering it especially ideal for this research.

5. Conclusion

A hybrid renewable energy system with a DG backup has been developed for an autonomous hostel in Nottingham, United Kingdom to meet its energy demands while reducing long-term costs and emissions. The system combines photovoltaic (PV) panels and wind turbines to maximize the use of renewable energy. A load profile was implemented to optimize the operation of the battery and diesel generator, focusing on extending battery lifespan and minimizing diesel usage. By employing voltage source control and load profile modeling, the system was successfully simulated and managed using MATLAB R2023b. The results demonstrated a significant reduction in the diesel generator's daily runtime, leading to decreased emissions. Furthermore, the Energy Management System ensures safe battery discharge, enhancing both its longevity and overall cost-efficiency.

Recommendations

Future development of this work could focus on achieving zero emissions by replacing diesel energy entirely with reliable and consistent renewable sources. Increasing energy storage capacity would allow for effective storage of excess energy generated during peak PV and wind periods, enhancing system sustainability. Additionally, future research should assess the financial feasibility of these improvements to ensure both economic and environmental viability

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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