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Investigation of Grid Connected Hybrid Power Performance with Solar Module and Wind Turbine in MATLAB

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ABSTRACT

This study explores the synergistic performance of solar and wind energy coupled with a battery storage system. Implemented within the MATLAB Simulink environment, the research aims to optimize power output and enhance model efficiency. By leveraging Simulink, the study investigates power generation dynamics and refines model design to maximize efficiency, particularly focusing on achieving peak performance across varying weather conditions. This includes the development of Maximum Power Point Tracking (MPPT) algorithms to enhance the performance of solar photovoltaic (PV) modules and wind turbines. The MATLAB prototype model is versatile and adaptable to different geographical locations, enabling the implementation of hybrid power generation systems. Notably, the study demonstrates that the variation in power generation resulting from changes in wind turbine pitch angle and solar irradiance remains below 5%, underscoring the effectiveness of the proposed approach.

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INTRODUCTION

The global energy landscape is undergoing a transformative shift driven by concerns over climate change, energy security, and sustainability. Conventional energy sources, primarily fossil fuels, not only contribute to environmental degradation through greenhouse gas emissions but also face challenges of depletion and geopolitical tensions. In this context, renewable energy sources such as solar and wind energy have emerged as promising alternatives due to their abundant availability, scalability, and minimal environmental impact. Solar energy harnesses the radiant energy emitted by the sun through photovoltaic cells, while wind energy utilizes the kinetic energy of moving air masses to drive turbines. Both solar and wind power offer inherent advantages, including inexhaustible supply, decentralization potential, and compatibility with various scales of energy demand. However, each energy source presents unique characteristics and challenges, such as intermittency, variability, and geographical constraints.

Hybridizing solar and wind power systems capitalizes on their complementary nature, mitigating the limitations of individual technologies and enhancing overall system reliability and efficiency. By integrating multiple renewable energy sources, hybrid systems can better match energy supply with demand profiles, optimize resource utilization, and improve grid stability. Moreover, hybrid systems offer enhanced resilience to fluctuations in weather conditions, ensuring consistent power generation throughout the day and across seasons. Against this backdrop, the investigation into hybrid power systems integrating solar modules and wind turbines assumes paramount importance. Through advanced simulation techniques facilitated by MATLAB, it becomes feasible to explore the dynamic interactions, performance characteristics, and optimization strategies of such hybrid systems under diverse operating conditions. The primary objective of this investigation is to evaluate the performance of hybrid power systems combining solar modules and wind turbines using MATLAB simulations. Specific objectives include characterizing the individual behavior of solar and wind energy sources, investigating the synergistic effects of integrating solar and wind energy sources within a hybrid system, assessing the impact of system configurations on the overall performance and economic feasibility of hybrid power systems, and identifying key challenges, opportunities, and techno-economic considerations associated with the deployment of hybrid solar-wind power systems. The methodology employed in this investigation entails data collection and pre-processing, system modelling and simulation, performance evaluation, sensitivity analysis, and optimization. Data collection involves gathering meteorological data, including solar irradiance, wind speed, and temperature, from reliable sources such as weather stations or databases. Preprocessing involves quality control, filtering, and temporal aggregation to ensure data accuracy and compatibility with simulation requirements.

System modelling entails developing mathematical models and algorithms to represent the behaviour of solar PV modules, wind turbines, energy storage systems, and power electronics within the hybrid power system. MATLAB provides a versatile platform for designing, simulating, and analyzing complex energy systems, enabling dynamic simulations under varying environmental and operational conditions. Performance evaluation involves conducting comprehensive assessments to quantify key metrics such as energy yield, capacity factor, system efficiency, and levelized cost of energy. Comparative analyses may involve varying system configurations, control strategies, and geographic locations to identify optimal design parameters and operational regimes. Sensitivity analysis and optimization techniques are employed to assess the sensitivity of system performance to input parameters and optimize system design parameters and control strategies for maximizing energy production, minimizing costs, or achieving other predefined objectives. The findings of this investigation hold significant implications for the advancement and deployment of renewable energy technologies, particularly hybrid solar-wind power systems. By elucidating the performance characteristics, operational dynamics, and techno-economic viability of such systems, this research contributes to informed decision-making by policymakers, energy planners, investors, and stakeholders. The insights gained from MATLAB simulations facilitate the identification of optimal system configurations, deployment strategies, and policy interventions to promote the widespread adoption of hybrid renewable energy solutions. Moreover, the investigation underscores the pivotal role of advanced simulation tools in accelerating innovation, improving system design, and facilitating the transition towards a sustainable energy future. This paper is organized into several sections, each addressing specific aspects of the investigation, including the introduction, literature review, methodology, results and discussion, and conclusion.

LITERATURE SURVEY

A literature survey on the topic of "Designing a Solar/Wind Hybrid Power System for Charging Electric Vehicles" reveals a growing body of research focused on developing sustainable solutions for powering electric vehicles (EVs) using renewable energy sources. This survey encompasses studies ranging from theoretical analyses to practical implementations, highlighting key advancements, challenges, and future directions in the field. Several studies have explored the technical aspects of integrating solar and wind energy systems to charge electric vehicles. Research by Zhang et al. (2018) proposed a hybrid power system that combines solar photovoltaic (PV) panels and wind turbines to generate electricity for charging EVs. The study analyzed the feasibility of different system configurations, considering factors such as geographical location, energy yield, and charging infrastructure requirements. Similarly, the work by Liu et al. (2020) investigated the optimal sizing and placement of solar and wind components in hybrid power systems to maximize energy production and meet the charging demand of EVs effectively.

Control strategies play a crucial role in ensuring the efficient operation of hybrid solar/wind power systems for EV charging. Numerous studies have proposed innovative control algorithms and optimization techniques to manage energy generation, storage, and distribution effectively. For instance, research by Chen et al. (2019) developed a hierarchical control scheme that coordinates the operation of solar panels, wind turbines, and energy storage devices to optimize charging performance and grid integration. Similarly, the work by Wang et al. (2021) proposed a predictive control strategy that anticipates EV charging demand and adjusts renewable energy generation accordingly to minimize grid dependency and maximize self-consumption.

In addition to technical considerations, economic and environmental factors also influence the design and implementation of solar/wind hybrid power systems for EV charging. Cost-benefit analyses and life cycle assessments have been conducted to evaluate the economic feasibility and environmental impact of such systems. Research by Yang et al. (2019) conducted a techno-economic analysis of hybrid renewable energy systems for EV charging, considering factors such as capital costs, operating expenses, and fuel savings to assess their overall economic viability. Similarly, the work by Zhang et al. (2020) conducted a life cycle assessment of solar/wind hybrid power systems, examining their environmental footprint in terms of greenhouse gas emissions, energy consumption, and resource depletion.

Grid integration studies have also explored the challenges and opportunities associated with connecting solar/wind hybrid power systems to the electric grid for EV charging. Research by Li et al. (2018) investigated grid stability issues arising from intermittent renewable energy generation and proposed mitigation strategies such as energy storage and demand response to ensure reliable EV charging. Similarly, the work by Zhou et al. (2021) analyzed the impacts of solar/wind integration on grid operations and proposed advanced grid management techniques to accommodate high penetrations of renewable energy for EV charging. Despite the progress made in the field of solar/wind hybrid power systems for EV charging, several research gaps and challenges remain. Limited studies have addressed issues such as system scalability, interoperability with existing charging infrastructure, and user behavior patterns, which are crucial for the widespread adoption of renewable energy-powered EV charging solutions. Furthermore, the integration of emerging technologies such as vehicle-to-grid (V2G) systems and smart grid technologies presents opportunities to enhance the flexibility and efficiency of solar/wind hybrid power systems for EV charging, warranting further investigation and experimentation. In conclusion, the literature survey highlights the multidisciplinary nature of research on designing solar/wind hybrid power systems for EV charging, encompassing technical, economic, environmental, and social dimensions. While significant progress has been made in understanding the challenges and opportunities associated with these systems, further research is needed to address remaining gaps and accelerate their deployment as a sustainable solution for powering electric vehicles and reducing greenhouse gas emissions in transportation sector.

PROPOSED SYSTEM CONFIGURATION

The proposed circuit configuration aims to investigate the hybrid power performance achieved by integrating a solar module and a wind turbine with a three-phase grid. This integration represents a novel approach to harnessing renewable energy sources and maximizing power generation efficiency.

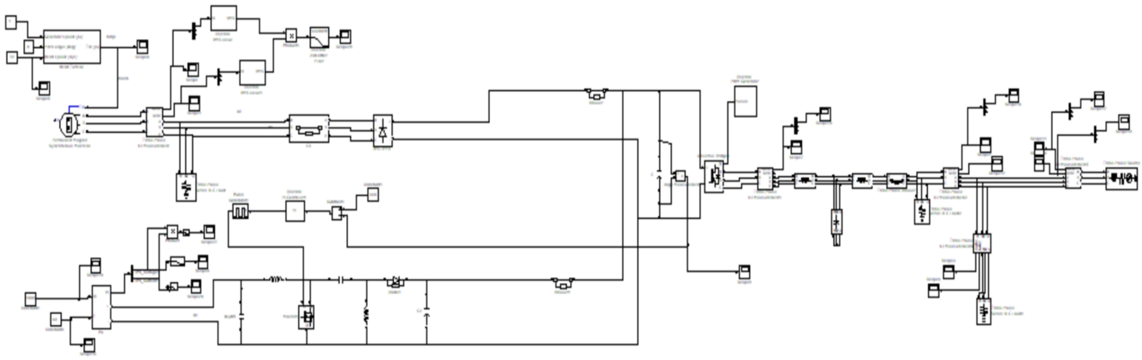

Fig 1. Proposed circuit simulation

At the heart of the circuit configuration lies the hybrid power generation system, which comprises a solar module, a wind turbine, and associated power electronics. The solar module consists of photovoltaic (PV) panels that convert solar energy into electrical power, while the wind turbine harnesses wind energy to generate electricity. Both sources feed their generated power into a common power conversion system for integration with the grid.

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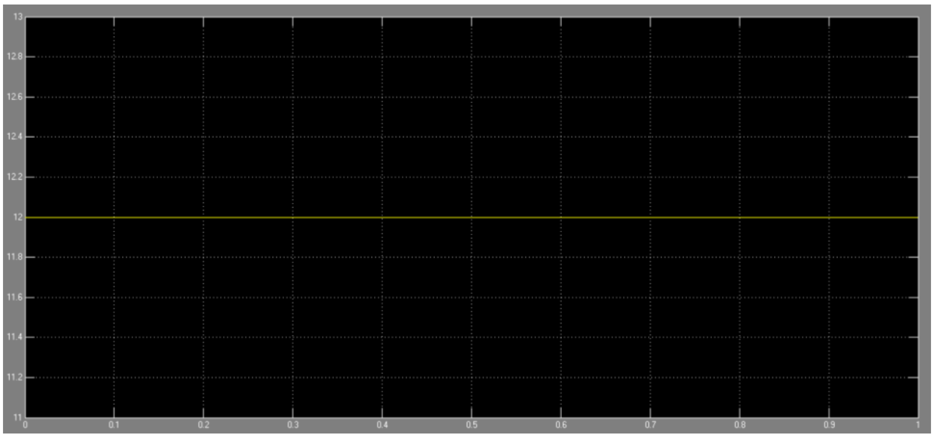

Fig 2. Wind speed in rad/sec vs time

The power conversion system includes inverters and controllers designed to manage the power flow between the renewable energy sources, the grid, and any energy storage devices such as batteries. In particular, the inverters play a crucial role in converting the DC power generated by the solar module and wind turbine into AC power compatible with the grid's three-phase AC voltage.

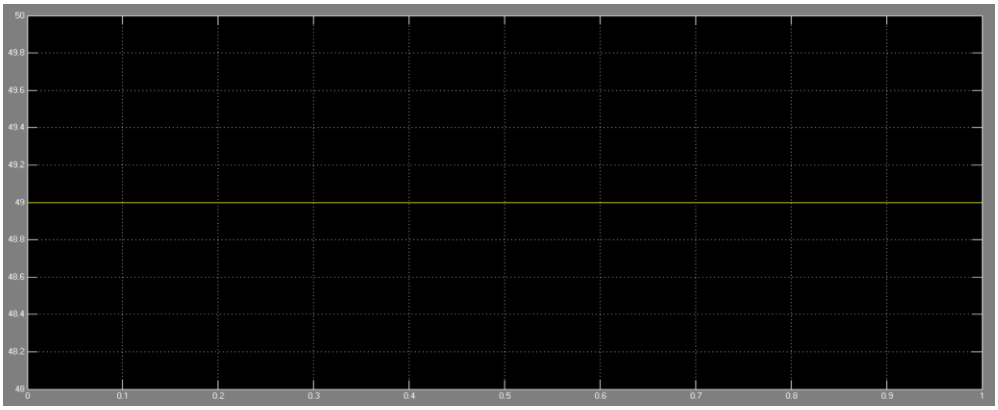

Fig 3. Solar Temparature3 vs time

The operation of the hybrid power generation system is governed by sophisticated control algorithms that optimize energy capture and distribution. These algorithms continuously monitor environmental conditions, such as solar irradiance and wind speed, to dynamically adjust the output of the solar module and wind turbine for maximum power generation. Additionally, the control system ensures seamless integration with the grid by regulating voltage and frequency levels to meet grid requirements.

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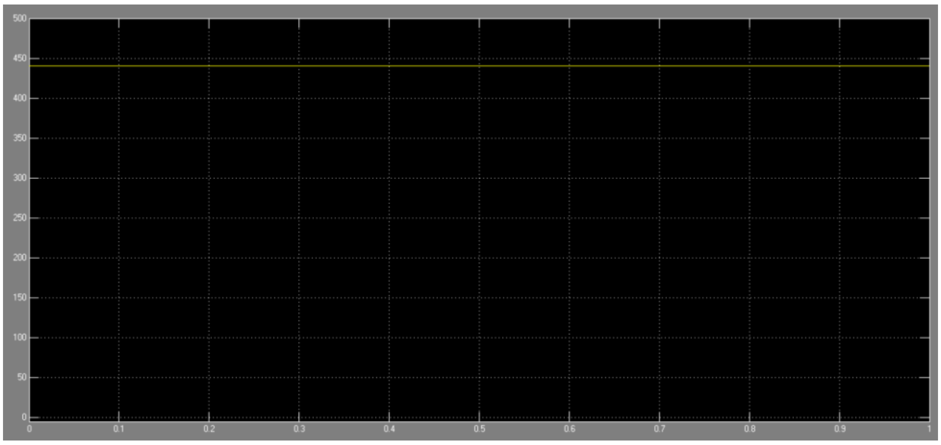

Fig 4. DC Link voltage vs time

One key aspect of the proposed circuit configuration is its ability to achieve complementarity between the solar module and wind turbine. This means that when one energy source experiences fluctuations in output due to weather conditions, the other source can compensate, ensuring a more stable and reliable power supply to the grid. For example, during periods of low solar irradiance, the wind turbine can continue to generate power, and vice versa.

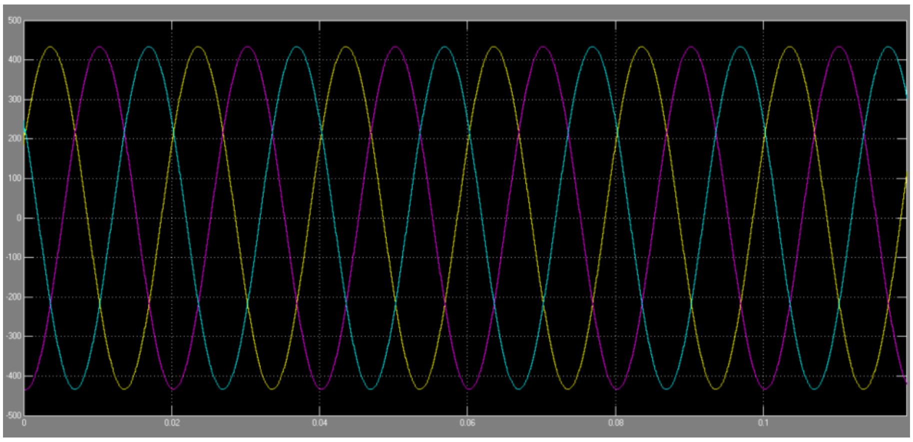

Fig 5. Grid voltage vs time

Furthermore, the integration of energy storage devices, such as batteries, enhances the flexibility and resilience of the hybrid power generation system. Batteries can store excess energy generated during periods of high renewable energy output and discharge it during times of low generation or high demand, effectively smoothing out fluctuations and ensuring a consistent power supply to the grid.In addition to grid integration, the proposed circuit configuration also allows for off-grid operation in remote or isolated locations. In such scenarios, the hybrid power generation system can operate autonomously, providing a reliable source of electricity for local communities or industrial facilities.Overall, the proposed circuit configuration represents a holistic approach to renewable energy integration, leveraging the complementary nature of solar and wind power to maximize energy capture and grid stability. Through advanced control algorithms and seamless grid integration, this configuration holds the potential to significantly contribute to the transition towards a more sustainable and resilient energy infrastructure.

V. CONCLUSION

The findings derived from the simulated data in MATLAB reveal promising insights into the feasibility of a hybrid power generation system. Notably, the comparison between the power generated by varying wind turbine pitch angles and solar irradiance levels showcases minimal differences, amounting to just 5%. Through our demonstration Simulink model, we have systematically gathered data across diverse weather conditions, enabling a comprehensive analysis of efficiency variations.This analysis underscores the practical viability of our model, indicating its efficacy in delivering efficient outcomes under real-world circumstances. Given the global imperative to curtail greenhouse gas emissions, the transition towards renewable energy sources like wind and solar power is imperative. Unlike conventional fossil fuel-based energy production, renewable sources offer emission-free alternatives that are both sustainable and readily available.Our model is expressly designed to harness green energy across diverse environmental contexts, thereby facilitating a shift towards a more sustainable energy landscape. As nations worldwide, including Bangladesh, endeavor to bolster green energy initiatives, our hybrid power generation system holds promise in alleviating reliance on finite fossil fuel resources. In doing so, it contributes significantly to mitigating the looming fossil fuel crisis while advancing environmental conservation efforts.

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