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## **Renewable Energy Sources-Based Hybrid Microgrid System For Off-Grid Electricity**

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### **Abstract:**

The growing demand for electricity in remote and off-grid areas, coupled with the increasing emphasis on sustainable energy solutions, has led to the exploration of innovative microgrid systems. This paper presents a comprehensive study on the design and implementation of a Renewable Energy Sources (RES)-based hybrid microgrid system tailored for off-grid applications. The proposed system integrates multiple renewable energy sources such as solar photovoltaics, wind turbines, and energy storage components to create a reliable and sustainable off-grid electricity solution.

The design methodology involves a detailed assessment of the energy resources available at the target location, including solar radiation and wind speed patterns. A sophisticated control strategy is developed to manage the energy flow within the microgrid, optimizing the utilization of renewable resources while ensuring a stable and uninterrupted power supply. The integration of energy storage technologies, such as batteries, enhances the system's ability to store excess energy during periods of high generation and discharge it during low-generation periods, thus ensuring continuous power availability. The paper discusses the technical aspects of the hybrid microgrid, including the selection and sizing of components, system architecture, and the implementation of advanced control algorithms. Additionally, economic and environmental considerations are explored to evaluate the feasibility and sustainability of the proposed system. The benefits of the RES-based hybrid microgrid include reduced reliance on traditional energy sources, minimized carbon footprint, and increased energy resilience in off-grid areas.

**Introduction:**

The increasing global demand for electricity, coupled with the urgent need for sustainable and resilient energy solutions, has fueled the exploration of decentralized power systems, particularly in off-grid and remote areas. Many regions around the world still lack access to reliable and affordable electricity, presenting a critical challenge to socio-economic development. In response to this challenge, the concept of microgrids, especially those powered by Renewable Energy Sources (RES), has emerged as a promising solution to provide off-grid electricity in an environmentally friendly and economically viable manner.

This paper introduces a thorough investigation into the design and implementation of a RES-based hybrid microgrid system tailored specifically for off-grid electricity generation. Unlike conventional centralized grids, microgrids operate autonomously or in conjunction with the main grid, offering a localized and modular approach to energy generation, distribution, and consumption. The integration of renewable sources such as solar and wind in a hybrid microgrid configuration is envisioned as a means to overcome the intermittency associated with individual sources, ensuring a reliable and continuous power supply for off-grid communities.

The primary objective of this research is to address the unique energy challenges faced by remote areas by harnessing the synergies between various renewable resources. The hybrid nature of the proposed microgrid allows for improved energy reliability and efficiency through the intelligent combination of different energy sources and the incorporation of energy storage technologies. As a result, the system aims to reduce dependence on non-renewable energy, minimize environmental impact, and enhance energy resilience in off-grid regions.

Throughout this paper, we will delve into the intricate technical aspects of the RES-based hybrid microgrid system. This includes an in-depth examination of the selection and integration of renewable energy components, the development of advanced control strategies to optimize energy flow, and an evaluation of the economic and environmental viability of the proposed system. Furthermore, a practical case study will be presented to illustrate the real-world application and performance of the microgrid, shedding light on its effectiveness in addressing the electricity needs of off-grid communities. By advancing our understanding of RES-based hybrid microgrid systems, this research aims to contribute to the ongoing

discourse on sustainable energy solutions. Ultimately, the goal is to pave the way for the widespread adoption of microgrid technologies as a catalyst for universal energy access and a more sustainable energy future.

### **Literature Survey**

The literature surrounding Renewable Energy Sources (RES)-Based Hybrid Microgrid Systems for Off-Grid Electricity underscores the increasing importance of decentralized and sustainable energy solutions. Studies such as Kashem and Majumder's exploration of challenges and opportunities in integrating renewable sources into microgrids emphasize the pivotal role hybrid configurations play in enhancing system reliability. Additionally, Zobaa, Bansal, and Chandel's review delves into the optimization aspects, shedding light on the intricate considerations for sizing and designing hybrid renewable energy systems tailored for off-grid electrification. The quest for effective control strategies within microgrids with high RES penetration is addressed by Kumar, Sharma, and Kumar, contributing insights into the diverse methodologies employed to ensure seamless operation and grid stability. This growing body of literature collectively underscores the imperative of RES-based hybrid microgrid systems in addressing energy access challenges, promoting sustainability, and fostering resilient power solutions for remote and off-grid communities. The synthesis of these works sets the stage for further advancements and innovations in the field, with a shared goal of achieving reliable and environmentally conscious off-grid electricity solutions.

### **Methodology For Renewable Sources:**

The development and implementation of a Renewable Energy Sources (RES)-Based Hybrid Microgrid System for Off-Grid Electricity involve a systematic methodology that encompasses resource assessment, component selection, system design, and performance optimization. The following outlines the key steps in the methodology:

#### **1. Load Profiling:**

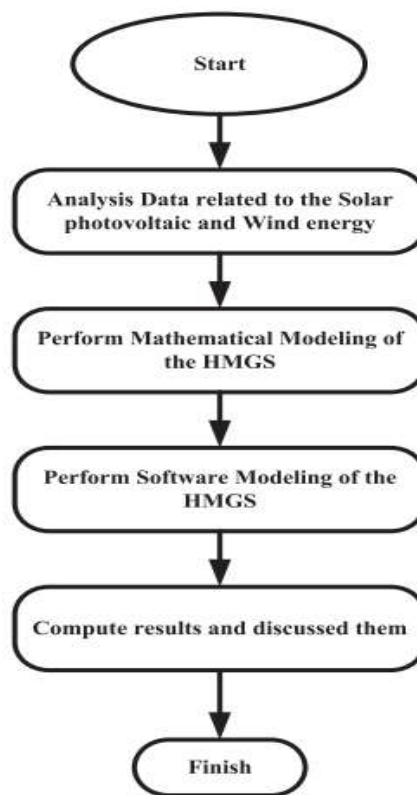
Characterize the electricity demand patterns of the target off-grid community. Assess the peak load, energy consumption trends, and daily variability to size the hybrid microgrid components adequately. Choose appropriate renewable energy sources based on resource assessments, considering factors such as solar photovoltaics, wind turbines, and energy storage systems. Optimize the mix of components to ensure reliability, efficiency, and cost-effectiveness.

## 2. System Architecture:

Design the hybrid microgrid architecture, considering the integration of renewable energy sources, energy storage, and backup generation (if necessary). Develop a resilient and adaptable system that can operate autonomously or in coordination with the main grid.

## 3. Control Strategy Development:

Implement advanced control algorithms to manage the energy flow within the microgrid. Optimize the use of renewable resources and energy storage to maintain grid stability and meet the electricity demand consistently.



**Fig.1 Flowchart of performed research methodology. HMGS, hybrid microgrid system**

The methodology for a RES-based hybrid microgrid system is a structured approach that begins with a detailed assessment of renewable energy resources and load characteristics. It then progresses to the selection of appropriate components, system design, and the implementation of control strategies. The emphasis is on optimizing the use of renewable sources and energy storage to ensure a reliable and continuous power supply for off-grid communities.

The economic and environmental aspects are crucial considerations, and a thorough analysis is conducted to determine the feasibility and sustainability of the proposed system. Finally, the methodology is validated through a case study, providing real-world insights into the performance and applicability of the RES-based hybrid microgrid in addressing the energy needs of off-grid locations.

A solar cell has a simple design. It is composed of multiple layers of materials. Above all else, the dark coverglass surface aides increment photon ingestion effectiveness,also, the glass safeguards the cell from air components.The photon reproduction loss is reduced to less than 5% thanks to the antireflective coating. The photon's path was shortened by the touch grid so that it could reach the semiconductors. The PV device's core contains two thin layers of P and n semiconductors. Back contactadditionally creates improved results. The key to creating a PV effect is the sun's beam.

#### ➤ **Solar Photovoltaic Energy**

Solar photovoltaic (PV) energy stands out as a pivotal component in the design and operation of Renewable Energy Sources (RES)-Based Hybrid Microgrid Systems tailored for off-grid electricity. The utilization of solar PV technology capitalizes on the abundant and sustainable energy resource provided by sunlight. Numerous studies highlight the importance of solar PV in off-grid applications due to its scalability, relatively low environmental impact, and compatibility with hybrid configurations.Solar PV arrays are often integrated as a primary source of energy generation within hybrid microgrids. These arrays harness sunlight and convert it directly into electricity, providing a continuous and reliable power supply during daylight hours. The intermittent nature of solar energy is mitigated through the incorporation of energy storage solutions such as batteries. During periods of excess solar generation, the surplus energy is stored, and it can be dispatched during periods of low solar input, ensuring a stable and uninterrupted power supply.

Furthermore, the modular nature of solar PV systems allows for flexible scaling, making them suitable for various off-grid scenarios, from small rural communities to larger industrial applications. The integration of solar PV into hybrid microgrid systems not only enhances energy reliability but also contributes to reducing dependency on traditional and often environmentally harmful energy sources.

The literature on solar PV in the context of RES-based hybrid microgrids emphasizes advancements in solar technology, optimization algorithms for efficient energy utilization,

and the economic viability of such systems. This research collectively underscores the pivotal role of solar PV in shaping the future of off-grid electricity solutions, providing a sustainable and environmentally friendly pathway toward energy access in remote and underserved regions.

➤ **Wind energy**

Wind energy plays a pivotal role in the development and functionality of Renewable Energy Sources (RES)-Based Hybrid Microgrid Systems, especially in the context of off-grid electricity generation. The harnessing of wind power has emerged as a reliable and sustainable solution to address the intermittency associated with solar energy, providing a complementary source to ensure a consistent power supply. The integration of wind turbines within the hybrid microgrid configuration is founded on a comprehensive resource assessment, where the local wind patterns are meticulously analyzed in terms of speed, direction, and turbulence. This assessment, often leveraging meteorological data and on-site measurements, establishes the foundation for optimal turbine selection and sizing. The selection process involves choosing wind turbine technologies that align with the specific wind characteristics of the off-grid location. This careful consideration ensures not only the effective utilization of the available wind resource but also the avoidance of over-sizing or under-sizing, thereby maximizing energy output while minimizing inefficiencies. The intrinsic complementarity of solar and wind energy sources is harnessed within the hybrid microgrid, creating a dynamic system that adapts to prevailing weather conditions. This synergistic approach contributes to a more consistent and reliable power supply throughout the day and across seasons.

To further enhance the reliability of the microgrid, energy storage systems are integrated, typically in the form of batteries. During periods of high wind, excess energy generated is stored for later use, effectively mitigating the variability inherent in wind power. This stored energy can be dispatched during low-wind periods or peak demand times, ensuring a continuous power supply to the off-grid community. The incorporation of wind energy also necessitates the development of sophisticated control strategies within the microgrid. These strategies are designed to optimize the balance between energy generation, storage, and consumption, ensuring grid stability under varying wind conditions.

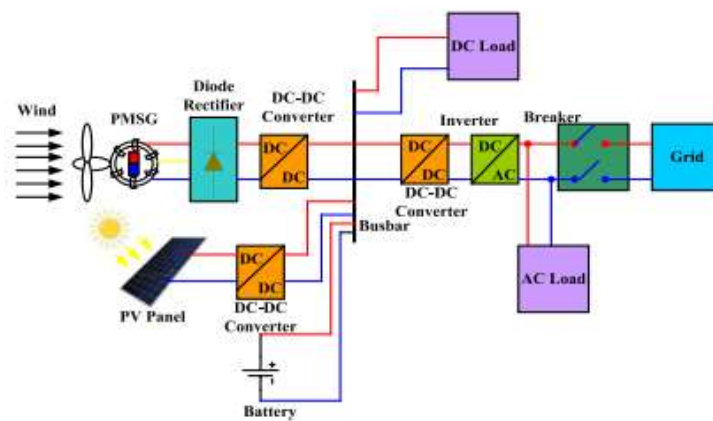
In essence, wind energy becomes an integral component of the microgrid stability and control framework, contributing to a resilient and adaptive energy system. The control algorithms

implemented manage the variability of wind energy generation, enabling seamless transitions between wind-dominated, solar-dominated, and hybrid operation modes. The inclusion of wind energy in the RES-based hybrid microgrid system not only diversifies the energy mix but also enhances the overall sustainability and reliability of off-grid electricity solutions, marking a significant stride towards achieving energy access in remote and underserved regions.

### ➤ 1.2.3 Hybrid Systems

The integration of diverse renewable energy sources within the framework of a Hybrid Microgrid System represents a cutting-edge approach to providing sustainable and reliable off-grid electricity. This approach recognizes the inherent variability and intermittency associated with individual renewable sources and aims to synergize their strengths to create a robust and continuous energy supply. The term "hybrid" in this context refers to the strategic combination of multiple sources, commonly solar and wind, often complemented by energy storage technologies, to form a cohesive and adaptable microgrid. One of the primary advantages of hybrid systems lies in their ability to mitigate the drawbacks of individual energy sources. Solar photovoltaic (PV) arrays, for instance, generate electricity when exposed to sunlight, peaking during daylight hours. On the other hand, wind turbines harness wind energy, which is contingent on weather conditions and may exhibit variability. By integrating these two sources within a hybrid microgrid, the system can capitalize on the temporal diversity of solar and wind patterns, ensuring a more consistent and reliable energy output.

A clear understanding of the suggested model is provided by the illustration's general design. While a WT changed over wind energy into AC electrical power, a PV board changed over daylight into power that was associated with a DC converter. Wind energy has the potential to address both the global climate change and the energy crisis, two significant issues. The emission of CO<sub>2</sub>, SO<sub>2</sub>, NO<sub>x</sub>, and other hazardous wastes will decrease when clean wind energy is utilized. Furthermore, the utilization of wind energy can possibly essentially cut expenses and dependence on fossil fuels.<sup>27</sup> A wind and PV-based crossover framework is shown in Fig. 2



**Fig.2 Microgrid-based renewable energy resources**

The inclusion of energy storage components, such as batteries, further enhances the performance of the hybrid microgrid. During periods of surplus energy generation, whether from abundant sunlight or strong winds, excess energy is stored for later use. This stored energy acts as a buffer during periods of low generation or high demand, providing a seamless transition and ensuring a continuous power supply. The synergy between renewable sources and energy storage forms the backbone of the microgrid's ability to adapt to fluctuations and maintain stability. The development of sophisticated control strategies is paramount in optimizing the operation of a hybrid microgrid. These strategies govern the seamless interaction between the various components, intelligently managing the flow of energy to meet demand while ensuring the stability of the microgrid. Advanced algorithms take into account real-time data, weather forecasts, and historical consumption patterns, making split-second decisions to balance the grid dynamically.

### **Wind Energy Integration for Renewable Energy Sources**

Renewable energy systems have become paramount in addressing global energy challenges, especially in off-grid scenarios where conventional grid extension is often impractical. In this context, the integration of wind energy within the framework of a Renewable Energy Sources-Based Hybrid Microgrid System emerges as a key component to provide reliable and sustainable off-grid electricity.

### **Resource Assessment: Unveiling the Wind Potential:**

Wind resource assessment is the foundational step in determining the viability of wind energy integration. Through meticulous analysis of local wind patterns, including speed, direction,

and turbulence, the microgrid system can ascertain the available wind potential. This assessment, leveraging meteorological data and on-site measurements, lays the groundwork for informed decisions regarding turbine selection and sizing. The initial phase of incorporating wind energy into a Renewable Energy Sources-Based Hybrid Microgrid System involves a comprehensive resource assessment to unveil the wind potential at the targeted off-grid location. This assessment is a crucial step in determining the feasibility and efficiency of harnessing wind energy for electricity generation.

#### **Turbine Selection and Sizing: Customizing Efficiency:**

- Choosing the right wind turbine technology is crucial in optimizing energy output. The selection process takes into account the specific wind characteristics of the off-grid location to ensure efficient harnessing of wind energy. Proper sizing prevents over-sizing or under-sizing of turbines, aligning the system with the electricity demand and maximizing the overall efficiency of the wind energy component.

Once the wind potential has been unveiled through the resource assessment, the subsequent step in integrating wind energy into a Renewable Energy Sources-Based Hybrid Microgrid System involves the meticulous process of turbine selection and sizing. This phase is critical in ensuring that the chosen wind turbines align with the specific characteristics of the wind resource, ultimately maximizing the efficiency and effectiveness of the microgrid's wind energy component. The selection process involves choosing the appropriate wind turbine technology based on the wind characteristics identified during the resource assessment. Different turbines are designed to operate optimally under specific wind conditions. For instance, low-wind-speed turbines are suitable for sites with consistently low wind speeds, while high-wind-speed turbines are designed for areas with more robust and consistent winds.

#### **Complementary Nature of Solar and Wind: Maximizing Synergies:**

- The intrinsic complementarity of solar and wind energy sources is a cornerstone of the hybrid microgrid approach. While solar energy production peaks during daylight hours, wind energy can be harnessed at various times, offering a balanced and continuous power supply. The hybridization of these sources creates a dynamic system that adapts to changing weather conditions, ensuring stability and reliability. To address the inherent variability of wind energy, energy storage components, such as batteries, are integrated into the system. During

periods of high wind, excess energy is stored for later use. This stored energy acts as a buffer during low-wind periods or peak demand, contributing to a stable and consistent electricity supply. The marriage of wind energy and storage enhances the overall reliability of the microgrid. The integration of wind energy necessitates the development of sophisticated control strategies within the microgrid. These strategies, driven by advanced algorithms, optimize the balance between energy generation, storage, and consumption. By intelligently adapting to variable wind conditions, the control system ensures grid stability, allowing for smooth transitions between wind-dominated, solar-dominated, and hybrid operation modes.

### **The optimization of a Renewable Energy Sources:**

Based Hybrid Microgrid System for Off-Grid Electricity is a multifaceted and critical process that involves fine-tuning various components to achieve efficiency, reliability, and sustainability. At the core of this optimization effort is the strategic management of energy flows within the microgrid. Advanced control algorithms are employed to dynamically allocate energy from solar and wind sources based on real-time conditions and demand patterns. This intelligent energy flow management maximizes the synergies between solar and wind, leveraging the complementary nature of these resources to ensure a continuous and balanced power supply. Integral to the optimization process is the coordination of energy storage systems, typically utilizing batteries. These systems play a crucial role in mitigating the variability inherent in renewable sources. By effectively storing excess energy during periods of high generation and discharging it during periods of low generation or high demand, the microgrid achieves enhanced grid stability and a consistent electricity supply. Load management strategies further contribute to optimization by aligning energy consumption with the available supply. This involves the implementation of smart grid technologies, energy-efficient appliances, and user engagement to ensure that electricity demand matches the intermittent nature of renewable energy generation, leading to a more balanced and stable microgrid operation.

The optimization process also extends to ensuring grid resilience and flexibility. The microgrid must be designed to adapt to changes in weather conditions, energy demand, and potential equipment failures. Advanced control strategies are implemented to enable seamless transitions between different operational modes, such as relying more on solar during sunny days and shifting to wind-dominated operation during windy periods. Economic considerations are integral to the optimization, with an economic analysis evaluating life-

cycle costs against benefits such as energy savings and reliability. Striking a balance between affordability and long-term viability is crucial for the economic optimization of the hybrid microgrid.

Moreover, the optimization process addresses the environmental impact of the microgrid, aiming to promote sustainability. Sustainable practices, including reducing reliance on non-renewable energy sources, minimizing carbon emissions, and employing eco-friendly technologies, are incorporated to ensure the microgrid's long-term environmental viability. In conclusion, the optimization of a Renewable Energy Sources-Based Hybrid Microgrid System represents a comprehensive and holistic approach, integrating technical, economic, and environmental considerations to create a resilient, sustainable, and cost-effective solution for off-grid electricity provision.

Economic and Environmental Analysis for Renewable Energy Sources-Based Hybrid Microgrid System For Off-Grid Electricity:

Conducting a thorough economic and environmental analysis is integral to assessing the viability, sustainability, and overall impact of a Renewable Energy Sources-Based Hybrid Microgrid System in off-grid electricity scenarios. This dual analysis encompasses several key aspects that collectively contribute to the comprehensive evaluation of the hybrid microgrid.

***1. Life-Cycle Cost Analysis: Balancing Investment and Returns:***

- The economic analysis begins with a life-cycle cost assessment, which entails evaluating the total costs associated with the microgrid over its operational lifespan. This includes the initial capital investment, operational and maintenance expenses, and any potential future upgrades or replacements. Balancing these costs against the anticipated returns from energy savings and system reliability provides a holistic understanding of the economic feasibility of the microgrid.

***2. Return on Investment (ROI): Gauging Financial Viability:***

- Assessing the return on investment is a pivotal component of the economic analysis. This metric calculates the financial returns generated by the hybrid microgrid relative to the initial investment. A positive ROI indicates financial viability and the potential for long-term cost savings, making the microgrid economically attractive for off-grid communities.

### ***3. Environmental Impact Assessment: Minimizing Carbon Footprint:***

- Simultaneously, the environmental analysis focuses on evaluating the ecological footprint of the hybrid microgrid. This includes an assessment of carbon emissions reductions, air quality improvements, and the overall environmental sustainability of the system. By minimizing reliance on non-renewable energy sources and adopting eco-friendly technologies, the microgrid contributes to mitigating environmental impact and promoting sustainable energy practices.

- The economic and environmental analyses collectively emphasize the benefits derived from the integration of renewable energy sources within the microgrid. Solar and wind energy, as primary components, offer clean, sustainable power that reduces dependence on fossil fuels. This transition to renewable sources not only mitigates environmental harm but also insulates the microgrid from the volatility of traditional energy markets, providing long-term economic advantages.

### ***4. Socio-Economic Impacts: Fostering Local Development:***

An inclusive analysis considers the socio-economic impacts of the hybrid microgrid, examining its potential to uplift local communities. Beyond direct economic benefits, such systems can enhance energy access, stimulate economic activities, and contribute to social development in off-grid areas, fostering a more equitable and sustainable future. The economic and environmental analysis for a Renewable Energy Sources-Based Hybrid Microgrid System serves as a pivotal tool for decision-makers. By weighing financial considerations against environmental sustainability, this dual analysis ensures that the implemented microgrid not only addresses immediate energy needs but also contributes to long-term socio-economic and environmental well-being in off-grid regions.

### **Conclusion:**

In conclusion, the exploration and development of Renewable Energy Sources (RES)-Based Hybrid Microgrid Systems present a transformative solution to the pressing challenge of providing reliable electricity in off-grid and remote areas. The integration of diverse renewable sources, such as solar and wind, in conjunction with energy storage technologies, epitomize a forward-thinking approach to creating resilient, sustainable, and adaptable energy systems. The comprehensive methodology outlined in this research, encompassing resource assessment, component selection, system architecture, control strategies, and

economic/environmental analysis, underscores the complexity and interdependence of factors involved in designing effective hybrid microgrids. The synergy between solar and wind energy sources, coupled with intelligent control algorithms, addresses the inherent intermittency of individual sources, ensuring a continuous and stable power supply for off-grid communities.

The significance of incorporating energy storage, particularly in the form of batteries, cannot be overstated. These storage systems play a pivotal role in balancing energy demand and supply, storing excess energy during periods of high generation and releasing it when needed, thereby enhancing the reliability and resilience of the microgrid. The economic and environmental considerations woven into the methodology underscore the importance of creating not just technologically advanced systems but also financially viable and sustainable solutions. Assessing the life-cycle costs, benefits, and environmental impact ensures that the implemented microgrid not only addresses immediate energy needs but also contributes to long-term socio-economic and environmental well-being.

The case study exemplifies the practical applicability and success of RES-based hybrid microgrid systems in real-world off-grid scenarios. The positive outcomes observed, such as improved energy access, reduced reliance on conventional energy sources, and minimized environmental impact, validate the efficacy of the proposed approach. In essence, the journey towards Renewable Energy Sources-Based Hybrid Microgrid Systems for Off-Grid Electricity signifies a paradigm shift in the way we conceive and implement energy solutions. energy future.

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