# Energy Management of Small Scale Microgrid

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***Abstract- This paper presents the development of an efficient energy management system (EMS) tailored for a small-scale hybrid microgrid integrating wind and solar energy sources with battery storage. The proposed system encompasses the design and implementation of wind and solar energy conversion systems, complemented by battery storage, power electronic converters, and control algorithms. The EMS is engineered to maintain power balance amidst the variability inherent in renewable energy generation and fluctuating load demands. Operating in a standalone mode, the microgrid serves as a versatile testing platform for various control algorithms and energy management strategies under diverse conditions. To validate the effectiveness of the control algorithms, real-time control is executed through rapid control prototyping, facilitating experimental testing and validation. This small-scale renewable energy-based microgrid offers a valuable test bench for research and development in smart grid applications, contributing to advancements in sustainable energy solutions***

## I. INTRODUCTION

With the rapid depletion of fossil fuels and growing environmental concerns, the shift towards renewable energy sources has become a global priority. Among various solutions, hybrid renewable energy systems combining multiple sources such as wind, solar, and battery storage have emerged as effective alternatives to conventional energy systems, especially in off-grid and rural areas. However, the intermittent and unpredictable nature of these sources poses significant challenges in maintaining a stable and reliable power supply.

This paper addresses these challenges by developing a small-scale hybrid microgrid that integrates wind and solar photovoltaic (PV) systems with a battery energy storage unit. The core of this setup is a robust and intelligent Energy Management System (EMS) designed to coordinate energy generation, storage, and consumption effectively. The EMS ensures power balance, maximizes the use of available renewable energy, and manages battery charging/discharging based on real-time load demands and generation variability.

To implement and validate the system, the authors utilize power electronic converters, controllers for real-time testing. This enables the system to serve as a research and development platform for testing different control strategies, load conditions, and grid scenarios. The microgrid can operate in a standalone mode, making it ideal for remote or isolated locations where grid access is unavailable or unreliable.

Overall, the paper contributes to the growing field of smart grids and decentralized power systems by offering a scalable, flexible, and efficient microgrid model that supports the transition toward clean and sustainable energy.

## II. LITERATURE SURVEY

[1] Energy Management System for Small Scale Hybrid Wind Solar Battery Based Microgrid P. Satish et al

Key findings: The microgrid is designed to operate in standalone mode, making it suitable for remote or off-grid areas. The study proposes a microgrid that combines wind and solar energy conversion systems with battery storage. Power electronic converters, control algorithms, and controllers are developed to ensure seamless integration and operation of these components.

[2] Design and Simulation of Small Scale Microgrid Testbed. Alias Khamis M.N.M. Nasir et al

Key findings: The paper presents a design and simulation of a small-scale microgrid testbed using MATLAB/Simulink, incorporating photovoltaic (PV) and wind turbine (WT) micro sources with battery storage. The findings provide valuable insights for the development of small-scale microgrid systems, particularly in regions with unreliable grid infrastructure.

[3] Simulation and Analysis Approaches to Microgrid System Design. Daniel Akinyele et al

Key findings: The paper highlights the importance of simulation and analysis in microgrid systems design, allowing for the evaluation of different design scenarios and the optimization of system performance. The study proposes a holistic simulation framework based on the Social-Technical-Economic-Environmental-Policy (STEEP) model. This approach integrates multiple dimensions to provide a more comprehensive assessment of microgrid systems, addressing the shortcomings of traditional models.

[4]A review of modeling and simulation tools for microgrids based on solar photovoltaics.T. B. Seane R. et al

Key findings: The paper highlights the importance modeling and simulation in the design, development, and operation of microgrids based on solar photovoltaics (PV). The study emphasizes the potential of solar PV-powered community microgrids as sustainable solutions for neighborhoods and cities in Sub-Saharan Africa. These microgrids can operate in both grid-connected and island modes, enhancing energy independence and resilience in local communities.

[5] Energy Management of Microgrid in Grid-Connected and Stand-Alone Modes. Quanyuan Jiang et al

Key findings: The paper proposes an energy management system (EMS) for microgrids that can operate in both grid-connected and stand-alone modes. The study delineates the operational differences between grid-connected and stand-alone modes. In grid-connected mode, the microgrid interacts with the main grid to optimize economic benefits. Conversely, in stand-alone mode, the microgrid operates independently, prioritizing reliable power supply to customers over economic considerations.

[6] Energy Management System for Small Scale Hybrid Wind Solar Battery Based Microgrid.P. Satish Kumar. et al

Key findings: The EMS employs rapid control prototyping to perform real-time control, allowing for experimental testing and validation of control algorithms in a microgrid environment. The study proposes a microgrid that combines wind and solar energy conversion systems with battery storage. Power electronic converters, control algorithms, and controllers are developed to ensure seamless integration and operation of these components.

[7] Energy Management Systems in Microgrids.Süleyman Emre Eyimaya and Necmi Altin. et al

Key findings: Each category is evaluated based on its effectiveness in managing energy flow, maintaining supply-demand balance, and adapting to the variability of renewable energy sources. The paper discusses various control strategies employed in EMS to manage DERs effectively. These strategies aim to optimize the operation of microgrids by ensuring efficient energy distribution and maintaining system stability.

[8] Energy Management System for Small Scale Hybrid Wind Solar Battery Based Micro Grid. Mr. A. Pradeep et al

Key findings: The microgrid design is scalable, with principles applicable to varying sizes by adjusting component capacities based on specific requirements. An efficient EMS is designed to maintain power balance within the microgrid, addressing variations in renewable energy generation and load demand. The EMS coordinates multiple distributed generators to optimize performance.

[9] Energy management strategy for a hybrid micro grid system using renewable energy. Christian Bipongo Ndeke.

Key findings: The proposed EMS was validated through simulations using MATLAB/Simulink, demonstrating its effectiveness in real-time energy management.An advanced EMS is developed to coordinate the complex interactions between various energy sources, storage systems, and loads. The strategy incorporates predictive algorithms to anticipate energy availability and adjust system operations accordingly, addressing the intermittent nature of renewable energy sources.

[10] “Control Techniques in AC, DC, and Hybrid AC–DC Microgrid: A Review”, Saroja Kanti Sahoo et al.,

Key findings: Hybrid AC–DC microgrids combine AC and DC subgrids connected through interlinking converters, enabling diverse renewable energy sources but requiring complex control to manage power flow and maintain stability. The paper highlights that with increasing renewable energy integration, advanced control techniques are essential to handle intermittency, maintain system stability, and optimize energy use. Overall, it emphasizes the need for tailored control approaches specific to microgrid architectures to ensure efficient and reliable operation.

[11] Distributed generation for access to electricity: “off-main-grid” systems from homebased to microgrid. Freris L

Key findings: The study traces the progression from standalone home-based systems, such as solar home systems (SHS), to community-level microgrids. This evolution reflects a shift towards more integrated and scalable solutions to meet the growing energy demands of off-grid communities. The paper underscores the importance of policy frameworks and institutional support in promoting distributed generation. Governments and development organizations play a crucial role in creating enabling environments through incentives, subsidies, and capacity-building initiatives.

[12] ‘‘Control techniques in AC, DC, and hybrid AC-DC microgrid: A review,’’ S. K. Sahoo,

Key findings: Hybrid AC–DC microgrids integrate both AC and DC subgrids through interlinking converters, enabling the connection of diverse renewable energy sources but requiring more complex control to manage power flow and stability across subgrids. The paper highlights that as renewable energy integration increases, advanced control strategies are necessary to handle intermittency, maintain stability, and optimize energy use. Overall, the review emphasizes the importance of tailored control approaches specific to microgrid types to ensure efficient and reliable operation.

[13] Hybrid renewable energy systems for power generation in stand-alone applications: a review. Bajpai P,

Key findings :The authors highlight that hybrid systems, which combine two or more renewable sources such as solar, wind, and micro-hydro, offer improved reliability and efficiency over single-source systems due to their complementary nature. One of the key findings is the importance of integrating energy storage systems, such as batteries or hydrogen storage, to ensure a continuous power supply despite the intermittent nature of renewable resources.

[14] ‘‘Power management of a stand-alone wind/photovoltaic/fuel cell energy system,’’ C. Wang and M. Nehrir.

Key findings: The study discusses the sizing of system components, including wind turbines, PV arrays, fuel cells, electrolyzers, and batteries, to optimize performance and ensure that the system can meet energy demands under different conditions. The integration of these components through an AC-linked bus is also detailed. The proposed system utilizes wind and PV as primary energy sources, with a proton exchange membrane fuel cell (PEMFC) and an electrolyzer combination serving as a backup and long-term energy storage solution. Batteries are included to handle transient power demands and maintain system stability.

[15], ‘‘Reliability varying characteristics of PV-ESS-based standalone microgrid,’’ X. Song

Key findings: The research emphasizes the critical role of ESS in enhancing microgrid reliability. By analyzing reliability profiles across different ESS sizes, the authors introduce the concept of Expected Hourly Redundant Power (EHRP) as a novel metric to determine optimal ESS sizing. This approach aids in balancing the trade-off between ESS capacity and reliability improvement. The study investigates how varying levels of PV penetration affect reliability indices such as Loss of Load Probability (LOLP), Average Service Availability Index (ASAI), System

Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), and Customer Average Interruption Duration Index (CAIDI). A notable observation is the "surge effect" in SAIFI (SE-SAIFI), where increasing PV capacity beyond a certain threshold leads to a sharp rise in the frequency of power interruptions. This highlights the necessity for careful PV capacity planning to avoid adverse effects on system reliability.

[16] Tazi K, Performance analysis of micro-grid designs with local PMSG wind turbines. Tazi K

Key findings: comparative analysis of two microgrid configurations that integrate local permanent magnet synchronous generator (PMSG) wind turbines, photovoltaic panels, and battery energy storage systems. The study evaluates the performance, power quality, and operational reliability of each configuration. In the first design, the PMSG wind turbine is connected to a common DC bus via a rectifier, while in the second, it is connected to a three-phase AC circuit through a transformer. The authors find that the DC bus configuration offers superior power quality, particularly in terms of reduced voltage harmonics, making it suitable for applications where clean power is essential. However, the AC-based design, despite higher harmonic content, proves to be more robust in terms of supporting larger loads and maintaining functionality during inverter or transformer faults.

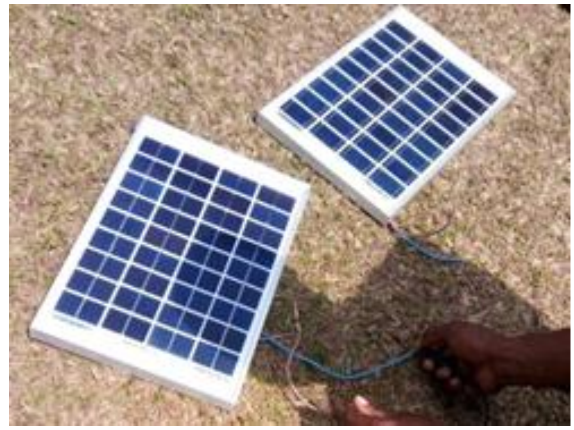
## III. PROBLEM STATEMENT

Energy management systems (EMS) play a critical role in optimizing energy use, reducing waste, and promoting sustainability. Small-scale micro grids can provide energy security and reliability to remote or off-grid communities Solving the problem of optimizing energy management in small-scale micro grids can provide a scalable and replicable solution for other micro grids, contributing to a wider adoption of renewable energy sources.

## IV. COMPONENTS USED

Major components which are used to develop Small scale micro grid are listed below:
Solar Photovoltaic (PV) Panels
Charge Controller
Inverter
Battery Bank

1. Solar Photovoltaic (PV) Panels



- Rating: 250 W – 500 W per panel
- Voltage Output: 24V / 48V DC (depending on configuration)

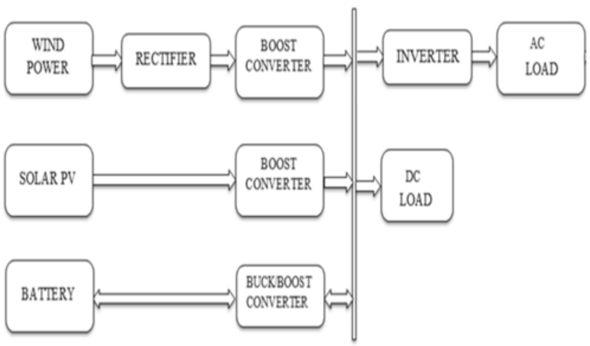
2. Charge Controller


- Input Voltage: Depends on PV array (e.g., 150V DC)
- Output Voltage: 12V / 24V / 48V DC

3. Inverter


- Rating: 1kW – 10 kW (depending on load)
- DC Input: 24V / 48V DC
- AC Output: 230V / 415V AC, 50Hz

## V. BLOCK DIAGRAM




A hybrid renewable energy system that integrates wind power, solar photovoltaic (PV) energy, and battery storage to supply both AC and DC loads efficiently. Wind power, which generates variable AC electricity depending on wind speed, is first converted into DC using a rectifier. This DC is then stepped up to a suitable voltage level using a boost converter before being fed into a common DC bus. From this DC bus, the power is sent to an inverter, which converts it back into AC to supply the AC loads.

Simultaneously, the solar PV system generates DC power directly, which is also passed through a boost converter to raise the voltage level to match that of the DC bus. This enables the solar power to be supplied directly to DC loads or contribute to the common energy pool. Additionally, a battery storage system is included in the setup to ensure continuous power availability and stability. The battery is connected through a buck-boost converter, which allows it to either charge (buck mode) when excess energy is available or discharge (boost mode) to supply power during demand peaks or when renewable sources are insufficient.

All three sources—wind, solar, and battery—are interconnected through the DC bus, allowing for coordinated and flexible power management. The system prioritizes renewable generation for supplying loads, and the battery acts as a buffer to maintain energy balance. This configuration ensures efficient energy utilization, grid independence, and reliable supply to both AC and DC loads, making it a practical solution for modern hybrid power systems.

## VI. IMPORTANCE OF THE PROJECT

The importance of a small-scale microgrid project lies in its relevance to today's pressing energy needs, technological advancements, and sustainable development goals. Below is a detailed explanation of why such a project is crucial:

1. Promotes Renewable Energy Integration
2. Provides Energy Access to Remote/Rural Areas
3. Improves Energy Reliability and Resilience
4. Educational and Research Significance
5. Scalability and Flexibility

## VII. METHODOLOGY

- Wind Power Conversion:

Wind energy is harnessed through a wind turbine that produces variable AC power depending on wind conditions. This AC power is converted into DC using a rectifier to ensure compatibility with the DC bus. A boost converter is employed to step up the rectified DC voltage to the desired level before feeding it into the common DC link.

- Solar PV Integration:

Solar PV panels generate DC electricity directly. This output is passed through a boost converter to elevate the voltage to the required DC bus level. The processed DC power is then injected into the common DC bus for further distribution.

- Battery Energy Storage Management:

A battery storage unit is connected to the DC bus via a buck-boost converter. This converter plays a dual role: it steps down the voltage to charge the battery during surplus energy conditions (buck mode) and steps up the battery voltage to supply power during deficits (boost mode). This ensures energy balance and enhances system reliability.

- DC and AC Load Supply:

The DC bus serves as a central point for distributing power to both DC and AC loads. DC loads are powered directly from the bus. For AC loads, the DC power is converted into AC using an inverter. The inverter ensures that the output voltage and frequency are suitable for the connected AC appliances.

- Power Flow Coordination:

The system operates under an intelligent control strategy that prioritizes renewable energy usage. When both wind and solar resources are available, their combined power feeds the loads and charges the battery if excess energy is present. During low-generation periods, the battery discharges to maintain supply continuity. This coordinated approach ensures optimal utilization of renewable resources and enhances system performance.

## 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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