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Research Paper

Energy Management System of a Hybrid Wind–Solar–Battery Microgrid Using Fuzzy Logic with Fuel Cell–Electrolyzer Integration

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Abstract

The intermittent nature of renewable energy sources poses significant challenges to the stable and reliable operation of microgrids. This paper presents an energy management system (EMS) for a hybrid wind–solar–battery microgrid integrated with a fuel cell and electrolyzer using fuzzy logic control. The proposed system employs a bidirectional DC–DC converter for battery energy storage and a fuel cell–electrolyzer combination to store excess energy as hydrogen and supply power during shortages. A fuzzy logic-based EMS is designed to coordinate power flow among the wind turbine, solar PV array, battery, fuel cell, and electrolyzer while maintaining DC bus voltage stability and optimizing energy utilization. The system is modeled and simulated in MATLAB/Simulink under varying renewable generation and load conditions. Results demonstrate effective power balance, improved system reliability, reduced battery stress, and efficient energy recovery through the fuel

cell–electrolyzer subsystem. The fuzzy logic controller ensures smooth transitions and adaptive decision-making without requiring a precise mathematical model.

Keywords: Hybrid Microgrid, Energy Management System, Fuzzy Logic Control, Wind–Solar–Battery System, Fuel Cell–Electrolyzer Integration, Renewable Energy, MATLAB/Simulink

I. Introduction

The growing demand for clean and sustainable energy has accelerated the adoption of renewable energy sources such as wind and solar in microgrid systems. However, the intermittent and unpredictable nature of these sources leads to power fluctuations and reliability issues. To address these challenges, hybrid microgrids integrate multiple energy sources with energy storage systems. This paper proposes an energy management system (EMS) for a hybrid wind–solar–battery microgrid integrated with a fuel cell and electrolyzer, controlled using fuzzy logic. The fuel cell–electrolyzer subsystem provides long-term energy storage by converting excess electricity into hydrogen and regenerating power when needed. The fuzzy logic-based EMS ensures optimal power sharing, voltage stability, and efficient utilization of available resources under varying generation and load conditions.

II. Literature Survey

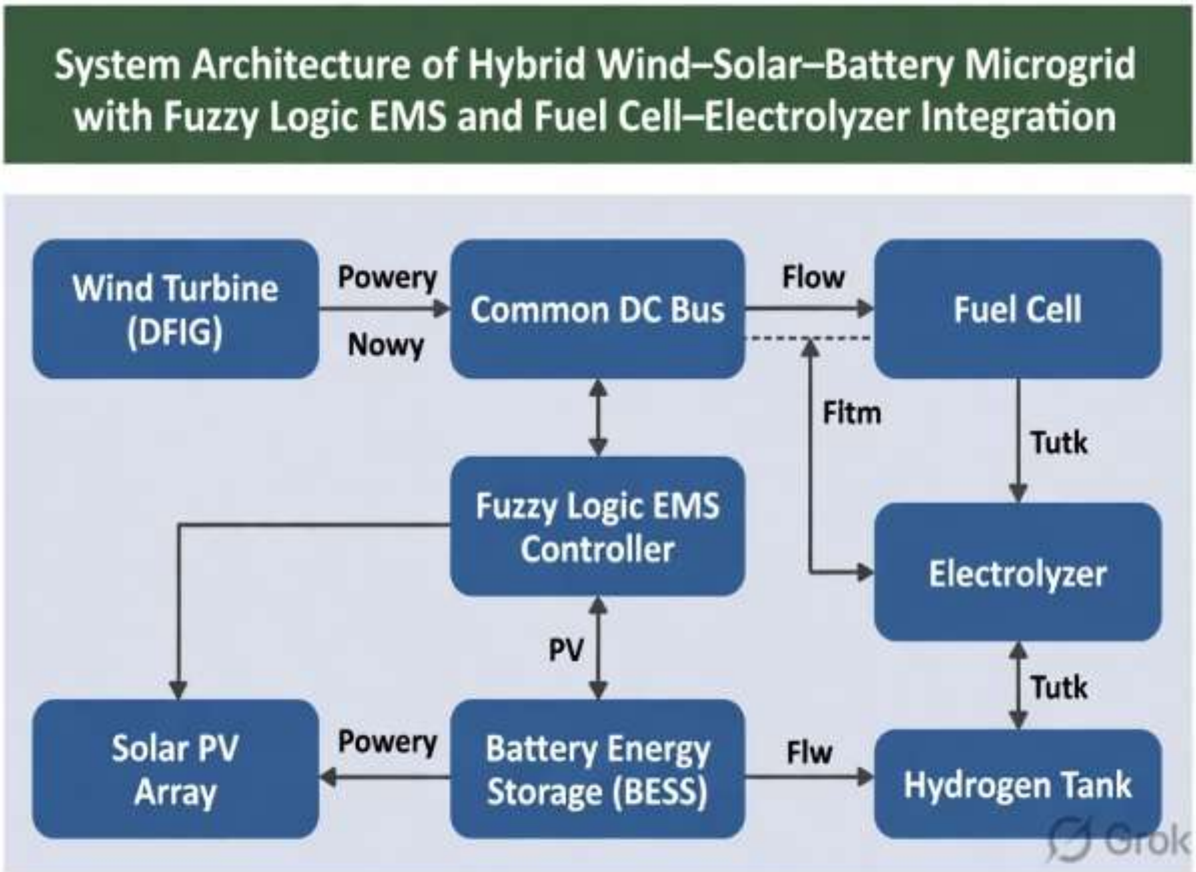
Several studies have explored hybrid renewable energy microgrids with various energy management strategies. Research by Lee et al. (2021) and Gupta et al. (2021) emphasized the need for efficient power conversion and storage in EV and microgrid applications. Works by Sha et al. (2018) and Zhu et al. (2020) proposed bidirectional converters but relied on conventional control methods. Recent advances by Kumar et al. (2024) and Sharma et al. (2023) demonstrated the superiority of intelligent control techniques such as fuzzy logic and ANN for dynamic power management and energy recovery.

Research Gap: Most existing designs either focus on topology development or use conventional linear control. Limited work integrates a fuzzy logic-based EMS with a fuel cell–electrolyzer subsystem for adaptive power management in hybrid wind–solar–battery microgrids. This study bridges the gap by combining a fuzzy logic controller with fuel cell–electrolyzer integration for improved reliability and efficiency.

III. Methodology

III-A. System Architecture

The proposed hybrid microgrid consists of a wind turbine with DFIG, solar PV array, battery energy storage system (BESS), fuel cell, and electrolyzer, all connected to a common DC bus. The fuzzy logic-based EMS coordinates power flow among these sources. The wind and solar systems supply power to the DC bus through converters. The battery is interfaced via a bidirectional DC–DC converter for charging and discharging. Excess energy is directed to the electrolyzer to produce hydrogen, which is stored and later used by the fuel cell during low generation periods. The EMS ensures voltage stability and optimal energy utilization.



III-B. Working Principle / Algorithm

Algorithm: Fuzzy Logic-Based Energy Management

Step 1: System Initialization — Define inputs: renewable power (wind + solar), load demand, battery SOC.

Step 2: Fuzzification — Convert crisp inputs into fuzzy sets using membership functions.

Step 3: Rule Evaluation — Apply fuzzy IF–THEN rules based on power balance and SOC limits.

Step 4: Inference — Aggregate rule outputs to determine control actions (charge/discharge battery, activate fuel cell/electrolyzer).

Step 5: Defuzzification — Convert fuzzy outputs into crisp control signals for converters.

Step 6: Power Flow Control — Regulate DC bus voltage and direct excess energy to electrolyzer or deficit energy from fuel cell.

Step 7: Continuous Monitoring — Update inputs in real time and repeat for adaptive energy management.

III-C. Hardware and Software Components

Software: MATLAB/Simulink for modeling and simulation.

Sources: Wind turbine with DFIG, solar PV array.

Storage: Battery energy storage system (BESS), fuel cell–electrolyzer with hydrogen storage.

Controller: Fuzzy logic-based energy management system (EMS).

IV. Results and Discussion

TABLE I: PERFORMANCE SUMMARY UNDER VARYING CONDITIONS

Scenario	Renewable Power (kW)	Load Demand (kW)	Battery SOC (%)	Fuel Cell Contribution	Electrolyzer Usage
High Generation	1200	800	75 → 80	Minimal	Active
Low Generation	400	900	30 → 20	Active	Inactive
Balanced Operation	850	850	Stable ~50	Inactive	Inactive

Simulation results confirm that the fuzzy logic EMS effectively maintains DC bus voltage stability and optimizes energy utilization. During high generation, excess power is directed to the electrolyzer for hydrogen production. During low generation, the fuel cell supplies deficit power while the battery supports transient needs. The system demonstrates improved reliability, reduced battery stress, and efficient long-term energy storage through the fuel cell–electrolyzer subsystem.

V. Conclusion and Future Work

This paper presented a fuzzy logic-based energy management system for a hybrid wind–solar–battery microgrid integrated with a fuel cell and electrolyzer. The proposed EMS ensures optimal power sharing, voltage stability, and efficient energy recovery under varying generation and load conditions. Simulation results validate the effectiveness of fuzzy logic control in achieving reliable and sustainable microgrid operation. The fuel cell–electrolyzer subsystem significantly enhances long-term energy storage and system reliability.

Future work includes hardware prototype development, real-time implementation on DSP/FPGA platforms, integration of machine learning for adaptive rule tuning, and experimental validation under various operating scenarios.

References

[1] C. H. T. Lee et al., “A critical review of emerging technologies for electric and hybrid vehicles,” IEEE Open J. Veh. Technol., 2021.

[2] V. Rathore et al., "A high-gain multilevel DC-DC converter for EV applications," IEEE Trans. Ind. Appl., 2022.

[3] H. Chen et al., "Electrified automotive powertrain architecture using composite DC-DC converters," IEEE Trans. Power Electron., 2017.

[4] A. Gupta et al., "Novel EV traction architecture with multi-input high conversion ratio converter," IEEE Open J. Veh. Technol., 2021.

[5] MATLAB/Simulink Documentation, MathWorks Inc., 2025.