Intelligent Energy Management System for a Hybrid Microgrid with Renewables and Battery Storage

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1. Introduction & Background

The global transition toward sustainable and decentralized energy systems has driven the adoption of innovative solutions for reliable and efficient power generation. Hybrid microgrids, localized networks integrating renewable energy sources (RES), energy storage systems (ESS), have emerged as a resilient and eco-friendly alternative to conventional centralized grids. These systems can operate in both grid-connected and standalone modes, enhancing energy security and sustainability, particularly in remote or under-electrified regions.

However, the intermittent nature of RES and the complex coordination required among diverse components pose significant energy management challenges. Maintaining stability under fluctuating supply-demand conditions demands advanced energy management systems (EMS) capable of real-time. While traditional EMS approaches have limitations in adaptability and computational efficiency, intelligent algorithms like Fuzzy Logic Controllers (FLCs) offer a promising alternative. FLCs provide a rule-based, computationally efficient framework for handling uncertainty and nonlinearity, making them well-suited for dynamic microgrid environments.

The research focuses on how FLC IEMS can minimize cost of energy from utility grid, achieve optimum use of solar PV and ensure power quality at load terminals.

2. Objectives

The primary objectives of this research thesis are outlined as follows:

- Design a microgrid comprising of renewables and battery storage, with capabilities of being grid-connected and standalone.
- Develop an intelligent algorithm for the energy management system that reduce the cost of energy drawn from the grid during grid-connected mode, and ensure energy security during standalone mode.
- Model and simulate both the test microgrid and intelligent energy management system and integrate both designs to test and validate the intelligent energy management performance.

The main aim is to ensure optimum use of solar PV and power quality at the load terminals at all time in both operation modes.

3. Methodology

To carry out the objectives of this study, the following research methodology steps were followed:

- Identification of technical requirements, Simulation software selection, microgrid component sizing, fuzzy logic algorithm development

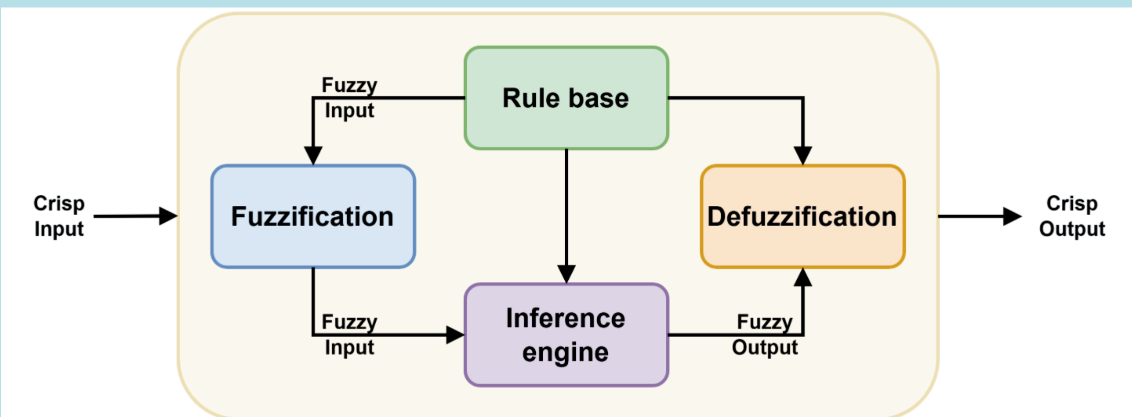


Figure 1: Fuzzy logic structure

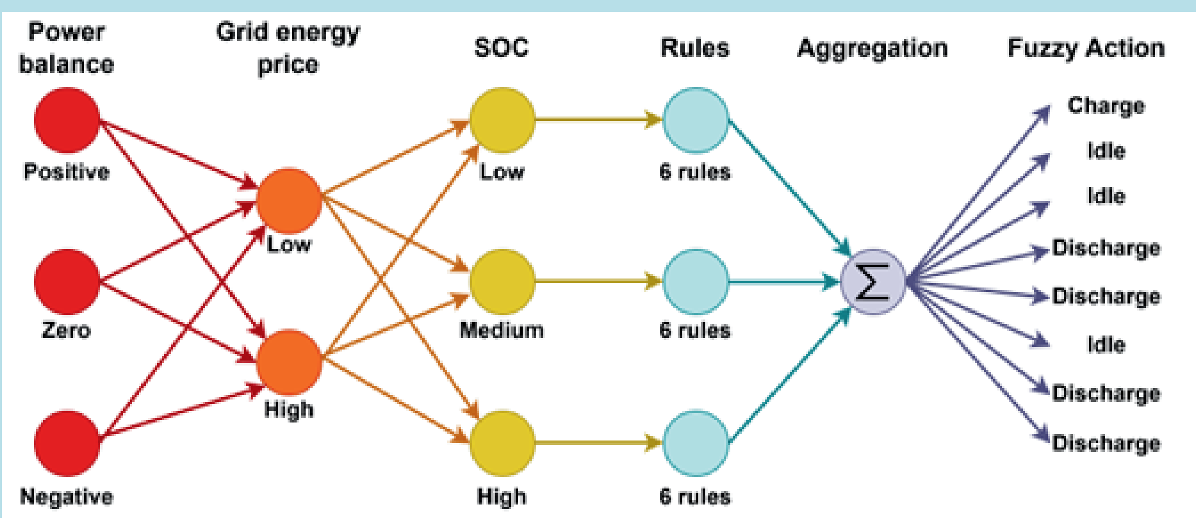


Figure 2: Fuzzy logic design steps

4. Results & Discussion

The case studies were compared based on technical and economical key metrics:

- Technical: Renewable Factor (RF), frequency and voltage, total amount of excess energy and unmet electrical load demand.
- Economic: Cost of Energy (CoE).

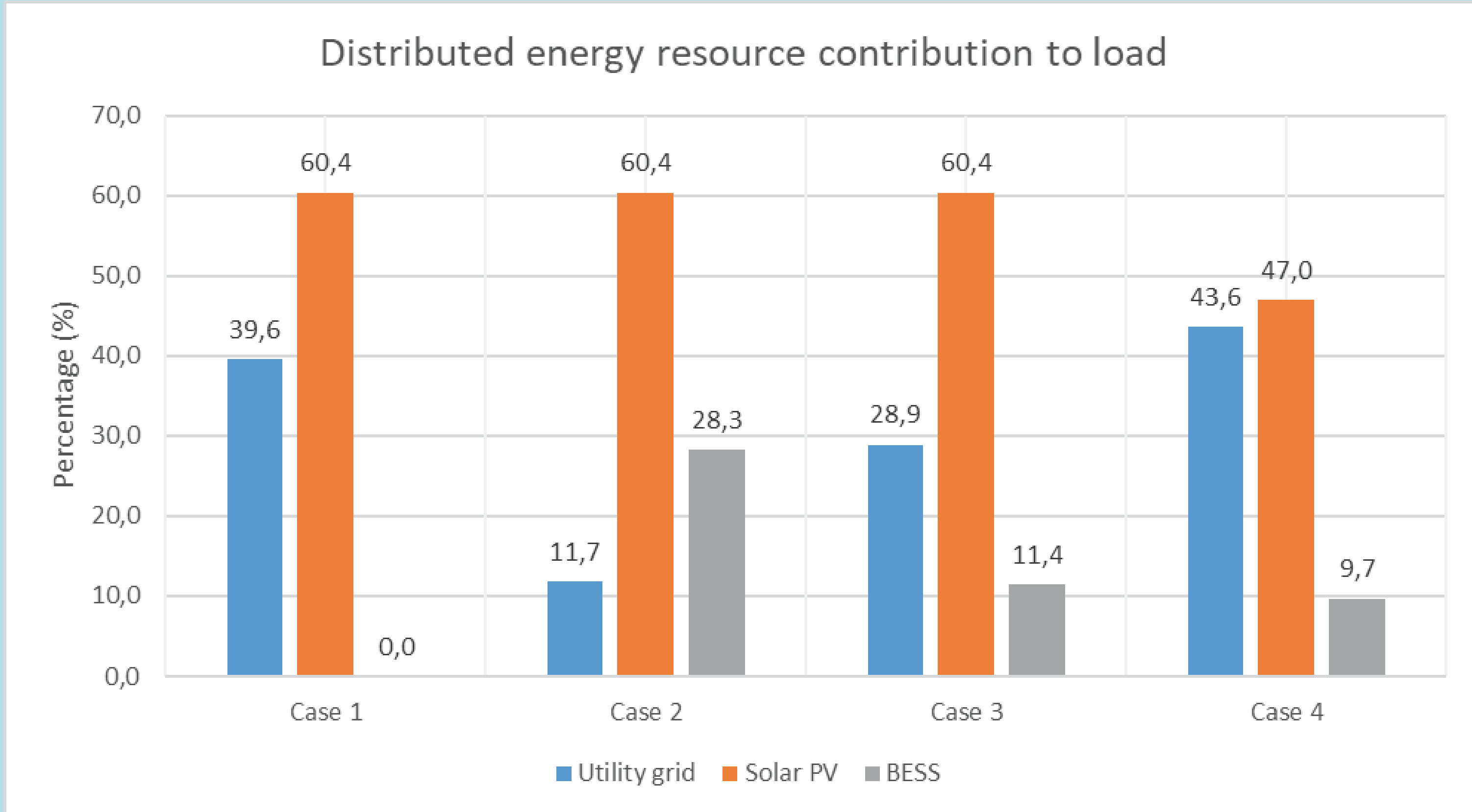
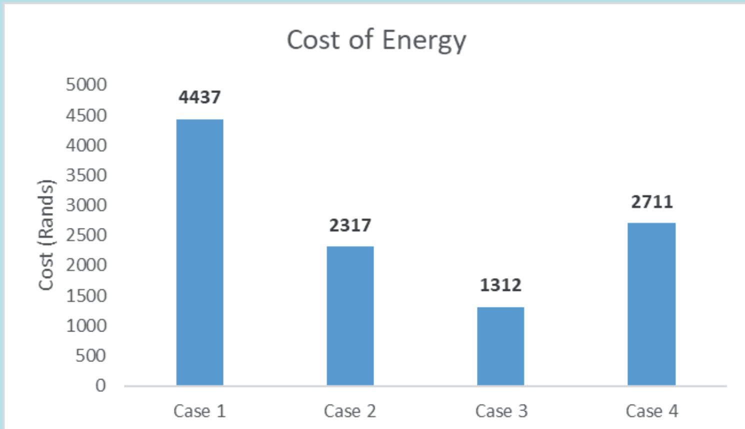


Figure 3: Distributed energy resource (DER) contribution to the load demand



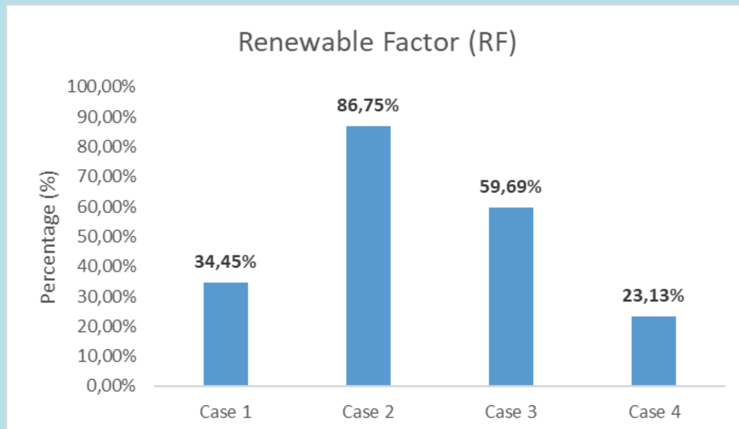


Figure 4: Renewable Factor

Figure 5: Cost of Energy from the grid

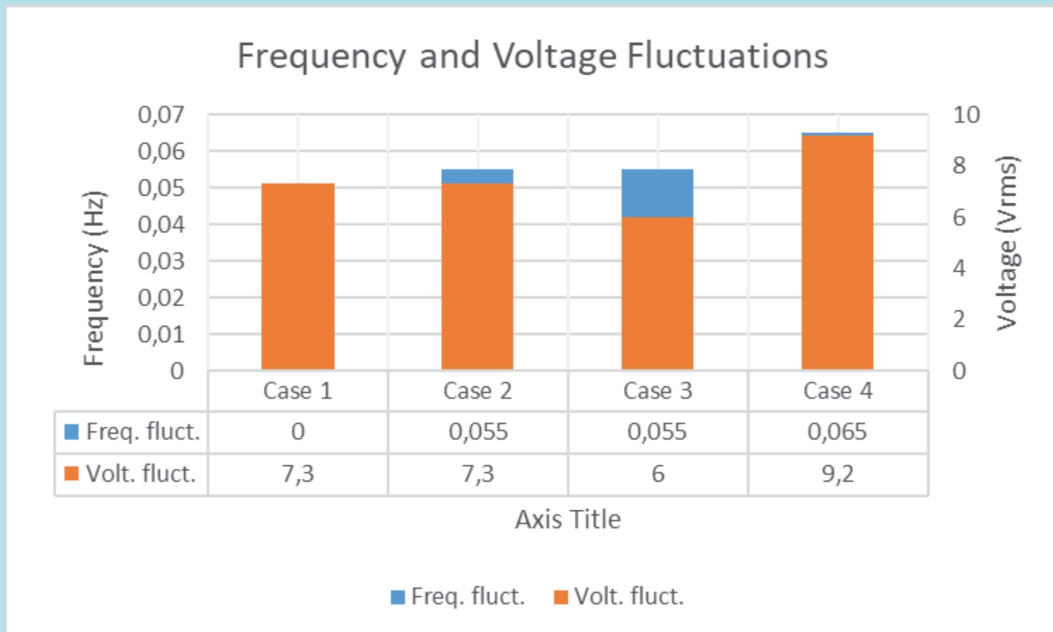


Figure 6: Frequency and voltage fluctuations

5. Key Findings

- Based on technical metrics, the solar PV met contributed the most energy supply to the load demand, achieving 60% in case 1,2 and 3, and only 43% in case 4 due to increased load demand.
- The integration of FLC IEMS in case 3 achieved the objective of minimizing the cost of energy from the utility grid, with total cost being R1312.00.
- Despite case 2 achieving the highest RF due to irregular BESS discharging, case 3 achieved 59.49%, with effective charging and discharging coordination due to the integration of FLC IEMS.
- Integration of FLC IEMS in case 3 achieved frequency fluctuations of 49.945 Hz to 50.055 Hz, within the limits specified in SAGC.
- Case 3 achieved voltage fluctuations of 394 V to 406 V from the nominal value of 400V.

6. Conclusion

Intelligent energy management systems integrated in hybrid microgrid play a critical role in facilitating the mode of operation based on time of use tariff to minimize cost of energy drawn utility grids, power coordination of DER, ensuring efficient discharging and charging patterns of BESS ensuring power quality across within the microgrid and the load. The intelligent energy management system can be cascaded with the integration of intelligent algorithms such as artificial neural network to make it robust, contributing to resilient hybrid microgrids and achieving energy security.