CHAPTER 10

ITERATIVE PARETO FUZZY FOR MULTI-MICROGRID SIZING OPTIMIZATION

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10.1 INTRODUCTION

Electric power distribution plays a critical role in ensuring the stable, efficient, and reliable delivery of electricity from centralized generation sources to end users. As global electricity demand continues to increase, the need to supply high-quality power at an affordable cost while minimizing environmental impact has become more pressing. Traditionally, electricity generation has relied heavily on fossil fuels such as coal and diesel. While effective in meeting energy needs, these sources are finite, increasingly costly, and major contributors to environmental degradation through greenhouse gas emissions and pollution. These challenges have accelerated the global transition towards cleaner and more sustainable energy sources.

Renewable energy technologies such as solar photovoltaic (PV), wind turbines, and battery energy storage systems (BESSs) have emerged as promising alternatives. Integrating these technologies into electric power distribution systems offers multiple benefits, including reduced dependency on fossil fuels, improved energy security, and significant reductions in harmful emissions. However, the integration process is not without challenges. Hybrid renewable energy systems, which combine multiple sources such as solar, wind, and storage, require careful design to ensure stability, cost-effectiveness, and efficiency. A central aspect of this design is component sizing, where decisions must be made regarding the appropriate capacity of each system component.

Improper sizing can lead to operational inefficiencies, overinvestment, or underperformance, all of which compromise the technical and economic viability of the system. Furthermore, the design process must navigate conflicting objectives (Kreishan & Zobaa, 2023). Minimizing system costs may reduce technical performance, while improving technical performance often requires higher investment. Efficiency considerations add another layer of complexity. Therefore, optimizing microgrid sizing cannot rely on a single-objective approach, as it fails to capture the trade-offs among multiple important criteria.

To address this complexity, the iterative pareto fuzzy (IPF) optimization technique provides a structured solution for balancing technical, economic, and efficiency objectives in microgrid sizing. IPF identifies the best compromise solution from the set of non-dominated configurations. It does so by first generating the Pareto front through multi-objective analysis, which captures optimal trade-offs among conflicting objectives. Fuzzy logic is then applied to evaluate and rank these solutions based on a normalized membership function, simulating human-like reasoning in assessing performance levels. This integration ensures that the final selected solution offers the most balanced and practical outcome, making IPF an effective tool for optimizing hybrid renewable energy systems in distributed power networks.

10.2 ITERATIVE PARETO FUZZY

The IPF optimization technique is a hybrid multi-objective framework developed to solve complex decision-making problems that involve multiple, often conflicting objectives. In energy system design, especially for microgrids powered by renewable energy, designers must simultaneously consider technical performance, economic viability, and system efficiency. Conventional single-objective methods fail to capture these trade-offs effectively, making multi-objective approaches such as IPF highly relevant.

The foundation of the IPF method lies in Pareto optimality, a principle introduced by Vilfredo Pareto that identifies solutions which cannot be improved in one objective without degrading another. These solutions form what is known as the Pareto front, offering a set of equally optimal trade-off solutions rather than one single answer (Deb, 2005). In the context of hybrid renewable energy systems, Pareto front solutions may represent configurations that are technically reliable, cost effective, or highly efficient but rarely all three at once.

To refine the decision-making process beyond identifying non-dominated solutions, IPF integrates fuzzy logic. Introduced by Zadeh, fuzzy logic models human reasoning through degrees of truth, enabling the system to evaluate solutions not just in binary terms of optimal or suboptimal, but across a spectrum of preferences (Zadeh, 1965). Each objective function is associated with a fuzzy membership function that quantifies its desirability.

The IPF technique operates through a structured three-stage process (Mukhtaruddin et al., 2015). First, all feasible system configurations are generated based on defined sizing ranges for components like PV arrays, wind turbines, and BESSs. Second, Pareto dominance is applied to filter out inferior solutions, yielding a set of non-dominated solutions. Third, the non-dominated solutions are evaluated using fuzzy logic, where each objective is assigned a membership function reflecting decision-maker preferences. A fuzzy decision index is then calculated for each solution, allowing for a final ranking that guides the selection of the most suitable system configuration.

Unlike some evolutionary or heuristic-based multi-objective algorithms such as non-dominated sorting genetic algorithm-II (NSGA-II) or particle swarm optimization (PSO) (El-qasery et al., 2025; Punyam Rajendran & Gebremedhin, 2025), which rely on iterative population updates and random search dynamics, the IPF approach is deterministic and decision-focused. It provides a comprehensive yet transparent