Research Article

Simultaneous switches placement in distribution networks under uncertainty: A fuzzy multi-objective approach

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Extended Abstract:
This research article presents a novel and robust methodology for the optimal placement of sectionalizing switches and fuses in modern smart distribution networks, explicitly addressing the inherent uncertainties present in real-world operational environments. The primary objective of the proposed framework is to simultaneously enhance system reliability and reduce investment costs, recognizing that these two goals are often in conflict and require a balanced, multi-objectiplinary approach. The authors argue that conventional planning methods, which often rely on deterministic models and single-objective optimization, are insufficient for capturing the complex, stochastic nature of distribution systems. Factors such as fluctuating load demands, variable failure rates of components, and the unpredictable repair times for faults introduce a significant level of uncertainty that must be explicitly modeled to design a truly resilient and cost-effective network.

To address this challenge, the paper introduces a fuzzy multi-objective optimization function that serves as the core of its planning framework. In this model, the conflicting objectives—the System Average Interruption Duration Index (SAIDI), a key reliability metric that quantifies the average outage duration for a customer in a year, and the total investment cost of switches—are not treated as rigid, deterministic values. Instead, they are represented using fuzzy membership functions. This fuzzy logic approach allows for a more realistic and flexible representation of the planning problem, where the goals are not simply "met" or "not met," but exist on a continuum of acceptability. By defining a membership function for each objective, the model can evaluate the degree to which a given solution is "good" from both an economic and a technical perspective.

A key innovation of the paper lies in its treatment of uncertainty. The model explicitly incorporates the probabilistic nature of three critical parameters: electrical load, failure rates of line segments, and repair times. Load is not a fixed value but varies throughout the day and across seasons. Similarly, the probability of a fault occurring on a particular line is not a constant and can be influenced by weather, age of infrastructure, and other external factors. Finally, the time required to isolate a fault and restore service is highly variable. By modeling these parameters with their inherent randomness, the proposed method moves away from static, "worst-case" or "average-case" scenarios towards a more dynamic and probabilistic assessment of network performance.

The optimization problem, formulated as a fuzzy multi-objective function, is solved using the Honey Bee Mating Optimization (HBMO) algorithm. The HBMO is a nature-inspired metaheuristic algorithm that mimics the mating behavior of honeybee colonies. In the algorithm, the queen bee represents the current best solution, while the drones represent other candidate solutions in the search space. The mating process, which includes a probabilistic selection of drones and a recombination of their "genetic" information, drives the exploration and exploitation of the solution landscape. The

authors justify the choice of HBMO for its ability to handle complex, non-linear, and multi-modal optimization problems effectively, which is precisely the nature of the switch placement problem under uncertainty.
The effectiveness and practicality of the proposed method are rigorously validated through simulations on two distinct test systems: the standard RBTS (Roy Billinton Test System) bus 4 feeder and a real-world distribution feeder from Ardabil city in Iran. The use of both a standardized benchmark and a real network provides a compelling validation of the method's versatility. The results from the RBTS network demonstrate the methodology's ability to outperform conventional approaches, particularly in scenarios involving Distributed Generation (DG). The study shows that the presence and strategic placement of DG units can significantly enhance reliability, and the proposed fuzzy optimization framework is adept at identifying the optimal synergy between switch placement and DG integration.
The case study on the Ardabil feeder is particularly noteworthy as it grounds the theoretical framework in a practical, real-world context with all its associated complexities. The results confirm that the method can successfully navigate the uncertainties of a live distribution network and propose a switch placement strategy that offers a superior balance between cost and reliability. A detailed sensitivity analysis is also performed, which investigates the impact of varying the weight coefficients in the fuzzy objective function. This analysis reveals that by adjusting these weights, the planner can generate a spectrum of viable solutions, ranging from a highly cost-driven plan to one that is reliability-prioritized, providing system operators with valuable flexibility for decision-making under different economic and regulatory conditions.
Furthermore, the paper extends its analysis to the simultaneous placement of both sectionalizing switches and fuses. This is a critical and realistic extension, as these two devices serve complementary roles in network protection and restoration. The results indicate that a coordinated, joint optimization of both types of devices yields a more significant improvement in both reliability metrics (like SAIDI and SAIFI - System Average Interruption Frequency Index) and overall system cost than the optimization of either device in isolation. This finding underscores the importance of a holistic and integrated approach to distribution network planning.
In conclusion, this article makes a significant contribution to the field of smart distribution network planning by developing a sophisticated, uncertainty-aware, and multi-objective optimization framework for switch and fuse placement. By leveraging fuzzy logic to model the inherent vagueness of real-world planning goals and using the powerful HBMO algorithm to solve the resulting complex problem, the authors provide a practical and effective tool for utilities. This tool enables them to enhance the resilience and reliability of their networks while maintaining strict economic constraints, a crucial capability in the era of increasing renewable integration and the growing societal demand for uninterrupted, high-quality power supply. The successful validation on both a standard test network and a real-world feeder solidifies the method's potential for practical application in modern grid planning and operation.

Keywords: uncertainty, fuzzy multi-objective function, reliability

Received: 21 3 July 2024
Revised: 11 Sep. 2024
Accepted: 20 Nov. 2024

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Citation: A. Norouzi, H. Shayeghi, M. Delshad, J. Olamaei, A. Jalili, "Simultaneous switches placement in distribution networks under uncertainty: A fuzzy multi-objective approach", Journal of Novel Researches on Smart Power Systems, vol. 13, no. 3, pp. 73-80, December 2024 (in Persian).