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A novel fuzzy–backward/forward sweep power flow for uncertainty management in radial distribution network with photovoltaic generation

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Abstract

This research presented a novel framework of fuzzy-backward/forward sweep (F-BFS) power flow to address uncertainties in radial distribution networks with photovoltaic generation. The F-BFS framework integrated fuzzified values to model uncertainty parameters in radial distribution network power flow analysis, whereas the Grey Wolf Optimizer (GWO) was employed to optimize photovoltaic distributed generation (PVDG) placement and sizing, aiming to minimize power losses and improve voltage deviations. Load uncertainties in the residential, commercial, and industrial sectors were modeled using triangular fuzzy membership functions derived from real-world data representing Malaysian urban loads. Simulations on the 33-bus distribution network validated the approach and demonstrated its effectiveness in handling fuzzy uncertainties across three load sectors. The findings showed that the proposed F-BFS-GWO method significantly reduced the total power losses and improved the voltage profiles. Under high load conditions, active power losses were reduced by approximately 28.04% in residential, 46.06% in commercial, and 46.24% in industrial sectors at the highest membership degree in the fuzzy set, compared to the scenario without photovoltaic generation. The critical voltage magnitudes at the weakest bus under high-load conditions in the fuzzy set also improve significantly, reaching nearly 1.0 p.u. The main contributions of this work are the integration of fuzzy-logic within a BFS framework to manage multi-sector load uncertainties, coupled with a hybrid F-BFS–GWO algorithm that enhances system planning and optimization under the risk of uncertainty of photovoltaic generation and load demand. © 2025 The Authors.

Author keywords

Backward/forward sweep power flow; Fuzzy logic; Grey Wolf Optimizer (GWO); Photovoltaic distributed generation (PVDG); Radial distribution network

Indexed keywords

Engineering controlled terms

Computer circuits; Distributed power generation; Electric load loss; Electric losses; Fuzzy sets; Housing; Islanding; Membership functions; Uncertainty analysis

Engineering uncontrolled terms

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Engineering main heading

Fuzzy logic

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