Multi-objective operation optimization of an electrical distribution network with soft open point
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HIGHLIGHTS
• The SOP’s capability of bringing benefits on multiple objectives simultaneously was investigated.
• A multi-objective framework was developed to improve distribution network operation with SOP.
• An optimization method integrating both global and local search techniques was proposed.
• The optimization method is capable of obtaining diverse Pareto optimal solutions.

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ABSTRACT
With the increasing amount of distributed generation (DG) integrated into electrical distribution networks, various operational problems, such as excessive power losses, over-voltage and thermal overloading issues become gradually remarkable. Innovative approaches for power flow and voltage controls are required to ensure the power quality, as well as to accommodate large DG penetrations. Using power electronic devices is one of the approaches. In this paper, a multi-objective optimization framework was proposed to improve the operation of a distribution network with distributed generation and a soft open point (SOP). An SOP is a distribution-level power electronic device with the capability of real-time and accurate active and reactive power flow control. A novel optimization method that integrates a Multi-Objective Particle Swarm Optimization (MOPSO) algorithm and a local search technique – the Taxi-cab method, was proposed to determine the optimal set-points of the SOP, where power loss reduction, feeder load balancing and voltage profile improvement were taken as objectives. The local search technique is integrated to fine tune the non-dominated solutions obtained by the global search technique, overcoming the drawback of MOPSO in local optima trapping. Therefore, the search capability of the integrated method is enhanced compared to the conventional MOPSO algorithm. The proposed methodology was applied to a 69-bus distribution network. Results demonstrated that the integrated method effectively solves the multi-objective optimization problem, and obtains better and more diverse solutions than the conventional MOPSO method. With the DG penetration increasing from 0 to 200%, on average, an SOP reduces power losses by 58.4%, reduces the load balance index by 68.3% and reduces the voltage profile index by 62.1%, all compared to the case without an SOP. Comparisons between SOP and network reconfiguration showed the outperformance of SOP in operation optimization.

1. Introduction

Growing awareness of energy and environment, and the demand for a reliable, secure, and sustainable power grid lead to the continuously expanding deployments of Distributed Generators (DG). However, high penetrations of DG significantly affect the operation of electrical distribution networks, where the technical challenges are mainly power loss increments, line and transformer overloads, and voltage violations [1–5].

The use of power electronic devices provides alternative solutions to overcome these challenges. The application of power electronics to High Voltage Direct Current (HVDC) transmission systems has gained increasingly importance in the bulk power transfer. The extensive growing demand for power electronic devices and their continuous developments offer significant reductions in converter costs [6], which provide a chance for their further applications in medium voltage (MV) and low voltage (LV) distribution networks.

Power electronic devices were applied in distribution networks for
Over the past few decades, multi-objective optimization problems have attracted considerable interests from researchers motivated by the real-world engineering problems [17]. Many multi-objective optimization problems are solved under the concept of a priori method, in which the decision maker defines the importance amongst objectives before the search performs, and the multi-objective optimization problem is transformed into a single objective one. Afterwards, a classical single objective optimization algorithm is used to find the optimum. The key drawback of the a priori method is the arbitrarily imposed limitation of the search space, which does not allow findings of all solutions in a feasible set [18]. In addition, since it is common that real-world objectives are incomensurable in nature and can be conflicting with each other, aggregating multiple objectives into one may result in losing significance. Pareto optimality, on the contrary, is based on a simultaneous optimization of multiple objective functions. It provides a set of non-dominated solutions named Pareto optimal solutions, illustrating the nature of trade-offs among conflicting objectives. Evolutionary algorithms, e.g., the widely recognized SPEA2 [19] and NSGA-II [20], are suitable to solve multi-objective optimization problems using the concept of Pareto optimality, since these techniques deal with a set of possible solutions simultaneously, which allow obtaining an entire set of Pareto optimal solutions in a single run. Particle Swarm Optimization is one of the most recently used evolutionary algorithms. It is a global search technique with the most attractive features of simple concept, easy implementation, fast computation and robust search ability. Compared with other evolutionary algorithms, Particle Swarm Optimization shows inoprable advantages in searching speed and precision [21]. There are different Pareto-based multi-objective Particle Swarm Optimization variants, and a state-of-the-art review was given in [22].

Despite the global exploration capability, evolutionary algorithms are comparatively inefficient in fine tuning solutions (the exploitation) [23]. To overcome this deficiency and to enhance the search capability of evolutionary algorithms, appropriate integrations of global and local search techniques to maintain the balance between exploration and exploitation have been proposed. In [24] an adaptive local search method for hybrid evolutionary multi-objective algorithms was
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