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Multi-Objective Optimization of Electrical Distribution Network Operation Considering Reconfiguration and Soft Open Points

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Abstract

High penetration levels of Distributed Generations (DG) significantly affect the operations of electrical distribution networks. In this paper, Distribution Network Reconfiguration (DNR), and the implementation of Soft Open Point (SOP) – a distribution-level power electronic device are investigated as effective solutions to facilitate large DG penetrations while meeting network operational constraints. DNR is developed based on the ant colony optimization, and the optimal SOP outputs are determined using the Taxi-cab algorithm after determining the network configuration. Both optimization problems are formulated within a multi-objective framework using the Pareto optimality. The performances of DNR and SOP to improve network operations are demonstrated on a modified 33-bus distribution system with various DG penetrations.

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Keywords: Distribution Network Reconfiguration (DNR); Soft Open Points (SOP); Distributed Generation (DG); Pareto optimality

1. Introduction

Distribution Network Reconfiguration (DNR) is the process of altering the topology of an electrical distribution network by changing switch status (open/close), thus redirects power flows within the network, in order to achieve certain objectives while satisfying network operational constraints.

DNR is a mixed-integer, non-linear optimization problem [1]. Although in theory a global optimal configuration can be obtained by enumerating all feasible solutions and choosing the one which meets the objective best, simple exhaustive searches are rarely sufficient for the complicated real DNR applications.

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There are solutions using heuristic algorithms to eliminate choices that are unlikely to lead to good configurations. In [2], a branch and bound type heuristic method is presented. Although this method is rapid in determining a configuration which reduces the power losses, it considers only one pair of switching operations at a time. The result highly depends on initial switch states. A power flow method-based heuristic algorithm is proposed in [3]. However, this method is only suitable for small systems and becomes prohibitive when handling large distribution networks.

There are also DNR approaches based on artificial intelligence, which often incorporates with metaheuristics. In [4], a particle swarm optimization method is proposed to maximize the power system reliability while minimizing the power losses. A harmony search algorithm for DNR problems with the objectives of improving voltage profiles and minimizing real power losses is proposed in [5]. Compared to heuristic algorithms, metaheuristics are able to handle large-system and multi-objective optimization problems. Furthermore, they are problem-independent so that can be applied to different networks.

A number of literatures formulate the reconfiguration problem as multi-objective. In [6], a simultaneous reconfiguration optimization method is proposed by aggregating all the objectives into one and considering different weighting factors. In [7], a fuzzy satisfaction method is used. It considers the desired objective value as a priori, which is hardly feasible in practice. In this paper, the Pareto optimality, which provides a set of diverse solutions representing trade-offs between different objectives is used. The objectives focused on are power loss reduction, load balance and DG penetration level increase.

An alternative solution to redirect power flows without changing the network topology is the implementation of Soft Open Point (SOP). It is a power electronic device installed in place of a Normally Open Points (NOP) between adjacent feeders of radial distribution networks, having the capability to transfer real power and control reactive power between its connecting points [8]. In this paper, the optimal SOP outputs are determined based on the result of DNR to provide further improvements along each of the aforementioned objectives.

2. Problem formulation

2.1. Multi-objective functions

The multi-objectives of both DNR and SOP output optimizations were similar including minimizing the power loss, the load balancing and maximizing the DG penetration level. The objectives are presented as P_{loss}, *LBI* and *DGPL* as shown below:

A. Minimizing the power loss (P_{loss})

$$obj_1 = minP_{loss} = \sum_{i=1}^{n_{branch}} I_i^2 \times r_i \quad (1)$$

I_i is the current passing through branch i and r_i is the resistance of the branch. n_{branch} is the total number of branches in a distribution network.

B. Load balancing

Load balancing is achieved by minimizing the load balance index (*LBI*), which is defined as:

$$obj_2 = minLBI = \sum_{i=1}^{n_{branch}} \left(\frac{I_{i-actual}}{I_{i-rated}}\right)^2 \quad (2)$$

where $I_{i-actual}$ and $I_{i-rated}$ are the real and rated current of branch i.