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Optimal Configuration of Soft Open Point for Active Distribution Network Based on Mixed-integer Second-order Cone Programming

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Abstract

Soft Open Point (SOP) refers to a power electronic device installed in place of a normally-open point in a distribution network. The application of SOP will greatly promote the economy, flexibility and controllability of the distribution network. In this paper, an optimal configuration method of SOP is proposed for the operation of active distribution system. Firstly, considering the characteristics of renewable energy generation, classic scenarios are constructed based on Wasserstein distance metric. Secondly, an optimal configuration model of SOP is presented. Then, a conic model conversion is proposed and mixed-integer second-order cone programming is used to solve the model with efficiency and convergence. Finally, case studies on IEEE 33-node test feeder are used to verify the proposed method.

Keywords: distributed generation (DG); soft open point (SOP); optimal configuration; Wasserstein distance metric; mixed-integer second-order cone programming (MISOCP)

1. Introduction

With the increasing integration of distributed generation (DG), the distribution system will give full expression to these aspects, including loss reduction, power supply reliability improvement, economics promotion and environmental pollution advancement, *etc*. However, the widely application of DGs, especially the intermittent DGs pose new challenges to the operating conditions, such as voltage exceeding,

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network congestion and the randomness of DG power supply [1]. Traditional distribution systems are incompetent to deal with the large integration of intermittent DGs due to their limited adjusting means. Soft open point (SOP), a new type of intelligent power distribution device, derives under the above background to replace normally-open point (NOP). Compared with NOP, the power control of SOP is more safe and reliable, and even able to realize the real-time optimization control. SOP is mainly based on the fully-controlled power electronic devices, which leads to higher investment and operation maintenance cost. Therefore, it is very necessary to make a reasonable configuration scheme for SOP. Reference [2] studied the basic principle and model of the SOP, while reference [3, 4] carried on the simulation analysis of steady-state and transient characteristics of SOP, respectively, which will provide a foundation for the optimal configuration of SOP.

An optimal configuration model of SOP considering DG operation characteristics is proposed in this paper. The model is essentially a mixed-integer nonlinear problem. The optimal scenario generation technique based on Wasserstein distance is adopted to build classic scenarios for the problem to be solved [5]. Furthermore, a conic model conversion is proposed to realize the required format, and the mixed-integer second-order cone programming (MISOCP) is used to solve the model. Finally, the optimal configuration model of SOP and MISOCP are verified on the IEEE 33-node test feeder.

2. Optimal configuration modelling of SOP in active distribution network

2.1. Scenario generation based on Wasserstein distance metric

The uncertainty of DG is usually represented by a continuous probability density distribution function. In the modelling stage, the discrete distribution instead of the continuous distribution is used to simplify the model, which is also called scenario generation. Taking into account that the power flow optimization problem is complex, it is difficult to approximate the original probability density distribution function with less discrete scenarios. In the scenario generation technique, the method based on Wasserstein distance metric is adopted in this paper.

Assuming that continuous probability density function of variable x is $f(x)$, S discrete scenarios are used to approximate $f(x)$. The optimal scenario z_s (s = 1, 2, ⋯, S) can be obtained by the formula (1).

$$\int_{-\infty}^{z_s} f(x)^{\frac{1}{r+1}} dx = \frac{2s-1}{2S} \int_{-\infty}^{+\infty} f(x)^{\frac{1}{r+1}} dx \tag{1}$$

2.2. Optimal configuration model

In this paper, we take the minimum annual expense of overall distribution system as the objective function, which is formulated as

$$\min C = C^{\text{INV}} + C^{\text{OPE}} + C^{\text{LOSS}} \tag{2}$$

The annual expense of overall distribution system is composed of the following three parts.

1) C^{INV}: fixed investment cost of SOP

$$C^{\text{INV}} = \frac{d(1+d)^y}{(1+d)^y - 1} \sum_{i=1}^{N} \sum_{j \in \Omega(i)} c^{\text{SOP}} S_{ij}^{\text{SOP}} \tag{3}$$

Where d is the discount rate and y is the SOP limited lifetime. Let N denote the number of all buses and $\Omega(i)$ be the set of all adjacent nodes of bus i. c^{SOP} denotes the investment cost of unit capacity and S_{ij}^{SOP} denotes the capacity of SOP installed between node i, j.

2) C^{OPE}: annual operation cost of SOP

$$C^{\text{OPE}} = \eta \sum_{i=1}^{N} \sum_{j \in \Omega(i)} c^{\text{SOP}} S_{ij}^{\text{SOP}} \tag{4}$$

Where η is the coefficient of annual operation cost.

3) C^{LOSS}: annual cost of losses in distribution system