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Optimal allocation and sizing of capacitors to minimize the transmission line loss and to improve the voltage profile

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ABSTRACT

In this paper, a modified discrete particle swarm optimization is presented to find the optimal placement and size of capacitors in a distribution system. The objective function is composed of the line loss and the capacitors investment cost. The bus voltage and the feeder current as constraints are included in the objective function by a constraint penalty factor.

To validate the proposed method, the 18-bus IEEE distribution system and the semi-urban distribution system which is connected to bus 2 of the Roy Billinton test system are used. The proposed method is applied to the problem and its robustness and accuracy are studied. The results are compared with pure DPSO, genetic algorithm, and nonlinear programming. It is illustrated in two examples that the proposed optimization method is more accurate and particularly more robust than others for the planning of capacitors.

1. Introduction

As the electrical loads are growing, the distribution system is developing to supply the customers with higher levels of demand. Growing the loads increases the lines current leading to the increase of loss. This also decreases the voltage level in the distribution network. Capacitors are used commonly to solve these difficulties. However, the investment cost is an issue which prevents their wide use. This highlights the importance of optimal allocation and sizing of the capacitors (OASC).

Given the discrete nature of the allocation and sizing problem, local minima are the main difficulty in the OASC problem. There are several publications on solving the OASC problem. These methods are categorized into two main groups: analytical-based methods [1–5] and heuristic-based methods [6–12]. The analytical methods have low computation time, but they do not deal appropriately with the local minima. For solving the local minima issue, the heuristic methods are extensively applied in the literatures [6–12].

A nonlinear programming package is employed in [1] for finding the location and size along with scheduling of capacitors to minimize the loss and to improve the voltage profile. Wu et al. in [2] employ the maximum sensitivities selection method for allocation of fixed and switched capacitors in a distorted substation voltage. Similarly in 1997, Chao et al. in [3] employ the sensitivity analysis for planning of the fixed and switched capacitors to minimize the loss and to improve the voltage profile. In [4], a two-phase approach is presented for solving the OASC problem. The capacitors size is assumed to be a continuous variable in the first phase and the optimization is performed using a conic optimization method, and then, the mixed integer programming is used to make the problem more practical by considering the discrete capacitor size. The optimization problem is formulated as a mixed-integer linear problem after a linearization in [5], and then, the mixed-integer linear programming is used for solving the problem.

The Genetic Algorithm (GA) as a heuristic-based method is studied and used in [6] for finding the optimal placement of capacitors. This optimization method along with a fast algorithm for computing the energy loss is presented in [7] for

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planning the capacitors. Masoum et al. in [8] use GA for optimal placement, replacement and sizing of the capacitors with consideration of nonlinear loads. These authors use the combination of GA and Fuzzy Logic in [9] and improve on the results obtained by GA. A hybrid method, composed of a modified differential evolution and integer programming, is proposed for solving the OASC problem in [10]. The results of this approach are compared with the hybrid differential evolution, simulated annealing, and ant system. Another heuristic method, Ant Colony Search algorithm, is used in [11] for reconfiguration and finding the placement of capacitors to reduce the line loss. Simulated Annealing (SA) as a heuristic method is employed in [12] for scheduling of the main transformer under load tap changers and the shunt capacitors in distribution systems.

In this paper, a heuristic method called the Discrete Particle Swarm Optimization (DPSO) algorithm is employed to find the optimal placement and size of capacitors to minimize the line loss and to improve the voltage profile. To deal appropriately with the local minima problem as the main issue in the OASC problem, the DPSO is modified by increasing the diversity of the optimizing variables. For this purpose, the mutation and crossover operators are applied to the optimizing variables. The results illustrate that the Modified DSPO (MDPSO) is more robust and more accurate compared with other methods for capacitor planning. The objective function is composed of the line loss and the capacitors investment cost. The bus voltage and the feeder current are constraints which should be maintained within standard levels.

In Section 2, the allocation and sizing of capacitors are formulated. The optimization algorithm and its implementation are explained in Section 3. The results and conclusions are given in Sections 4 and 5.

2. Problem formulation

The loads and capacitors are modelled as impedance, a series RL for loads and a capacitive reactance for capacitors. The objective function and the constraints are also expressed in this section.

2.1. Load and capacitor model

As mentioned before, the loads and capacitors are modelled as impedance. The impedance models used in this paper for loads and capacitors are given in (1) and (2):

$$Z_{\text{Load}_i} = R_{\text{Load}_i} + jX_{\text{Load}_i} \quad i = 1, 2, 3, \dots, NL \tag{1}$$

where NL is the number of Loads, Z_{Load_i} is the load impedance in load i, R_{Load_i} is the load resistance in load i, and X_{Load_i} is the load reactance in load i.

$$Z_{C_k} = -jX_{C_k} \quad k = 1, 2, 3, \dots, NC \tag{2}$$

where NC is the number of capacitors, Z_{C_k} is the capacitor impedance in capacitor k, and X_{C_k} is the capacitor reactance in capacitor k.

2.2. Objective function and constraints

Minimizing the total cost of capacitors as well as the distribution line loss is the main objective of the OASC problem. The bus voltage and the feeder current as constraints are included in the objective function with a penalty factor. As all of the objective function elements are simply converted into the composite equivalent cost, this problem is solved using a single-objective optimization method. The objective function is defined as follows:

$$\text{OF} = C_{\text{CAPITAL}} + \sum_{t=1}^{T} \frac{C_{O\&M} + C_{\text{LOSS}}}{(1+r)^t} + \lambda \tag{3}$$

where C_{CAPITAL} and $C_{O\&M}$ are the capital cost and the operation and maintenance cost of capacitors, C_{Loss} is the line loss cost, r is the discount rate, T is the number of years in the study timeframe, and λ is the constraint penalty factor.

The line loss can be converted into an equivalent cost as

$$C_{\text{LOSS}} = k_L . P_{\text{Loss}} \tag{4}$$

where k_L is the cost per MWh and P_{Loss} is the line loss.

The bus voltage and the feeder current should be maintained within standard levels as given in (5) and (6):

$$0.95pu \le V_{\text{bus}} \le 1.05 \tag{5}$$

$$I_f \le I_f^{\text{rated}} \tag{6}$$

where V_{bus} is the actual bus voltage, and I_f and I_f^{rated} are the actual and rated feeder current, respectively.

3. Methodology

3.1. Overview of PSO

PSO is a population-based and self-adaptive technique introduced originally by Kennedy and Eberhart in 1995 [13]. This algorithm handles a population of individuals in parallel to probe search areas of a multi-dimensional space where the