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Optimal allocation of capacitors in radial/mesh distribution systems using mixed integer nonlinear programming approach

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ABSTRACT

Capacitors in radial/mesh distribution systems are used to supply reactive power to minimize loss and to improve the voltage profile. The appropriate placement of capacitors is also important to ensure that system power losses and total investment capacitor costs are minimal. The capacitor placement problem consists of finding specific sitting and sizing to install capacitor banks in an electrical distribution system. Consequently, the losses are reduced due to the compensation of the reactive component of power flow. This paper presents a new mixed integer nonlinear programming approach for capacitor placement in radial/mesh distribution systems that determine the optimal sitting and sizing of capacitors with an objective of reduction power loss and investment capacitor costs. The proposed method is applied to 10, 34, and 85-bus radial distribution systems and CIVANLAR mesh distribution system. Various-scale application systems are used to compare the performance of the proposed method with the Fuzzy reasoning, particle swim optimization (PSO), plant growth simulation algorithm (PGSA), and Heuristic based. Numerical results show that the performance of the proposed MINLP method is better than the other methods. Also, the MINLP method is superior to some other methods in terms of solution power loss and costs.

1. Introduction

In the radial/mesh distribution system, capacitors are installed at suitable locations for the improvement of voltage profile and to diminish the active power losses in the distribution system. It is estimated that as much as 13% of total power generation is dissipated as I^2R losses in the distribution networks. Reactive currents flowing in the network account for a portion of these losses. By the installation of shunt capacitors, the losses produced by reactive currents can be reduced. This is also vital for power flow control, improving system stability, power factor correction, voltage profile management, and the reduction in active power losses. Hence it is essential to find the optimal sitting and sizing of capacitors required to maintain a nominal voltage profile and to reduce the feeder losses.

1.1. Literature review

Many approaches have been proposed to solve the capacitor placement problem. For instance, in [1], an efficient heuristic algorithm is presented in order to solve the optimal capacitor placement problem in radial distribution systems. A mixed integer non-linear programming approach for reconfiguration associated with capacitor allocation to minimize energy losses on radial electrical networks considering different load levels is presented in [2]. In [3], a new and efficient approach for capacitor placement in radial distribution systems that determine the optimal locations and size of capacitor with an objective of improving the voltage profile and reduction of power loss is presented. A methodology to allocate simultaneously capacitors and voltage regulators at distribution networks using both genetic algorithms and optimal power flow is proposed in [4]. In [5,6], a particle swarm optimization approach for finding the optimal size and location of capacitors is reported. A modified discrete particle swarm optimization strategy for finding the optimal rating and location of fixed and switched capacitors in distribution networks is proposed in [7,8]. In [9], a particle swarm optimization algorithm is presented for optimal capacitor placement and sizing in unbalanced distribution systems with harmonics consideration. A dedicated genetic algorithm for optimal capacitor placement and reconfiguration in distribution systems is presented in [10]. In [11], a pseudo-polynomial algorithm for optimal capacitor placement on electric power distribution networks is proposed. A genetic algorithm for simultaneous power quality improvement, optimal placement and sizing of fixed capacitor banks in radial distribution networks with nonlinear loads and distributed generation imposing voltage–current harmonics is

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Nomenclature

Indices

n, m	index of buses

Constants

N	number of buses
$Q_{C\max}$	maximum capacity of capacitor (kvar)
K_p	annual cost per unit of the real power loss ($/kW/year)
K_C	annual cost per unit of the reactive power injection ($/kvar/year)
$Q_{Load,n}$	reactive load power in bus n (kvar)
$P_{Load,n}$	active load power in bus n (kW)

Variables

TC	total cost ($)
P_{Loss}	total real power loss (kW)
Q_{Cn}	reactive power injection at bus n (kvar)
U_{Cn}	binary variable, which is equal to 1, if the capacitor is selected at bus n; otherwise, it is 0

proposed in [12]. In [13], bacterial foraging oriented by particle swarm optimization algorithm is proposed for fuzzy optimal placement of capacitors in the presence of nonlinear loads in unbalanced distribution networks. Fuzzy-DE and Fuzzy-MAPSO methods are presented for capacitor placement in radial distribution feeders in order to reduce the real power loss, to improve the voltage profile and to achieve economical saving in [14]. In [15], parallel dual tabu search for capacitor placement in smart grids is proposed. A method comprising of heuristic search technique and simulated annealing has been proposed for solving the problem of optimal capacitor placement in radial distribution system and the effects of network and load unbalances, supply harmonics and non-linear load have been studied in [16]. In [17], the problem of optimally placing fixed and switched type capacitors in a radial distribution network is considered. A computationally efficient methodology for the optimal location and sizing of static and switched shunt capacitors in radial distribution systems is proposed in [18]. In [19], some fast, GA-based methods are compared and applied for solving the problem of optimal sizing and sitting of capacitors in unbalanced multi-converter distribution systems. A fuzzy decision making which using a new evolutionary method for the optimal location and sizing of shunt capacitors in radial distribution systems is proposed in [20]. In [21], a new single-objective probabilistic approach based on the use of a micro-genetic algorithm is proposed for the optimal location and sizing of shunt capacitors in radial distribution systems. An efficient approach for capacitor allocation in radial distribution systems that determine the optimal locations and sizes of capacitors with an objective of reduction of power loss and improving the voltage profile is presented in [22].

In [23], a methodology is presented using two parts. Sensitivity analysis to select proper location for capacitor placement and in the second part plant growth simulation algorithm for optimization size of capacitors is used. The presented method is based on separation the sitting and sizing, so the optimal placement aren't acquired. In [24,25], a Fuzzy reasoning and particle swarm optimization are presented to optimal capacitor placement in radial distribution system but, the size of capacitors aren't standard range. In other words the size of capacitors is considered continuous.

The advantages of this paper are listed bellow:

- The proposed technique can potentially handle meshed networks.
- The proposed formulation is more simplified for understanding and simulation.
- The problem of capacitor placement considering losses is a nonlinear and includes integer and binary variables beside continuous variables so the type of it is MINLP. The proposed solver must be capable to solve MINLP not its approximation.
- The sizes of capacitors are considered to be discrete and standard range.
- The proposed solver is capable to find highly accurate optimal solution (with a gap < 0.01) within a reasonable computing time.

The disadvantage of this paper respect to other methods such as [26] is:

- The proposed method does not consider the switchable capacitors and a planning horizon consisting of multiple periods.

This paper, extending the problem formulation of previous researches on capacitor optimization presents a mixed integer nonlinear programming approach for capacitor placement in radial/mesh distribution systems that determine the optimal numbering, sitting and sizing of capacitors. Various-scale application systems are used to compare the performance of the proposed method with the Fuzzy reasoning, particle swim optimization (PSO), plant growth simulation algorithm (PGSA), and Heuristic based. Numerical results show that the performance of the proposed MINLP method is better than the other methods. Also, the MINLP method is superior to some other methods in terms of solution power loss and costs.

1.2. Procedure

Most previous MINLP techniques were limited to acyclic systems and radial distribution system. This paper formulate the optimal capacitor placement model for radial/mesh distribution system as a mixed integer nonlinear programming (MINLP), and solve them using Generalized Algebraic Modeling Systems (GAMS) software package with SBB and MINLP solvers. The proposed method is applied to 10, 34, and 85-bus as large scale radial distribution systems and CIVANLAR mesh distribution system.

1.3. Contributions of proposed method

This paper proposes a novel method based on mixed integer nonlinear programming approach which the method is capable of dealing with radial/meshed distribution networks, which is a point worth mentioning in this paper, as most previous MINLP techniques were limited to radial systems. The proposed method is applied to 10, 34, and 85-bus radial distribution systems and CIVANLAR mesh distribution system. Various-scale application systems are used to compare the performance of the proposed method with the Fuzzy reasoning, particle swim optimization (PSO), and Heuristic based. Numerical results show that the performance of the proposed MINLP method is better than the other methods. Also, the MINLP method is superior to some other methods in terms of solution power loss and costs.

1.4. Paper organization

The remainder of the paper is organized as follows. Section 2 is devoted to problem formulation and simulation method capacitor placement as a mixed integer nonlinear programming formulation. For test result, four numerical examples are used to illustrate the proposed method to compare the other methods (Section 3). Section 4 concludes the paper.