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Capacitor placement of distribution systems using particle swarm optimization approaches

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ABSTRACT

Capacitor placement plays an important role in distribution system planning and operation. In distribution systems of electrical energy, banks of capacitors are widely installed to compensate the reactive power, reduce the energy loss in system, voltage profile improvement, and feeder capacity release. The capacitor placement problem is a combinatorial optimization problem having an objective function composed of power losses and capacitor installation costs subject to bus voltage constraints. Recently, many approaches have been proposed to solve the capacitor placement problem as a mixed integer programming problem. This paper presents a new capacitor placement method which employs particle swarm optimization (PSO) approaches with operators based on Gaussian and Cauchy probability distribution functions and also in chaotic sequences for a given load pattern of distribution systems. The proposed approaches are demonstrated by two examples of application. Simulation results show that the proposed method can achieve an optimal solution as the exhaustive search can but with much less computational time.

Introduction

The problem of capacitors placement in distribution systems of electrical energy involves the determination of the number, location, type and size of the capacitors to be placed on the distribution feeders such that the total cost of installation and operation of the system is minimum with respect to the load on the system. This problem is combinatorial in nature and the application of discrete capacitors will be considered to solve it in this paper. That is, there are a total of $(L+1)^J$ possible solutions, where J is the bus number and L is the number of available capacitor sizes. It is worth mentioning that $(L+1)^J$ possibilities will become a large number to evaluate exhaustively even for a medium-size distribution system.

In this context, considerable efforts have been devoted to solve the capacitor placement problem. A variety of solution approaches based on mathematical programming techniques and gradient-based algorithms [1–5] have been developed to solve the capacitor placement problem over the years. In contrast to these analytical optimization techniques, meta-heuristics of natural computing field have been recently proposed in literature [6–11].

The purpose of developing such meta-heuristics is to decrease the exhaustive search space, while providing as the final result (objective function) an optimal or near-optimal value. Moreover, classical gradient-based algorithms have disadvantages, such as (i) requirement of continuous and differentiable objective functions, (ii) difficulty in escaping local minima, and (iii) difficulty to handle discrete control variables.

To overcome these disadvantages, flexible meta-heuristics, such as particle swarm optimization (PSO) approaches, have been studied. The PSO algorithm is a stochastic algorithm. It does not need gradient information about the objective function, as the gradient-based algorithm does. PSO uses the analogy of swarming and collaboration principles and is one powerful method for solving unconstrained and constrained nonlinear global optimization of optimal capacitor placement.

The framework of PSO is simple. PSO is easy to be implemented within a personal computer and is inexpensive in terms of memory requirements and computational time. Moreover, the PSO technique can generate a high quality solution within shorter calculation time and stable convergence characteristics than other stochastic methods.

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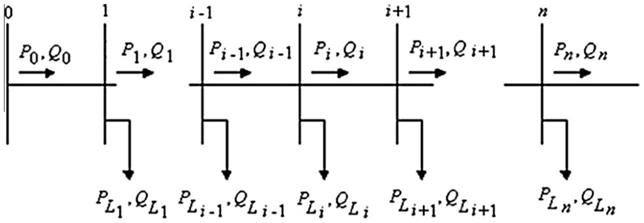

Fig. 1. Single-lime diagram of a main feeder.

This paper presents an optimal capacitor placement method that applies PSO approaches. The PSO originally developed by Kennedy and Eberhart in 1995 [12,13] is a population-based algorithm of the swarm intelligence. Similarly to genetic algorithms [14], an evolutionary algorithm approach, PSO is an optimization tool where each member is seen as a particle, and each particle is a potential solution to the problem under analysis. Each particle in PSO has a randomized velocity associated to it, which moves through the space of the problem. However, unlike genetic algorithms, PSO does not have operators such as crossover and mutation. PSO does not implement the survival of the fittest individuals; rather, it implements the simulation of social behavior. PSO approaches have been utilized in optimization problems in power systems area, such as power flow [15], loss power minimization [16], reactive power dispatch [17], economic dispatch [18–20], stabilizers tuning [21], expansion planning [22], unit commitment problem [23], reactive power and voltage control [24], and so on. A survey of the PSO applications in electrical power systems is presented in [25].

In PSO, a uniform probability distribution to generate random numbers is used. However, the use of other probability distributions may improve the ability to fine-tune or even to escape from local optima. In the meantime, the use of the Gaussian and Cauchy probability distributions has been proposed to generate random numbers to update the velocity equation [26,27] inspired by studies of mutation operators in fast evolutionary programming [28,29]. All these approaches attempted to improve the performance of the standard PSO, but the amount of parameters of the algorithm to tune remained the same.

This paper employs the Gaussian and the Cauchy probability distributions and also chaotic sequences in PSO approaches to search the size and location of capacitors to be installed on a radial distribution feeder. In other words, the main contribution of the paper can be summarized as using different distribution to generate random numbers required by the PSO. During each iterative procedure referred to as a generation, a new set of particles is produced using rules of evolution with improved performance. The fitness value for each particle of PSO is composed of the total power losses and the cost of capacitors added for that corresponding configuration. To demonstrate the effectiveness, the proposed approach is applied to two application example systems.

The remaining sections of this paper are organized as follows. Section 'Problem description and formulations' describes the problem and its formulations. Section 'Particle swarm optimization' then describes the Gaussian, Cauchy and chaotic sequences for PSO approaches adopted here, while Sections 'Computational procedures and The application examples' discuss the computational procedures and analyze the results applied to two examples, respectively. Lastly, Section 'Conclusions and future research' presents our conclusions and future research work.

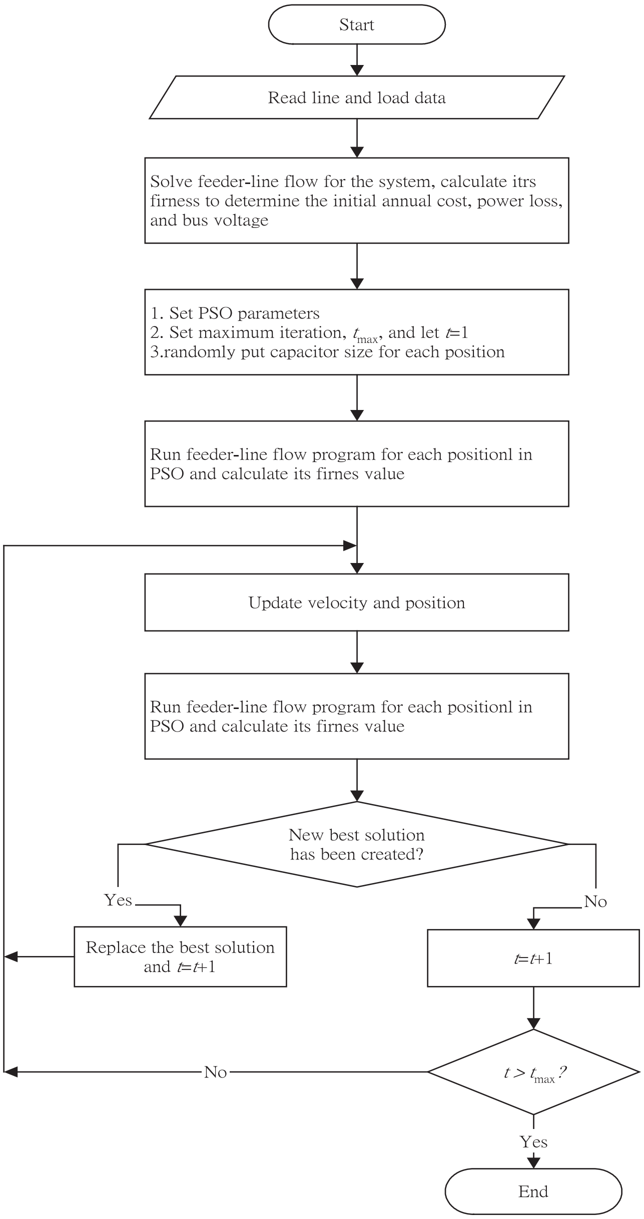

Fig. 2. Main calculation procedures of the proposed method.

Problem description and formulations

This work discusses the capacitor placement problem of distribution systems. The objective is to minimize the annual cost of the system, subject to operating constraints under a certain load pattern. Mathematically, the objective function of the problem can be described as min F = min ($COST$), where $COST$ includes the cost of power loss and capacitor placement, and will be further discussed later. The voltage magnitude at each bus must be maintained within its limits expressed as follows

$$V_{\min} \leqslant |V_i| \leqslant V_{\max} \tag{1}$$

where $|V_i|$ is voltage magnitude of bus i, $V_{\min}$ and $V_{\max}$ are bus minimum and maximum voltage limits, respectively.

A set of feeder-line flow formulations to avoid the complex iteration process for power flow analysis is applied. Considering the single-line diagram depicted in Fig. 1, the following set of recursive equations is used for power flow computation [7–9,11]:

$$P_{i+1} = P_i - P_{Li+1} - R_{i,i+1}[(P_i^2 + Q_i^2)/|V_i|^2] \tag{2}$$

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{i,i+1}[(P_i^2 + Q_i^2)/|V_i|^2] \tag{3}$$

$$|V_{i+1}|^2 = |V_i|^2 - 2(R_{i,i+1}P_i + X_{i,i+1}Q_i) + (R_{i,i+1}^2 + X_{i,i+1}^2)\frac{(P_i^2 + Q_i^2)}{|V_i|^2} \tag{4}$$