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Full Length Article

Optimal sizing and locations of capacitors in radial distribution systems via flower pollination optimization algorithm and power loss index

A.Y. Abdelaziz [a], E.S. Ali [b,*], S.M. Abd Elazim [b]

[a] Electric Power and Machine Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt
[b] Electric Power and Machine Department, Faculty of Engineering, Zagazig University, Zagazig, Egypt

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ABSTRACT

In this paper, a new and powerful algorithm called Flower Pollination Algorithm (FPA) is proposed for optimal allocations and sizing of capacitors in various distribution systems. First the most candidate buses for installing capacitors are suggested using Power Loss Index (PLI). Then the proposed FPA is employed to deduce the size of capacitors and their locations from the elected buses. The objective function is designed to reduce the total cost and consequently to increase the net saving per year. The proposed algorithm is tested on 15, 69 and 118-bus radial distribution systems. The obtained results via the proposed algorithm are compared with other algorithms like Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Plant Growth Simulation Algorithm (PGSA), Direct Search Algorithm (DSA), Teaching Learning-Based Optimization (TLBO), Cuckoo Search Algorithm (CSA), Artificial Bee Colony (ABC) and Harmony Search Algorithm (HSA) to highlight the benefits of the proposed algorithm. Moreover, the results are introduced to verify the effectiveness of the suggested algorithm to minimize the losses and total cost and to enhance the voltage profile and net saving for various distribution systems.

1. Introduction

At the distribution level, about 13% of the generated power is lost as ohmic losses [1,2]. These losses can be diminished by installing shunt capacitors at appropriate positions. Moreover, the voltage profile, power factor and power system stability are improved. Thus, the optimal sizing and locations of these capacitors have a vital and irreplaceable role in distribution systems.

During last years, several algorithms and techniques are introduced to find the proper locations and optimal sizes of shunt capacitors. Nonlinear Programming [2], Simulated Annealing (SA) [3], Tabu Search (TS) [4], Genetic Algorithm (GA) [5], Particle Swarm Optimization (PSO) [6,7], Direct Search Algorithm (DSA) [8], Teaching Learning Based Optimization (TLBO) [9], Plant Growth Simulation Algorithm (PGSA) [1], Heuristic Algorithm [10], Cuckoo Search Algorithm (CSA) [11–13], Artificial Bee Colony(ABC) [14–16], Ant Colony Search Algorithm (ACO) [17,18], Bacteria Foraging (BF) [19], Firefly Algorithm (FA) [20], Harmony Search (HS) [21,22] and big bang-big crunch optimization [23] are developed to deal with the capacitor placement problem. However, these algorithms may fail to reach the optimal cost. In order to overcome these drawbacks, the Flower Pollination Algorithm (FPA) is proposed in this paper to solve the problem of optimal capacitor placement. It has only one key parameter p (switch probability) which makes the algorithm easier to implement and faster to reach optimum solution.

FPA is proposed in this paper as a new optimization algorithm to diminish the total active power losses, the total cost and to reinforce the voltage profiles for different distribution systems. The locations of the shunt capacitors problem are obtained at first by examining the buses of higher Power Loss Index (PLI). Then FPA is introduced to decide the optimal locations and sizing of capacitors from specified buses. The effectiveness of the proposed algorithm in enhancing the voltage profile and reducing ohmic losses is shown for three distribution systems with different scales and topologies. The results of the FPA are compared with various algorithms to confirm its notability.

Abbreviations: FPA, Flower Pollination Algorithm; PLI, Power Loss Index; GA, Genetic Algorithm; PSO, Particle Swarm Optimization; PGSA, Plant Growth Simulation Algorithm; DSA, Direct Search Algorithm; TLBO, Teaching Learning-Based Optimization; CSA, Cuckoo Search Algorithm; ABC, Artificial Bee Colony; HSA, Harmony Search Algorithm; SA, Simulated Annealing; TS, Tabu Search; ACO, Ant Colony Search Algorithm; BF, Bacteria Foraging; FA, Firefly Algorithm; HS, Harmony Search; DE, Differential Evolution.

* Corresponding author. Tel.: (002) 0111-2669781, fax: (002) 055-2321407.
E-mail address: ehabsalimalisalama@yahoo.com (E.S. Ali).

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2. Overview of flower pollination algorithm

FPA was introduced in 2012 by Yang [24]. It was inspired by the pollination task of flowering plants. The main objective of a flower is basically reproduction using pollination. Flower pollination is correlating with the transfer of pollen, which is often associated with pollinators like birds and insects. Pollination appears in two main types: abiotic and biotic. Most flowering plants rely on the biotic pollination task, in which the pollen is transmitted by pollinators. The rest of pollination follows abiotic form that does not demand any pollinators like grass [25,26]. Wind and diffusion support in the pollination task of such flowering plants. On the other hand, pollination can be executed by self-pollination or cross-pollination. Self-pollination is the pollination of one flower from the pollen of the same flower or other flowers of the same plant. Cross-pollination is the pollination from the pollen of a flower of other plants.

The purpose of the FPA is the survival of the fittest and the optimal reproduction of plants in terms of numbers as well as the fittest [27]. This can be treated as an optimization task of plant species. All of these factors and tasks of flower pollination generated optimal reproduction of the flowering plants. Also, FPA proves its capability to solve various problems in power system [28–30]. Thus, it has been adopted in this paper to solve the problem of optimal sizing and locations of capacitors in distribution systems.

2.1. Flower pollination algorithm

For FPA, the following four steps are used:

Step 1: Global pollination represented in biotic and cross-pollination tasks, as pollen-carrying pollinators fly following Lévy flight [26].
Step 2: Local pollination appeared in abiotic and self-pollination as the task does not request any pollinators.
Step 3: Flower constancy which can be introduced by insects, which is on par with a reproduction probability that is proportional to the similarity of two flowers involved.
Step 4: A switch probability $p \in [0, 1]$ is used to control the interaction of local and global pollination.

The above steps have to be converted into proper updating equations. For example at the global pollination step, the pollinators load the flower pollen gametes, so the pollen can leave over a long distance. Therefore, global pollination step and flower constancy step can be stated by:

$$x_i^{t+1} = x_i^t + \gamma L(\lambda)(g_* - x_i^t) \tag{1}$$

In fact, $L(\lambda)$ the Lévy flights based step size that corresponds to the intensity of the pollination. Since long distances can be wrapped via many distance steps, a Lévy flight can be employed to imitate this behavior strongly. That is, $L > 0$ from a Lévy distribution.

$$L \sim \frac{\lambda \Gamma(\lambda) \sin(\pi\lambda/2)}{\pi} \frac{1}{s^{1+\lambda}} \quad (s \gg s_0 > 0) \tag{2}$$

$\Gamma(\lambda)$ is the criterion gamma function, and this distribution is proper for large steps $s > 0$.

For the local pollination, both Step 2 and Step 3 can be symbolized as

$$x_i^{t+1} = x_i^t + \varepsilon(x_j^t - x_k^t) \tag{3}$$

where x_j^t and x_k^t are pollen from several flowers of the same plant species simulating the flower constancy in a limited neighborhood.

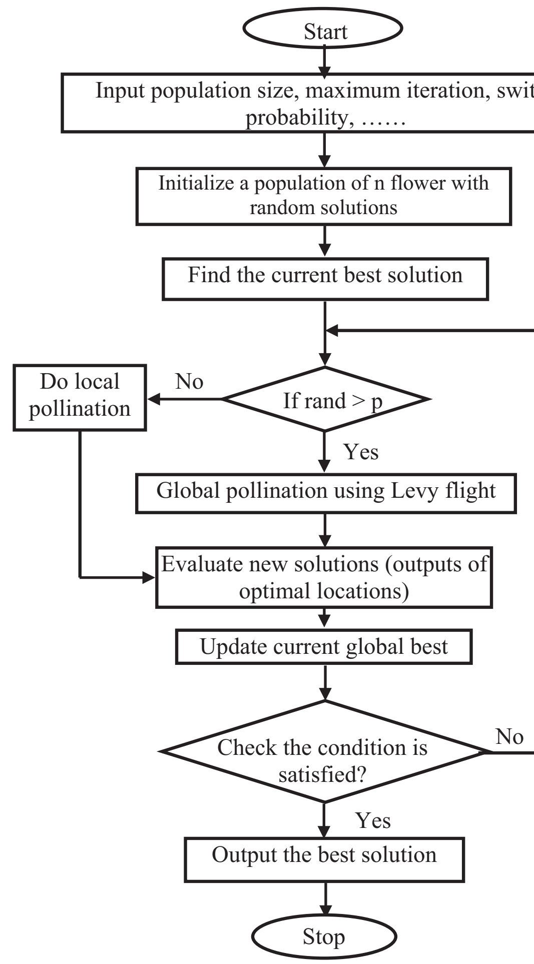

Fig. 1. Flow chart of FPA.

For a local random walk, x_j^t and x_k^t hail from the same species then ε is pulled from a uniform distribution as [0, 1].

In principle, flower pollination actions can take place at all levels, both local and global. In fact neighboring flower positions are pollinated by local flower pollen than those far away. In order to imitate this, one can utilize a switch probability p effectively to convert between general global pollination to intense local pollination. Initially, one can employ a value of $p = 0.5$. The flow chart of FPA is given in Fig. 1.

3. Problem formulation

3.1. Power loss index

In this paper, PLI is used to appoint the candidate buses for capacitors. The area of search is greatly reduced and consequently the time consumed in the optimization process. The disadvantage of this index is the necessary computations. It is required to perform load flow and determine the reduction in active power losses by injection reactive power at each bus except the swing one [13]. The PLI is calculated by the following expression.

$$\text{PLI}(\mathrm{i}) = \frac{lr(i) - lr_{\min}}{lr_{\max} - lr_{\min}} \tag{4}$$

The buses of larger PLI will have the priority to be the candidate bus for installing compensator devices.