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Flower Pollination Algorithm and Loss Sensitivity Factors for optimal sizing and placement of capacitors in radial distribution systems

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ABSTRACT

In this paper, 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 Loss Sensitivity Factors (LSF). Then the proposed FPA is employed to deduce the locations of capacitors and their sizing from the elected buses. The proposed algorithm is tested on 10, 33 and 69 bus radial distribution systems. The obtained results via the proposed algorithm are compared with others to highlight the benefits of the proposed algorithm in reducing total cost and maximizing the net saving. Moreover, the results are introduced to verify the effectiveness of the proposed algorithm to enhance the voltage profiles for various distribution systems.

Introduction

In distribution networks, reactive power flows cause high power losses, high voltage drop and low power factor. These effects can be reduced by optimally installing of shunt capacitors [1]. Compensation of reactive power presents the basic role in power system planning to provide compatible locations of the compensation apparatus to guarantee the minimum cost of compensation with suitable voltage profiles [2].

Many techniques and optimization algorithms have been addressed in literature to deal with the problem of locations and sizing of capacitors in distribution systems. Genetic Algorithm (GA) [2], Particle Swarm Optimization (PSO) [3,4], Firefly Algorithm (FA) [5], Memetic Algorithm [6], Differential Evolutionary (DE) [7–9], Evolutionary Algorithm (EA) [10,11], Fuzzy Logic [12–15], Hybrid Algorithm [16], Heuristic Algorithm [17–19], Cuckoo Search Algorithm [20], Plant Growth Simulation Algorithm (PGSA) [21–23], Harmony Search (HS) [24], Ant Colony Optimization (ACO) [25], Mixed Integer Non Linear Programming (MINLP) [26], Artificial Bee Colony (ABC) [27], Teaching Learning Based Optimization (TLBO) [28] and Direct Search Algorithm (DSA) [29] are introduced as a solution to capacitor placement problem. However, these algorithms appear to be effective to deal with this problem, they may not guarantee reaching the optimal cost due to many reasons. In [4,5,10,20–22,24], the values of capacitors are treated as a continuous value. Moreover, the suggested objective function in [6,7,23,29] is so conventional and doesn't take all costs in consideration. The studies in [3,4,6,9,13,16,17,19,22–24,26] are limited to small scale system. Also, some use large number of buses to compensate [2,11,24]. On the other hand, the mentioned techniques have their own defects and have many parameters to assign that lead to large processing time [8,12–15,27]. Recently, the Flower Pollination Algorithm (FPA) is proposed in this paper to deal with 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. Moreover, this transferring switch between local and global pollination can guarantee escaping from local minimum solution. In addition, it is clear from the literature survey that the application of FPA to solve the problem of capacitor location has not been discussed. This encourages us to adopt FPA to deal with this problem.

FPA technique is introduced in this paper in order to minimize the investment cost of new compensation sources and the active power losses with mitigating the voltage profiles for different distribution systems. The locations of the shunt capacitors problem are obtained at first by examinations the buses of higher LSF. Then FPA is introduced to decide the optimal locations and sizing of capacitors from specified buses. The effectiveness of the proposed

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Nomenclature

P_k, Q_k	the total effective active and reactive power supplied behind the bus 'k'
V_k	the magnitude of voltage at bus k
R_{ik}, X_{ik}	the resistance and reactance of transmission line between bus 'i' and 'k'
V_i	the magnitude of voltage at bus i
x_l^t	the pollen l
g_*	the current best solution found at the current generation
γ	scaling factor
$\Gamma(\lambda)$	the standard gamma function
p	switch probability
K_P	the cost per kW h
P_{Loss}	the total power losses after compensation
T	the time in hours
CB	the number of compensated buses
K_C	the cost per kVAr
K_I	the cost per installation
Q_{Ci}	the value of installed reactive power in kVAr
P_{Swing}	the active power of swing bus
Q_{Swing}	the reactive power of swing bus
L	the number of transmission line in a distribution system
$Pd(q)$	the demand of active power at bus q
$Qd(q)$	the demand of reactive power at bus q
N	the number of total buses
$V_{\min}$	the minimum voltage at bus i
$V_{\max}$	the maximum voltage at bus i
PF	Power Factor
$PF_{\min}$	the minimum power factor
$PF_{\max}$	the maximum power factor
PF_{sys}	the power factor at swing bus
$Q_{C\min}$	the minimum injected reactive power in kVAr
$Q_{C\max}$	the maximum injected reactive power in kVAr

List of abbreviations

FPA	Flower Pollination Algorithm
LSF	Loss Sensitivity Factors
SA	Simulated Annealing
TS	Tabu Search
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
ACO	Ant Colony Optimization
FA	Firefly Algorithm
MINLP	Mixed Integer Nonlinear Programming
HS	Harmony Search
DE–PS	Differential Evolution and Pattern Search
GSA	Gravitational Search Algorithm
IP	Interior Point

FPA is shown for three distribution systems. The results of the FPA are compared with various techniques to detect its superiority.

Loss Sensitivity Factors

Loss Sensitivity Factors (LSF) are employed in this paper to assign the candidate buses for capacitors installation [4]. The area of search is greatly reduced and consequently the time consumed in optimization process by using LSF. For a transmission line 'l' connected between 'i' and 'k' buses, as given in Fig. 1.

The active power loss in this line is specified by $I_l^2 R_{ik}$, which can be given by:

$$P_{ik\text{-}loss} = \frac{\left(P_k^2 + Q_k^2\right) R_{ik}}{(V_k)^2} \tag{1}$$

Also, the reactive power loss in this line is obtained below:

$$Q_{ik\text{-}loss} = \frac{\left(P_k^2 + Q_k^2\right) X_{ik}}{(V_k)^2} \tag{2}$$

The LSF can be computed from the following equations:

$$\frac{\partial P_{ik\text{-}loss}}{\partial Q_k} = \frac{2Q_k * R_{ik}}{(V_k)^2} \tag{3}$$

$$\frac{\partial Q_{ik\text{-}loss}}{\partial Q_k} = \frac{2Q_k * X_{ik}}{(V_k)^2} \tag{4}$$

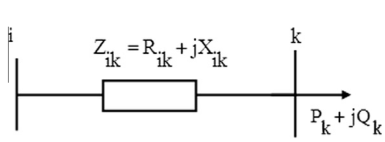

Fig. 1. Radial distribution system equivalent circuit.

These values are given from the base case load flow and are ordered in descending order for all transmission lines. Then, normalized voltages are obtained by dividing the base case voltages by 0.95. If the values of these voltages are less than 1.01 they can be considered as candidate buses for compensation devices [5].

Overview of Flower Pollination Algorithm

FPA was developed by Xin-She Yang in 2012 [30]. It is inspired by the pollination process of flowering plants. The main purpose of a flower is ultimately reproduction via pollination. Flower

Objective min or max $f(x), x = (x_1, x_2, \ldots\ldots\ldots, x_d)$
Initialize a population of n flowers/pollen gametes with random solutions
Find the best solution g_* in the initial population
Define a switch probability $p \in [0, 1]$
for $t = 1$: MaxGeneration (for all generations)
  While $(l < n)$ (n no. of flowers in the population)
If rand $< p$,
  Draw a (d-dimensional) step vector L from Lévy distribution
  Global pollination via $x_l^{t+1} = x_l^t + \gamma L(\lambda)(g_* - x_l^t)$
else
  Draw from a uniform distribution in [0, 1]
  Do local pollination via $x_l^{t+1} = x_l^t + \varepsilon(x_n^t - x_p^t)$
end if
  Evaluate new solutions
  If new solutions are better, update them in the population
end while
  Find the current best solution g_*
end for
Output the best solution found.

Fig. 2. Pseudo code of the proposed FPA.