IJBPAS, June, 2015, 4(6): 3269-3277

ISSN: 2277–4998

International Journal of Biology, Pharmacy and Allied Sciences (IJBPAS)

'A Bridge Between Laboratory and Reader'

www.ijbpas.com

OPTIMAL CAPACITOR PLACEMENT IN RADIAL DISTRIBUTION SYSTEMSUSING SHUFFLED FROG-LEAPING ALGORITHM (SFLA)

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ABSTRACT

This paper presents a new method which applies an shuffled frog-leaping algorithm (SFLA) for capacitor placement in distribution systems with an objective of improving the voltage profile and reduction of power loss. The solution methodology has two parts: in part one the loss sensitivity factors are used to select the candidate locations for the capacitor placement and in part two a new algorithm called shuffled frog-leaping algorithm (SFLA) is used to estimate the optimal size of capacitors at the optimal buses determined in part one. The other advantage is that the global searchability in the algorithm is implemented by introducing neighborhood source production mechanism which is a similar to mutation process. To demonstrate the validity of the proposed algorithm, computer simulations are carried out on 69-bus system and compared the results with the other approach available in the literature. The proposed method has outperformed the other methods in terms of the quality of solution and computational efficiency.

Keywords: Distribution systems, Loss Sensitivity Factors, Capacitor placement, shuffled frog-leaping algorithm

INTRODUCTION

The loss minimization in distribution systems has assumed greater significance recently since the trend towards distribution automation will require the most efficient operating scenario for economic viability variations. The power losses in distribution systems correspond to about 70% of total losses in electric power systems (2005). To reduce these losses, shunt capacitor banks are installed on distribution primary feeders. The advantages with the addition of shunt capacitors banks are to improve the power factor, feeder voltage profile, Power loss reduction and increases available capacity of feeders. Therefore it is important to find optimal location and sizes of capacitors in the system to achieve the above mentioned objectives.

Since, the optimal capacitor placement is a complicated combinatorial optimization problem, many different optimization techniques and algorithms have been proposed in the past. H. Ng *et al* (2000) proposed the capacitor placement problem by using fuzzy approximate reasoning. Sundharajan and Pahwa (1994) proposed the genetic algorithm approach to determine the optimal placement of capacitors based on the mechanism of natural selection. Ji-Pyng Chiou *et al* (2006) proposed the variable scale hybrid differential evolution algorithm for the capacitor placement in distribution system. Both Grainger et al (1981) and Baghzouz and Ertem (1990) proposed the concept that the size of capacitor banks was considered as a continuous variable. Bala *et al* (1995) presented a sensitivity-based method to solve the optimal capacitor placement problem.

In this paper, a new algorithm called shuffled frog-leaping algorithm (SFLA)is proposed to place the capacitors at candidate locations with an objective of reducing the power losses in the distribution system. The shuffled frog-leaping algorithm (SFLA) is a new meta heuristic approach, proposed by Karaboga [9]-[11]. It is inspired by the intelligent foraging behavior of honey bee swarm. The proposed method is tested on 69 bus radial distribution systems and results obtained are effective and encouraging.

Problem Formulation

The objective of capacitor placement in the distribution system is to minimize the annual cost of the system, subjected to certain operating constraints and load pattern. For simplicity, the operation and maintenance cost of the capacitor placed in the distribution system is not taken into consideration. The three-phase system is considered as balanced and loads are assumed as time invariant. Mathematically, the objective function of the problem is described as:

$$\min f = \min(COST) \; or \; \min f = \min(P_{loss})$$

where COST is the objective function which includes the cost of power loss and the capacitor placement. The voltage magnitude at each bus must be maintained within its limits and is expressed as:

$$V_{min} \le |V_i| \le V_{max}$$

Where │Vi│ is the voltage magnitude of bus i, Vmin and Vmax are bus minimum and maximum voltage limits, respectively. The power flows are computed by the following set of simplified recursive equations derived from the single-line diagram depicted in **Figure 1**.

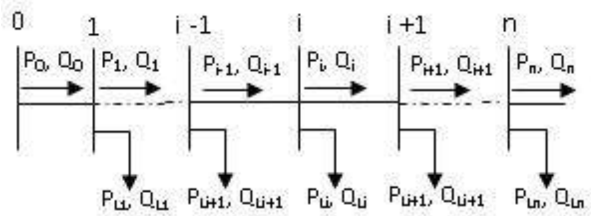

Figure 1: Single line diagram of main feeder

$$P_{i+1} = P_i - P_{Li+1} - R_{ij+1}\frac{P_i^2 + Q_i^2}{|V_i|^2}$$

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{ij+1}\frac{P_i^2 + Q_i^2}{|V_i|^2}$$

$$|V_i|^2 = |V_i|^2 - 2\left(R_{ij+1}P_i + X_{ij+}Q_i\right) + \left(R_{ij+1}^2 + X_{ij+1}^2\right)\frac{P_i^2 + Q_i^2}{|V_i|^2}$$

where Pi and Qi are the real and reactive powers flowing out of bus i, and PLi and QLi are the real and reactive load powers at bus i. The resistance and reactance of the line section between buses i and i+1 are denoted by Ri,i+1 and Xi,i+1 respectively. The power loss of the line section connecting buses i and i+1 may be computed as

$$P_{Loss}(i, i+1) = R_{ij+1}\frac{P_i^2 + Q_i^2}{|V_i|^2}$$

The total power loss of the feeder, PT, Loss, may then be determined by summing up the losses of all line sections of the feeder, which is given as

$$P_{F,Loss} = \sum_{i=0}^{N-1} P_{LOSS}(i, i+1)$$

Considering the practical capacitors, there exists a finite number of standard sizes which are integer multiples of the smallest size Q0c. Besides, the cost per kVAr varies from one size to another. In general, capacitors of larger size have lower unit prices. The available capacitor size is usually limited to

$$Q_{max}^C = LQ_0^C$$

where L is an integer. Therefore, for each installation location, there are L capacitor sizes ,Q0, 2 Q0 …L Q0L available. Given the annual installation cost for each compensated bus, the total cost due to capacitor placement and power loss change is written as

$$COST = K_p P_{T,Loss} \sum_i^c \left(K_{cf} + K_i^c Q_i^c\right)$$

where n is number of candidate locations for capacitor placement, Kp is the equivalent annual cost perunit of power loss in $/(kW-year); Kcf is the fixed cost for the capacitor placement. he constant K_c^I is the annual capacitor installation cost, and, i = 1, 2. . , n are the indices of the buses selected for compensation. The bus reactive compensation power is limited to

$$Q_c^i \le \sum_{i=1}^{n} Q_{Li}$$

where Qc^i and QLi are the reactive power compensated at bus i and the reactive load power at bus i, respectively.

Sensitivity Analysis and Loss Sensitivity Factors

The candidate nodes for the placement of capacitors are determined using the loss sensitivity factors. The estimation of these candidate nodes basically helps in reduction of the search space for the optimization procedure.

Consider a distribution line with an impedance R+jX and a load of Peff + jQeff connected between 'p' and 'q'buses as given above in fig.2.Active power loss in the kth line is given by, I_k^2* R[k] which can be expressed as,

$$P_{line\ loss}[q] = \frac{\left(P_{eff}^2[q] + Q_{eff}^2[q]\right) R[K]}{(V[q])^2}$$

Similarly the reactive power loss in the kth line is given by

$$Q_{lineloss}[q] = \frac{\left(P_{eff}^2[q] + Q_{eff}^2[q]\right) X[K]}{(V[q])^2}$$

Where, Peff[q] = Total effective active power supplied beyond the node 'q'.Qeff[q] = Total effective reactive power supplied beyond the node 'q'.

$$\frac{\partial P_{lineloss}}{\partial Q_{eff}} = \frac{(2 * Q_{eff}[q] * R[k])}{(V[q])^2}$$

$$\frac{\partial Q_{lineloss}}{\partial Q_{eff}} = \frac{(2 * Q_{eff}[q] * X[k])}{(V[q])^2}$$

3.1. Candidate node selection using Loss sensitivity factors

The Loss Sensitivity Factors (∂Plineloss / ∂Qeff) are calculated from the base case load flows and the values are arranged in descending order for all the lines of the given system. A vector bus position 'bpos[i]' is usedto store the respective 'end' buses of the lines arranged in descending order of the values (∂Plineloss /∂Qeff).The descending order of elements of "bpos[i]' vector will decide the sequence in which the buses are to be considered for compensation. This sequence is purely governed by the (∂Plineloss / ∂Qeff) and hence the proposed 'Loss Sensitive Coefficient' factors become very powerful and useful in capacitor allocation or Placement. At these buses of 'bpos[i]' vector, normalized voltage magnitudes are calculated by considering the base case voltage magnitudes given by (norm[i]=V[i]/0.95). Now for the buses whose norm[i] value is less than 1.01 are considered as the candidate buses requiring the Capacitor Placement.

These candidate buses are stored in 'rank bus' vector. It is worth note that the 'Loss Sensitivity factors' decide the sequence in which buses are to be considered for compensation placement and the 'norm[i]' decides whether the buses needs Q-Compensation or not. If the voltage at a bus in the sequence list is healthy (i.e.,norm [i]>1.01) such bus needs no compensation and that bus will not be listed in the 'rank bus' vector. The'rank bus' vector offers the information about the possible potential or candidate buses for capacitor placement. The sizing of Capacitors at buses listed in the 'rank bus' vector is done by using Plant Growth Simulation Algorithm.

Shuffled frog-leaping algorithm

The shuffled frog-leaping algorithm is a memetic meta heuristic that is designed to seek a global optimal solution by performing a heuristic search. It is based on the evolutionof memes carried by individuals and a global exchange of information among the population (Eusuff and Lansey2003). In essence, it combines the benefits of the local search tool of the particle swarm optimization (Kennedy and Eberhart 1995), and the idea of mixing information from parallel local searches to move toward a global solution(Duanet al. 1993). The SFL algorithm has been tested on several combinatorial problems and found to be efficient in finding global solutions (Eusuff and Lansey 2003).

The SFL algorithm involves a population of possible solutions defined by a set of frogs (i.e. solutions) that is partitioned into subsets referred to as memeplexes. The different memeplexes are considered as different cultures of frogs, each performing a local search. Within each memeplex, the individual frogs hold ideas, that can be influenced by the ideas of other frogs, and evolve through a process of memetic evolution. After a number of memetic evolution steps, ideas are passed among memeplexes in a shuffling process (Liong and Atiquzzaman 2004). The local search and the shuffling processes continue until conver gence criteria are satisfied (Eusuff and Lansey 2003).

1. **Test Results**

The proposed method was tested on 69-bus radial distribution system and results have been obtained toevaluate its effectiveness. The algorithm of this method was programmed in MATLAB environment and run on a Pentium IV, 3-GHz personal computer with 0.99 GB RAM. The results obtained in these methods are explained in the following sections.

5.1 System 69 Bus

The single line diagram is shown in fig. 3. The base values of the system are taken as 12.66 kV and100MVA.The sensitive analysis method is used to select the candidate installation locations of the capacitor to reduce the search space. The buses are ordered according to their sensitivity values as {19, 22, 20, 21, 23, 24, 25, 26 and 27}. In this case capacitor value has been taken as a continuous variable. The capacitor allowable range is from 100 kVAr to 1000 kVAr with step of 2kVAr. Top three nodes are selected as candidate locations(i.e. nodes 19, 22 and 20) to reduce the search space and then the amount to be injected in the selected nodes is optimized by SLFA. The amount of kVAr injected are 900, 986 and 150 kVAr respectively. The power loss before and after capacitor placement are 221.67 and 168.8 kW. The minimum and maximum voltages before capacitor placement are 0.9417 p.u (bus 27) and 0.9941 p.u (bus 2) and are improved to 0.9504 pu and 0.995 p.u after capacitor placement respectively. The CPU time needed by the proposed method is 3.07 sec.

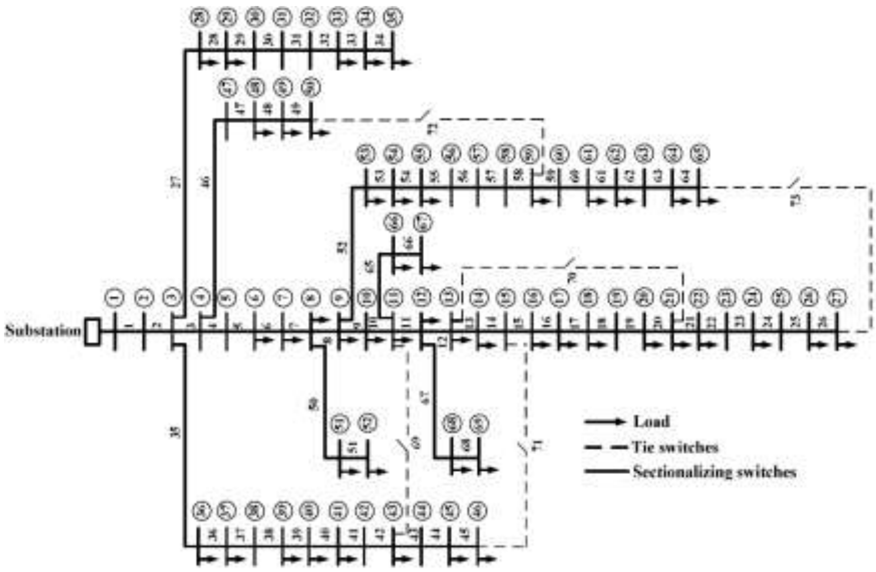

Figure 2:69 bus distribution system

Table 1: Summary of results for 69 bus system

Number	**3**	**5**	**7**
place	**2,12,16**	**2,6,7,13,15**	**2,4,9,10,14,18,20**
Presumable Capacity Range [Mvar]	**0.025 0.05 0.1 0.2 0.25 0.4 0.5**	**0.025 0.05 0.1 0.2 0.25 0.4 0.5**	**0.05 0.1 0.2 0.4 0.5 0.8 1**
LRI [%]	**0.9296**	**0.7627**	**0.9754**

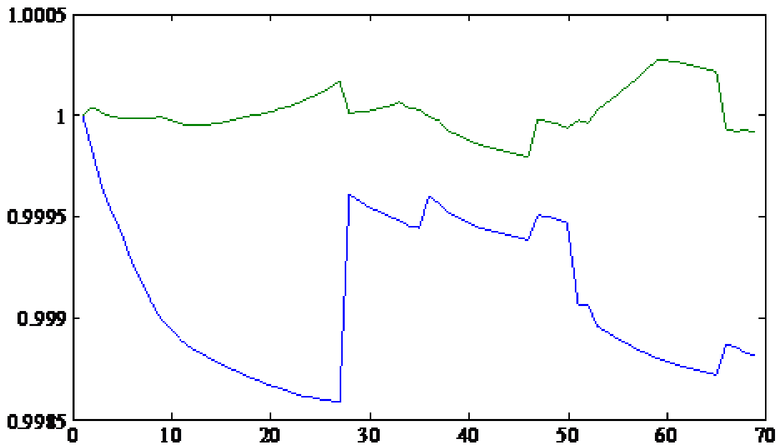

Figure 3: Voltage profile of 69 bus system before and after compensation.

CONCLUSION

In the present work, a new population based shuffled frog-leaping algorithm (SFLA) has been proposed to solve capacitor placement problem in distribution system. Simulations are carried on 69 -bus system. The results obtained by the proposed method outperform the other methods in terms of quality of the solution and computation efficiency. The main advantage of SLF Aalgorithm is that it does not require external parameters such as cross over rate and mutation rate etc, as in case of genetic algorithms, differential evolution and other evolutionary algorithms and these are hard to determine in prior. The other advantage is that the global search ability in the algorithm is implemented by introducing neighborhood source production mechanism which is a similar to mutation process.

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