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Maximum annual savings in radial distribution systems using firefly algorithm

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This paper presents a two stage approach that determines the optimal location and size of capacitors on radial distribution systems to improve voltage profile and to reduce the active power loss. In first stage, the capacitor locations can be found by using loss sensitivity method. Firefly algorithm is used for finding the optimal capacitor sizes in radial distribution systems. The sizes of the capacitors corresponding to maximum annual savings are determined by considering the cost of the capacitors. The proposed method is tested on 15-bus and 34-bus test systems and the results are presented.

Keywords: *Capacitor placement, loss sensitivity method, firefly algorithm, radial distribution system*

1.0 INTRODUCTION

Distribution system is that part of the power system which connects the high voltage transmission system to low voltage consumers. 70% of the total losses are occurring in the primary and secondary distribution system, while the remaining 30% in transmission and subtrans mission lines. Distribution losses are 15.5% of the generation capacity where as the target level is 7.5%. Therefore the primary and secondary distribution system must be properly planned to ensure losses within the tolerable limits.

Distribution systems have more losses and poor voltage regulation. Almost 13% of the generated power is wasted as $I^2 R$ losses. Loss reduction in distribution systems by applying the optimization methods is the current potential area of research. The basic requirements of a good distribution system are good voltage profile, availability of power on demand and reliability. The efficiency of the distribution system can be improved by adopting reactive power compensation, network reconfiguration, distributed generation and Hybrid methods. Each method has its own advantages and disadvantages. Capacitors are commonly used to provide the reactive power compensation in distribution systems. Shunt capacitors placement is the simple and efficient method in distribution networks to reduce losses, improve voltage profile, maximize transmitted power in cables and transformer, increase the thermal capacities of the distribution lines and transformers and improve power factor. However, shunt capacitor installation in distribution networks requires an appropriate location and size of the capacitors. Thus, optimal capacitor placement plays an important role in minimizing the losses through proper installation and sizing which can be achieved by using optimization techniques.

Dong *et al.* [1] presented a mixed integer programming model and the cost is evaluated by adopting the net present value criterion.Dinakara Prasad Reddy P *et al.* [2] proposed hybrid genetic algorithms method for loss reduction in distribution systems. X S Yang proposed a fire

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fly algorithm [3]for optimization problems. In this paper firefly algorithm is used to find the optimal capacitor size Segura *et al.* [6] presented a heuristic algorithm to solve the capacitor placement problem in distribution systems. Abdelaziz *et al.* [5, 7] introduced two methods. First method determines the locations and sizes of the capacitors and the loss reductions are calculated. Second method finds the solution for optimal placement of voltage regulators problem by determining the location and tapping ratio of the regulators keeping the voltage within the limits. Seifi *et al.*[8] presented fuzzy, dynamic programming and genetic algorithm are combined and applied as a hybrid method to solve the problem. The problem is formulated as a multi - objective non - differential problem. Pereira and Castro [9] presented a two-step algorithm. Bhattacharya and Goswami [10] proposed a new methodology using new membership functions in fuzzy and simulated annealing technique to solve the capacitor placement problem. Das [11] proposed a method which is designed as a multi objective approach using both genetic algorithm and fuzzy. Srinivasa Rao and Narasimham [12] proposed a new and efficient plant growth simulation algorithm which is used to determine the sizes of the capacitors.

Su *et al.* [16] introduced metaheuristic algorithm called ant colony search algorithm to solve the capacitor placement problem. Prakash and Sydulu [13] proposed Particle Swarm Optimization method to find the size of the capacitors to be installed. Venkatesh and Ranjan [14] proposed anew dynamic structure forane volutionary programming algorithm with fuzzy modeling to solve the capacitor placement problem. Khalil *et al.*[15] proposed binary particles warm optimization method for placing the fixed capacitor banks in the distribution systems.

2.0 CAPACITOR LOCATIONS USING LOSS SENSITIVITY METHOD

In this paper loss sensitivity method is used to find capacitor locations proposed by [2]. It is a logical process of computing the extreme effect on the real power losses of the system with respect to the nodal reactive power. The connection for calculating the loss sensitivity for any bus can be obtained as follows.

Consider a distribution line with an impedance R + jX and a load of $P_{eff} + jQ_{eff}$ connected between 'i' and 'j' buses as given below in Figure 1.

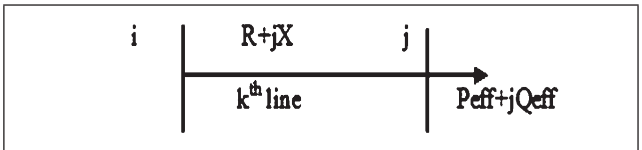

FIG. 1. A DISTRIBUTION LINE WITH AN IMPEDANCE AND A LOAD.

The active power losses (P_{loss}) and reactive power loss (Q_{loss}) in the distribution line are given as

$$PL[j] = \frac{(P^2[j] + Q^2[j]) * R_k}{(V[j])^2} \quad ...(1)$$

$$QL[j] = \frac{(P^2[j] + Q^2[j]) * X_k}{(V[j])^2} \quad ...(2)$$

Loss sensitivity SL, for any bus j can be given as

$$SL_j = \frac{(2 * Q_{eff}[j]) * R_k)}{(V[j])^2} \quad ...(3)$$

Based on SLj, the buses are ranked in descending order of its values. The bus having highest numeric value is ranked top in the priority list and is considered first for capacitor placement. The buses having high value of the loss sensitivity SL, along with voltage (V) in p. u. at each bus satisfying the condition $V/0.95>1.1$ are selected as candidate buses for capacitor placement.

Candidate location vector of 15 and 34 bus radial distribution system contains set of sequence of buses given as {6, 3} and {19, 20, 22} respectively.

3.0 FIREFLY ALGORITHM

The Fire Fly Algorithm (FFA) is a meta-heuristic nature-inspired population-based optimization algorithm, introduced in 2010 by X. S. Yang [3].

It is based on the firefly bugs behavior, including the light emission, light absorption and the mutual attraction, which was developed to solve the continuous optimization problems. The fire fly algorithm is inspired from a mating phase of the fire fly bio luminescent communication. Bioluminescent signals are known to serve as element of court ship rituals, methods of prey attraction, social orientation or as a warning signal to predators.

In comparison with the other evolutionary algorithms, FA has many major advantages in solving complex nonlinear optimization problems. Some of these advantages are simple concepts, usage of real random numbers, easy implementation, higher stability mechanism, depends on the global communication among the swarming particles and less execution efforts.

The development of firefly-inspired algorithm was based on three idealized rules:

- Artificial fireflies are unisex so that sex is not an issue for attraction.
- Attractiveness is proportional to their flashing brightness which decreases as the distance from the other firefly increases due to the fact that the air absorbs light. Since the most attractive firefly is the brightest one, to which it convinces neighbors moving toward. In case of no brighter one, it freely moves any direction.
- The brightness of the flashing light can be considered as objective function to be optimized. For maximization problems, the light intensity is proportional to the value of the objective function.

3.1 Attractiveness

Suppose it is a night with absolute darkness, where the only visible light is the light produced by fireflies. The light intensity of each firefly is proportional to the quality of the solution, it is currently located at. In order to improve own solution, the firefly needs to advance towards the fireflies that have brighter light emission than is his own. Each firefly observes decreased light intensity than the one firefly actually emit, due to the air absorption over the distance.

There are two important issues in the firefly algorithm, variation of light intensity and formulation of the attractiveness. For simplicity, we can always assume that the attractiveness of a firefly is determined by its brightness. Attractiveness of a firefly abides the law

$$\beta(r) = \beta_0 * \exp(-\gamma r_{ij}^{m}) \text{ with } m \geq 1 \quad \ldots(4)$$

Where,

r is the distance between any two fireflies,

β_0 is the initial attractiveness at r=0, and

γ *is* an absorption coefficient which controls the decrease of the light intensity.

3.2 Distance

The distance *r* between firefly *i* and *j* at positions x_i and x_j respectively and is defined as Cartesian distance:

$$r_{ij} = \|x_j - x_i\| \quad \ldots(5)$$

3.3 Movement

The movement itself consists of two elements: approaching the better local solutions and the random step. Moreover, the movement of firefly *i* which is attracted by a more attractive or brighter firefly *j* is given by i.e., brighter firefly jis given by:

$$x_i = x_i + \beta_o * \exp(-\gamma r_{ij}^2) * (x_j - x_i) + \alpha * \left(\text{rand} - \tfrac{1}{2}\right) \ldots(6)$$

Where the first term is the current position of a firefly, the second term is used for considering a firefly's attractiveness to light intensity seen by adjacent fireflies and the third term is used for the random movement of a firefly in case there are no brighter ones.

The coefficient α is a randomization parameter determined by the problem of interest, r and is a random number generator uniformly distributed in the space [0, 1].The parameter γ characterizes the variation of the attractiveness and its value is important to determine the speed of the convergence and how the FA behaves. For the most cases of implementations, $\beta_0 = 1$

3.4 Algorithm for Capacitor Placement and Sizing Using Loss Sensitivity Method and Firefly Algorithm for Maximum Annual Savings

After identifying the n number of candidate locations using loss sensitivity method, the capacitor sizes in all these n candidate locations are obtained by using the Firefly algorithm

Step 1: Initialize all the parameters and constants of Firefly Algorithm. They are cap_{min}, cap_{max}, ***noff***, ***noc***, α_{min}, α_{max}, β_0, γ and ***itermax*** (maximum number of iterations).

Step 2: Generate ***noff * noc*** number of fireflies randomly between the limits cap_{min} and cap_{max}. noff is the number of fireflies and noc is the number of capacitor units. Each row represents one possible solution to the optimal capcitor-sizing problem.

Step 3: By placing all the 'n' capacitors at each Firefly position at the respective candidate locations and load flow analysis is performed to find the fitness function. Fitness value corresponding to each Firefly is evaluated using the below equation for maximum annual savings. Fitness function for maximum savings (considering the capacitor cost) is given by

$$S = K_P . \Delta P + K_E . \Delta E - K_C . Q_C$$

Where S is the savings in \$/year, K_P is a factor to convert peak power losses to dollars, K_E is a factor to convert energy losses to dollars, K_C is the cost of capacitors in dollars, ΔP is the reduction in peak power losses, ΔE is the reduction in energy losses and Q kvar. Q_C is the size of the capacitor. The capacitor sizes corresponding to maximum savings are required. For any one Firefly, the negative S value indicates that savings are negative and S is fixed at S (minimum) and capacitor sizes corresponding to that particle are fixed at Q (minimum).

Step 4: Set the iteration count to 1.

Step 5: By placing all the noc number of capacitor units of each firefly at the respective optimal capacitor locations, and run the load flow program to find annual savings **S**.

Step 6: Obtain the best fitness value ***Gbest FV*** by comparing all the fitness values and also obtain the best firefly values ***Gbest FF*** corresponding to the best fitness value ***Gbest FV***.

Step 7: Determine alpha (***α***) value of the current iteration α***(iter)*** using the equation:

$$\alpha(iter) = \alpha_{max} - ((\alpha_{max} - \alpha_{min}) \text{ (current iteration number)} / itermax)$$

Step 8: Determine r_{ij} values of each firefly using the following equation:

$$r_{ij} = Gbest\ FV - FV$$

r_{ij} is obtained by finding the difference between the best fitness value ***Gbest FV*** (***Gbest FV*** is the best fitness value i.e., j^{th} firefly) and fitness value **FV** of the i^{th} firefly.

Step 9: New x_i values are calculated for all the fireflies using the following equation:

$$x_{i(new)} = x_{i(old)} + \beta_o * \exp(-\gamma r_{ij}^2) * (x_j - x_i) + \boldsymbol{\alpha}(\boldsymbol{iter}) * \left(\text{rand} - \frac{1}{2}\right)$$

where, β_0 is the initial attractiveness

γ is the absorption co-efficient

r_{ij} is the difference between the best fitness value ***Gbest FV*** and fitness value **FV** of the i^{th} firefly.

α (iter) is the randomization parameter varies between 20 to 0.0001 rand is the random number between 0 and 1.

X_{inew} is the cap_{new}.

Step 10: Increase the iteration count. Go to step 5, if iteration count is not reached maximum.

Step 11: ***Gbest FF*** gives the optimal capacitor sizes in 'n' optimal locations and the results are printed.

4.0 RESULTS AND DISCUSSION

The proposed method for loss reduction by capacitor place mentistes tedon IEEE 15 bus and 34 bus radial distribution systems. Losssen sitivity method is used to find the optimal capacitor locations and firefly algorithm is used to find the optimal capacitor sizes for maximum annual savings.

When the proposed method is tested on 15-bus we got annual saving of 14,012 dollars. The minimum voltage before and after compensations are 0.9445 and 0.9645 respectively.

When the proposed method is tested on 34 - bus we got annual saving of 26,182 dollars. The minimum voltage before and after compensations are 0.9417 and 0.9487 respectively.

The algorithm has been implemented in Matlab 2012. The various constants used in the proposed algorithm are cap_{min}=100 kvar, cap_{max}=1500 kvar, noff=40, α=0.5, β0=1, βmin=0.2, γ=1,K_P=150 $/kW, K_E =0.06 $/kWh, K_C= 5 $/kVArItmax =1000.

TABLE 1

Results for 15 Bus System

Bus No	**Size (kvar)**
3	693
6	334
Total kVAr placed	1027
Total Power loss in kW(before)	61.7944
Total Power loss in kW(after)	33.3302
Minimum Voltage(Before)	0.9445
Minimum Voltage(After)	0.9645
Savings in dollars	$ 14,012

TABLE 2

Results for 34 Bus System

Bus No	**Size (kvar)**
19	625
22	861
20	229
Total kVAr placed	1715
Total Power loss in kW(before)	221.7235
Total Power loss in kW(after)	170.0478
Minimum Voltage(Before)	0.9417
Minimum Voltage(After)	0.9487
Savings in dollars	$ 26,182

5.0 CONCLUSION

In this paper, a two stage methodology of finding the optimal locations and sizes of shunt capacitors for maximum annual savings of radial distribution systems are presented. Loss sensitivity method is used to find the optimal capacitor locations and Firefly algorithm is proposed to find the optimal capacitor sizes. By installing shunt capacitor satall the potential locations, the total real power loss of the system has been reduced significantly and at same time annual savings are increased and bus voltages are improved substantially. The proposed method is tested on IEEE 15 and 34 bus radial distribution systems. The proposed Firefly algorithm iteratively searches the optimal capacitor sizes for the maximum annual savings. Firefly algorithm is less complex because less parameters are there when compared to other algorithms.

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