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Capacitor Placement Using Bat Algorithm for Maximum Annual Savings in Radial Distribution systems

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ABSTRACT
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. Bat 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, 33 bus, 34-bus, 69-bus and 85-bus test systems and the results are presented.
Keywords - capacitor placement, loss sensitivity method, Bat algorithm, radial distribution system

I. 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 sub transmission lines. Distribution Losses are 15.5% of the generation capacity whereas 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^2R 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.

Su et al. (2005) introduced meta heuristic algorithm called ant colony search algorithm to solve the capacitor placement problem. Venkatesh and Ranjan. (2006) proposed a new dynamic structure for an evolutionary programming algorithm with fuzzy modeling to solve the capacitor placement problem.Khalil et al. (2006) proposed binary particle swarm optimization method for placing the fixed capacitor banks in the distribution systems. Prakash and Sydulu. (2006, 2007) proposed two methods to solve the capacitor placement problem. Particle Swarm Optimization method and α-coefficients method to find the size of the capacitors to be installed.

Das. (2008) proposed a method which is designed as a multi objective approach using both genetic algorithm and fuzzy. Damodar Reddy and Veera Reddy. (2008) presented a new methodology to solve the capacitor placement problem. Fuzzy approach is used to find the locations and real coed genetic algorithm is used to find the capacitor sizes to reduce the losses and improve the voltage profile based on the net savings. Srinivasa Rao and Narasimham. (2008) proposed a new and efficient plant growth simulation algorithm which is used to determine the sizes of the capacitors.

Sivanagaraju and Viswanatha Rao. (2009) presented a method using discrete particle swarm optimization to optimize the cost of conductors and energy savings. Seifi et al. (2009, 2009a) 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. (2009) presented a two-step algorithm. Bhattacharya and Goswami (2009) proposed a new methodology using new membership functions in fuzzy and simulated annealing technique to solve the capacitor placement problem.

Segura et al. (2010) presented a heuristic algorithm to solve the capacitor placement problem in distribution systems. Abdelaziz et al. (2010) 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.

Abbas Babazadeh et al. (2011) proposed particle swarm optimization for transportation network design problem. Paul and Jewell .(2012) presented the power loss index and sensitivity approach using fuzzy. Sizes of the capacitors are determined by genetic algorithms. Dong et al. (2013) presented a mixed integer programming model and the cost is evaluated by adopting the net present value criterion. Dinakara Prasad Reddy P et al. (2011, 2012 and 2013) proposed two methods for loss reduction in distribution systems using optimal capacitor placement i.e. differential evolution and hybrid genetic algorithms. X.S. Yang. (2013) proposed a bat algorithm for optimization problems. In this paper bat algorithm is used to find the optimal capacitor size.

II. Capacitor Locations Using Loss Sensitivity Method

In this paper loss sensitivity method is to find capacitor locations. 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.

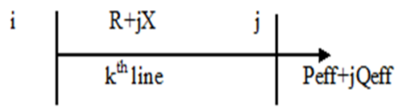

Fig1. A distribution line with impedance and a load.

The active power losses (PLoss) and reactive power loss (QLoss) in the distribution line are given as

$$P_{loss}[j] = \frac{(P_{eff}^2[j] + Q_{eff}^2[j])R[k]}{(V[j])^2} \quad (1)$$

$$Q_{loss}[j] = \frac{(P_{eff}^2[j] + Q_{eff}^2[j])X[k]}{(V[j])^2} \quad (2)$$

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

$$SLj = \frac{(2*Q_{eff}[j])*R[k])}{(V[j])^2} \quad (3)$$

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*/0.9>1.1 are selected as candidate buses for capacitor placement.

Candidate location vector of 15, 33, 34, 69 and 85 bus radial distribution system contains set of sequence of buses given as {6, 3},{6,28,29,5} {19, 20, 22} , {57, 58, 61} and {8,58,7,57} respectively.

III. Bat Algorithm

Bat Algorithm (BA) is a nature inspired metaheuristic algorithm developed by Xin She Yang in 2010. This paper presents the application of BA for finding the optimum sizes of capacitors after the optimum locations are determined using loss sensitivity method.

Metaheuristic algorithms use certain trade-off of randomization and local search. Randomization provides a good way to move away from local search to the search on the global scale. Therefore, almost all the metaheuristic algorithms intend to be suitable for global optimization. This algorithm is based on the echolocation behavior of micro bats. These bats can emit a very loud and short sound pulse, the echo that reflect back from the surrounding objects is received by their extraordinary big auricle.

Bat algorithm is developed by idealizing some of the characteristics of micro bats. The approximated or idealized rules are:

a) All bats use echolocation to sense distance and they also know the difference between prey and barriers.
b) Bats fly randomly with velocity V_i at position x_i with a fixed frequency f_{min}, varying wavelength λ and loudness A_0 to search for prey. They can automatically adjust the wavelength (or frequency) of their emitted pulses and the rate of pulse emission r ϵ [0,1] depending on the proximity of the target
c) Loudness varies from a large positive A_0 to a minimum constant value.

The steps of Bat Algorithm is as follows.

3.1 Population

The initial population i.e., number of virtual bats for BA (n) is generated randomly using equation (4). Where Qmin and Qmax are lower and upper bounds of capacitive compensation. After finding the initial fitness of the population for given objective function, the values are updated based on movement, loudness and pulse rate.

$$Xij= Qmin + (Qmax-Qmin) *rand (1, d) \quad (4)$$

3.2 Movement of Virtual Bats

The rules for updating the positions X_i, Frequency f_i and velocities V_i of the virtual bats are given as

$$f_i = f_{min} + (f_{max} - f_{min})\beta \quad (5)$$
$$V_i^t = V_i^{t-1} + (X_i^t - X_*) f_i \quad (6)$$
$$X_i^t = X_i^{t-1} + V_i^t \quad (7)$$

Where $\beta \in [0, 1]$ is a random vector and X_* is current global best solution. f_{min} and f_{max} are frequency minimum and frequency maximum.
For local search part once the solution is generated among the current best solution a new solution of each bat is generated using random walk.

$$X_{new} = X_{old} + \varepsilon A^t \quad (8)$$

Where $\varepsilon \in [-1, 1]$ is a random number.

3.3 Loudness and Pulse Emission

The loudness A_i and the rate of pulse emission r_i are updated accordingly as the iterations proceed. The loudness decreases and rate of pulse emission increases as the bat closes on its prey i.e., the equations for convergence can be taken as

$$A_i^{t+1} = \alpha A_i^t \quad (9)$$
$$r_i^{t+1} = r_i^0 [1 - \exp(-\gamma t)] \quad (10)$$

Where α and γ are constants. For any $0<\alpha<1$ and $\gamma>0$, we have

$$A_i^t \rightarrow 0, \quad r_i^t \rightarrow r_i^0 \quad \text{as } t \rightarrow \infty$$

The initial loudness A can typically be 0.9, while the initial emission rate r_i^0 can be [0, 1]. In this paper $r_i^0 = 0.5$.

3.4 Algorithm for Capacitor Placement and Sizing Using Loss sensitivity method and Bat Algorithm

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 Bat algorithm. Based on the above three rules, the basic steps of the Bat algorithm are framed.

Step 1: Initially [pop x n] number of nest population are generated randomly within the limits Qmin and Qmax where pop is the population size and n is the number of capacitors

Xij= Qmin + (Qmax-Qmin) *rand (1, d)

Step 2: By placing all the *n* capacitors of each nest at the respective candidate locations and load flow analysis is performed to find the total real power loss P_L. The same procedure is repeated for the nop number of particles to find the total real power losses. Fitness value corresponding to each nest 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_C is the size of the capacitor in kvar.

The capacitor sizes corresponding to maximum savings are required. For any one nest, 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_C (minimum).

Step 3: Start iterations

Step 4: Generate new population (solution) by using (5), (6) and (7) equations.

Step 5: If the random number is greater than the rate of pulse emission then select a solution among the best solution and generate a local solution around the best solution using equation (8).Otherwise new solution will be same as in step 4.

Step 6: Evaluate the fitness of new solution. If the fitness is greater than the current best solution, then replace the current best solution with the present obtained value and update loudness and pulse rate using equations (9) and (10). Here the value of A_i decreases and r_i increases.

Step 7: The iteration count is incremented and if iteration count is not reached maximum then go to step 4.

Step 8: The capacitor sizes corresponding to maximum fitness gives the optimal capacitor sizes in *j* capacitor locations and the results are printed.

Step9: The capacitor sizes corresponding to maximum savings gives the optimal capacitor sizes in n capacitor locations and the results are printed.

IV. Results

The proposed method for loss reduction by capacitor placement is tested on IEEE 15,33,34,69 bus and 85 bus radial distribution systems. Loss sensitivity method is used to find the optimal capacitor locations and Bat algorithm is used to find the optimal capacitor sizes for maximum annual savings. When the proposed method is tested on 15 bus, 33 bus, 34 bus, 69 bus and 85 bus systems the total real power losses before and after placement of capacitors and annual saving are shown in tables. The data used for finding the optimal capacitor sizes are nop = 50, Qmin=100 kvar, Qmax=1500 kvar, pa=0.25, K_P=150 \$/kW, K_E =0.06 \$/kWh, K_C = 5 \$/kVAr and Itmax =1000.

Table 1. Results for 15 Bus System

Bus No	Size (kvar)
3	827
6	160
Total kVAr placed	987
Total Power loss in kW (before)	61.7944
Total Power loss in kW (after)	34.5376
Savings in dollars	$ 13,398

Table 2. Results for 33 Bus System

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Bus No	Size (kvar)
6	113
28	1238
29	135
5	81
Total kVAr placed	1567
Total Power loss in kW (before)	369.2543
Total Power loss in kW (after)	291.6287
Savings in dollars	$ 38,678

Table 3. Results for 34 Bus System

Bus No	Size(kvar)
19	1152
22	765
20	2
Total kvar placed	1919
Total Power loss in kW (before)	221.7235
Total Power loss in kW (after)	169.2287
Savings in dollars	$ 25,713

Table 4. Results for 69 Bus System

Bus No	Size(Kvar)
57	71
58	67
61	1142
Total kvar placed	1280
Total Power loss in kW (before)	225
Total Power loss in kW (after)	151.9464
Savings in dollars	$ 42,737

Table 5. Results for 85 Bus System

Bus No	Size(Kvar)
8	1065
58	104
7	65
27	858
Total kvar placed	2092
Total Power loss in kW (before)	225
Total Power loss in kW (after)	168.9813
Savings in dollars	$ 87,761

V. Conclusion

In this paper, a two stage methodology of finding the optimal locations and sizes of shunt capacitors for reactive power compensation of radial distribution systems is presented. Loss sensitivity method is proposed to find the optimal capacitor locations and Bat algorithm is proposed to find the optimal capacitor sizes. By installing shunt capacitors at all 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, 33, 34, 69 and 85 bus radial distribution systems. The proposed Bat algorithm iteratively searches the optimal capacitor sizes for the maximum annual savings. Bat algorithm is less complex because less parameters are there when compared to other algorithms.

References

[1] Y.Z.Y. Dong, K.P. Wong, E. Liu and B. Yue., 2013.Optimal capacitor placement to distribution transformers for power loss reduction in radial distribution systems. IEEE Transactions on Power Systems, Vol. 28, No. 4, pp. 4072-4079.

[2] Reddy P, Dinakara Prasad. "Application of Loss Sensitivity Factor and Genetic Algorithm for Capacitor placement for Minimum Loss in radial distribution system." *International Journal of Engineering Sciences & Research Technology* (2013): 2400-2403.

[3] X.S. Yang., 2013.Bat algorithm: literature review and applications. *International Journal on Bio-Inspired Computation*. Vol. 5, No. 3, pp. 141–149.

[4] S. Paul and W. Jewell., 2012. Optimal capacitor placement and sizes for power loss reduction using combined power loss index-loss sensitivity factor and genetic algorithm. *IEEE Power and Energy Society General Meeting*, pp. 1-8.

[5] V. Usha Reddy, Dr.T.Gowri Manohar, Dinakara Prasad Reddy P. "Optimal Capacitor

Placement for Loss Reduction in Distribution Systems by Using Bat Algorithm." *International Journal of Electrical Engineering & Technology (IJEET)* 4.2 (2013): 338-343.

[6] Abbas Babazadeh, Hossain Poorzahedy and Saeid Nikoosokhan., 2011. Application of particle swarm optimization to transportation network design problem. *Journal of King Saud University Science*, 23, 293–300

[7] S. Segura, R. Romero and M.J. Rider., 2010.Efficient heuristic algorithm used for optimal capacitor placement in distribution systems. *Electrical Power and Energy Systems*, Vol. 32, pp. 71–78.

[8] A.Y. Abdelaziz, S.F. Mekhamer and M.H. Nada., 2010. A fuzzy expert system for loss reduction and voltage control in radial distribution system. *Electric Power Systems Research*, Vol. 80, pp. 893-897.

[9] S. Sivanagaraju and J. Viswanatha Rao., 2009.Optimal conductor selection in radial distribution systems using discrete particle swarm optimization. *World Journal of Modelling and Simulation*, vol.5, No.2, pp. 96-104.

[10] Seifi., 2009.A new hybrid optimization method for optimum distribution capacitor planning. *Modern Applied Science*, Vol. 3, No.4, pp. 196-202.

[11] Seifi and M.R. Hesamzadeh., 2009. A hybrid optimization approach for distribution capacitor allocation considering varying load conditions. *Electrical Power and Energy Systems*, Vol. 31, pp. 589–595.

[12] C.A.N. Pereira and C.A. Castro, 2009. Optimal placement of voltage regulators in distribution systems. *Proceedings of IEEE Bucharest Power Technical Conference*, pp.1-5.

[13] S.K. Bhattacharya and S.K. Goswami., 2009. A new fuzzy based solution of the capacitor placement problem. *Expert Systems with Applications*, Vol. 36, pp. 4207-4212.

[14] D. Das., 2008.Optimal placement of capacitors in radial distribution system using a Fuzzy-GA method. *Electrical Power and Energy systems*, Vol. 30, pp. 361-367.

[15] M. Damodar Reddy and Prof. V.C. Veera reddy., 2008.Optimal capacitor placement using fuzzy and real coded genetic algorithm for maximum savings. *Journal of Theoretical and Applied Information Technology*, pp. 219-226.

[16] R. Sreenivasa Rao and S.V. L. Narasimham., 2008.Optimal capacitor placement in radial distribution systems using plant growth simulation algorithm. *World Academy of Science, Engineering and Technology*, Vol. 45, pp. 715-722.

[17] K. Prakash and M. Sydulu., 2007.Particle swarm optimization based capacitor placement on radial distribution systems. *IEEE Power Engineering Society general meeting* 2007, pp. 1-5.

[19] Venkatesh and R. Ranjan., 2006. Fuzzy EP algorithm and dynamic data structure for optimal capacitor allocation in radial distribution systems. *IEE Proceedings on Generation, Transmission and Distribution*, Vol. 153, No. 1, pp. 80-88.

[20] T.M. Khalil, K.M.Y. Hosam and M.M. Abdel Aziz., 2006. A binary particle swarm optimization for optimal placement and sizing of capacitor banks in radial distribution feeders with distorted substation voltages. *Proceedings of AIML-06 International Conference*, pp. 129-135.

[21] K. Prakash and M. Sydulu., 2006. A novel approach for optimal location and sizing of capacitors on radial distribution systems using loss sensitivity factors and α-coefficients. *IEEE proceedings of Power Systems Conference and Exposition*, pp. 1910-1913.

[22] V. Usha Reddy, Dr.T.Gowri Manohar, Dinakara Prasad Reddy P. "Capacitor Placement for Loss Reduction in Radial Distribution Networks: A Two Stage Approach." *Journal for Electrical Engineering* 2.2 (2012): 114-119.

[23] V.Usha Reddy, Dinakara Prasad Reddy P. "Differential Evolution Method for capacitor placement of distribution systems." *International journal of advanced engineering sciences and technologies (IJAEST)* 4.2 (2011): 23-28.