J Electr Eng Technol Vol. 9, No. 1: 45-51, 2014
http://dx.doi.org/10.5370/JEET.2014.9.1.045

ISSN(Print) 1975-0102
ISSN(Online) 2093-7423

Opposition Based Differential Evolution Algorithm for Capacitor Placement on Radial Distribution System

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Abstract – Distribution system is a critical link between customer and utility. The control of power loss is the main factor which decides the performance of the distribution system. There are two methods such as (i) distribution system reconfiguration and (ii) inclusion of capacitor banks, used for controlling the real power loss. Considering the improvement in voltage profile with the power loss reduction, later method produces better performance than former method. This paper presents an advanced evolutionary algorithm for capacitor inclusion for loss reduction. The conventional sensitivity analysis is used to find the optimal location for the capacitors. In order to achieve a better approximation for the current candidate solution, Opposition based Differential Evolution (ODE) is introduced. The effectiveness of the proposed technique is validated through 10, 33, 34 and85-bus radial distribution systems.

Keywords : Distribution systems, Loss reduction, Loss sensitivity factors, Differential Evolution, Capacitor placement

1. Introduction

Distribution system power management is the major intimidation for the electrical engineers. Distribution system reconfiguration and capacitor placement are the two different practices adapted for distribution system loss reduction for more than five decades. Distribution system reconfiguration is the process of changing the open/close status of the switches present in the distribution system in order to reduce the power loss [1-6]. The reconfiguration problem later have been viewed as mutli-objective optimization problem by making the power flow constraints as multi-objectives [7-8]. Though, reconfiguration provides comparative solutions for the loss reduction, the complexity in terms of selection of variables and number of variables is tremendous. Because the total number of switches present in the system was considered as number of variables for reconfiguration. Due to this complexity, the capacitor placement has been carried out as a substitute practice for loss reduction.

Capacitor placement problem has two major concerns in it. The first one is the identification of capacitor location and the second is the amount of capacitor inclusion at the identified location.

The most conventional sensitivity analysis has been followed for finding the optimal location and the conventional searching adapted in order to find the amount of inclusion of capacitors. Therefore, it provides opportunity for the inclusion of optimization techniques for both the cases.

Since the nature of capacitor placement problem is complex combinatorial, different techniques have been followed by the authors in the past. The initial contribution was made by Schmill [9] using 2/3 rule for capacitor placement. Dynamic programming with assuming the capacitor sizes as discrete variables adapted by Duran [10]. The capacitor problem was viewed as a nonlinear problem by Grainger et al. [11], where variables were treated as continuous. The power flow constraints along with the loss reduction were handled through the fuzzy reasoning approach [12]. Mixed integer programming was adapted by Baran and Wu [13] for capacitor placement. The substation level voltage control with dynamic re-sizing of capacitors was dealt in [14].

The improvements in advanced optimization techniques such as genetic algorithm, microgenetic, particle swarm optimization, ant colony and differential evolution allowed the optimization procedures comparatively easier than the conventional procedures. Optimal capacitor placement was carried out through genetic algorithm by [15] and [16]. The number of locations was considered as the total variables for genetic algorithm. The microgenetic concepts involving enhanced genetic algorithm was proposed in [17]. The power flow constraints were handled through fuzzy logic concepts. Optimization procedure through particle swarm optimization principle was adapted in [18]. Optimization through plant growth simulation algorithm (PGSA) was first introduced for feeder reconfiguration in [4]. Later, the PGSA along with loss sensitivity factors was introduced [19] for optimal capacitor placement. Loss sensitivity factors were used to find the optimal location i.e weak

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Received: March 3, 2013; Accepted: August 28, 2013

buses which require capacitor. PGSA was incorporated in order to find out the optimal sizing of the capacitors. The optimization procedure combining both capacitor placement and reconfiguration was recently introduced. In [20], the ant colony optimization algorithm was introduced for the optimization. The advanced reconfiguration concept was adopted for the simultaneous operation in [21].

In this paper, Opposition based Differential Evolution [22] algorithm has been presented for efficient optimal capacitor placement. The conventional loss sensitivity factors are introduced to identify the optimal location of capacitors in the distribution system and the amount of injection of reactive power through capacitors is fine-tuned with the help of ODE.

Problem Formulation

The main objective of the optimal capacitor placement is to minimize the total annual cost of the system subject to the power flow constraints such as bus voltage ($|V_{min}| < |V_i| < |V_{max}|$), branch currents($|I_{jl}| < |I_{max,j\varepsilon nl}|$) and radiality constraints. The mathematical equation relevant to the objective function of the problem is defined as,

$$F = Minimize(C) \tag{1}$$

where, the term 'C' represents the total cost of the distribution system, it includes the cost for energy loss and capacitor cost.

The problem carried out with following assumptions.

(i) Loads are static
(ii) Distribution system is perfectly balanced
(iii) Well reactive power compensated system
(iv) Operation and maintenance costs of the capacitors are negligible.

The single line diagram of the balanced distribution system shown in the Fig. 1 used to describe the load flow calculations. In Fig. 1, P_i and Q_i represents the real and reactive power flow between the sending and receiving end buses, P_{Li} and Q_{Li} denotes the real and reactive power loads. The line resistance and reactance are denoted as $R_{i,j}$ and $X_{i,j}$. $\frac{y_i}{2}$ is the total shunt admittance at bus i

The following set of equations are used to calculate the

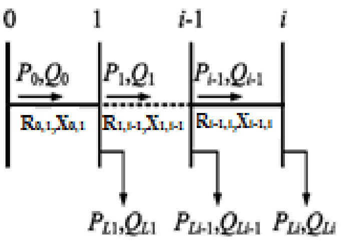

Fig. 1 Single line diagram of a main feeder

power flow,

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

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{i,i+1}\frac{P_i^2 + Q_i^2}{V_i^2} - V_i^2\frac{y_i}{2} \tag{3}$$

$$V_{i+1}^2 = V_i^2 - 2(R_{i,i+1}P_i + X_{i,i+1}Q_i) + (R_{i,i+1}^2 + X_{i,i+1}^2)\frac{P_i^2 + Q_i^2}{V_i^2} \tag{4}$$

The power loss $P_{F,Loss}$ of the feeder is determined by summing the losses of all line sections of the feeder and it is given by,

$$P_{F,Loss} = \sum_{i=1}^{nl} {}_{i,i+1}\frac{P_i^2 + Q_i^2}{V_i^2} \tag{5}$$

The total energy loss cost (E_{cost}) has been calculated as,

$$E_{cost} = P_{F,loss} * K_p \tag{6}$$

where K_p is the equivalent annual cost of power loss in \$/(kW-year)

In general, the cost per KVAR varies with respect to their size. The available capacitor sizes and their cost (K) were given in [19]. The total cost of the distribution system is given in Eq. (7).

$$C = E_{cost} + C_{q,cost} \tag{7}$$

where,

$$C_{q,cost} = C_{q,fixed} + C_i^{annual} * Q_i$$

$C_{q,fixed}$ is the fixed cost for the capacitor placement \$/year

C_i^{annual} is the annual cost for the capacitorinstallation in \$/(KVAR-year), i belongs to selected buses for capacitor installation

Q_i is the reactive power in (KVAR)

The percentage saving of the annual operating cost has been calculated using the Eq. (8) shown below,

$$\%saving = \frac{(Initialoperatingcost - Finaloperatingcost)}{Initialoperatingcost} \tag{8}$$

3. Identification of Optimal Location for Capacitor Placement

Optimal capacitor placement process has two major tasks (i) the capacitors location identification and (ii) the search for optimal sizing of capacitors. The capacitors need to be located at the weak buses of the distribution system. The term weak buses refer the buses with least voltage (< V_{min}) and the associated lines having the most value of rate of change of real power loss with respect to effective reactive power [19]. The total load connected beyond the associated bus is called as the effective reactive power.

The above mentioned procedure is called sensitivity analysis and the relevant buses are called sensitivity buses. The sensitivity analysis is a conventional procedure practiced for many years for identifying the optimal location of capacitors. The mathematical equations related to formation of sensitivity analysis are described with the Fig. 2. The Fig. 2 has a distribution line (m) connected between buses 'i' and 'i+1'with a series impedance of R_m+jX_m and an effective load of $P_{eff}+jQ_{eff}$ at bus 'i+1'.

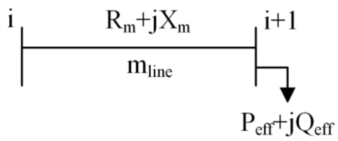

Fig. 2. Single line diagram of a distribution line

The real power loss of the distribution line (m) is calculated using the Eq. (9),

$$P_m = R_m \frac{(P_{i+1,eff}^2 + Q_{i+1,eff}^2)}{V_{i+1}^2} \qquad (9)$$

The loss sensitivity factor can be calculated using Eq. (10),

$$LSF_m = \frac{\partial P_m}{\partial Q_{i+1,eff}} = 2R_m \frac{Q_{i+1,eff}}{V_{i+1}^2} \qquad (10)$$

The Loss Sensitivity Factors (LSF) of all the lines can be calculated through conducting radial load flow. The calculated values of LSF are arranged in non-increasing order. The buses with most value LSF and lesser value (ie. < 1.01pu) of normalized voltage (|V|/0.95) [19] are selected as the candidate location for capacitor placement.

4. Search Strategy For Capacitor Sizing Through ODE Algorithm

Opposition based differential algorithm is a recent evolutionary algorithm with enhanced features such as self acceleration, self migration and assured optimal search with least population size. The efficiency of the algorithm can be well proven by applying into complex and/or large problems. In this paper, the purpose of introduction of ODE is to find the optimal capacitor size that need to be included at the optimal locations received at the end of sensitivity analysis. The number of variables for ODE searching is the number of identified locations. For instance, if the system has 'n' identified locations then ODE should have 'n' variables. The pseudocode of the ODE algorithm has been given below,

Set Mutation (F), Crossover Rate (CR), maximal iteration number (N_{max}),variable size (V), population size (P), count=0

//Initial Population
Z(P,V)=random()
// Calculate the fitness value for all population
Obj(Z(P))

//Opposite population
Z_{opp}(P,V)= Opposite (Z(P,V))

//Calculate the fitness value for all population
Obj(Z_{opp}(P))

//Find the best individual
Z_{best}(P)=best(Obj(Z(P)),Obj(Z_{opp}(P)))

//Execute the following steps for fixed number of iterations(N_{max}) till (count<N_{max})

{
//Mutation operation for the Z_{best}
Z_{plus}(P,V)=Z_{best}(P,V)+F*(Z_{best}(P,i)-Z_{best}(P,j))
// where i and j refers integers (< V) and i≠j

// Crossover operation for the Z_{best}
Z_{plus}(P,V)=Z_{best}(P,V), if(random()>CR)

//Process to identify best individuals
if(Obj(Z(P))>Obj(Z_{plus}(P)))
Z(P,V)=Z_{plus}(P,V)

//Opposition based Generation Jumping and selection of best individual for next iteration

Z_{opp}(P,V)=Opposite(Z(P,V))

Z(P,V)=best(Obj(Z(P)),Obj(Z_{opp}(P)))

//increment the iteration count
count=count+1;

}

Proposed method combines Loss Sensitivity Factors (LSF) and Opposition based Differential Evolution (ODE) for optimization. LSF is used for identifying the capacitor location and ODE used for identifying the optimal size of the capacitors.

5. Test Results

The effectiveness of the proposed algorithm has been validated through applying on 10, IEEE 33, 34 and 85 bus radial distribution systems. The commercially available capacitors sizes and their cost in $/kVAR-year are given in [19]. The constants K_p and $C_{q,fixed}$ are assumed as 168 $/(kW-year) and 1000 $ respectively [19].

The proposed algorithm has been programmed using MATLAB programming and run on a P-IV processor with 266 MHz personal computer. The results obtained have been discussed in details in the following sub sections.

5.1 10-Bus RDS

This system is a balanced single feeder radial distribution system [23] with the base of 23kV. The initial operating cost of the system is 1, 31,674 $/year. The optimal locations for capacitor placement have been identified by doing sensitivity analysis.

The Table 1 shows the values of loss sensitivity factor of each line along with end bus normalized voltage. The lines are arranged in descending order of the loss sensitivity factor and the end buses those have normalized voltage above 1.01 pu are eliminated from the list.

The first four buses from the sequence are selected as candidate nodes for the capacitor placement. The identified buses for capacitor location are 6, 5, 9 and 10. As a result, ODE takes four variables and search for the optimal size of capacitors. The ranges of the variables are from 150kVAR to 4050kVAR [19].

The size of the capacitors at the locations 6, 5, 9 and 10 are 1200kVAR, 1200kVAR, 200kVAR and 407kVAR. The bus voltages before and after capacitor placement have been shown in the Fig. 3. It shows that bus voltages of the weaker buses 8, 9 and 10 are improved.

Table 1. Initial configuration sensitivity factors of 10-Bus RDS

Line No.	Start Bus	End Bus	Loss Sensitivity Factor (*10^{-3})	End bus |V| in pu	Normalized voltage (|V| in pu / 0.95)
1	1	2	1.98	0.9929	1.0451
2	2	3	0.2	0.9874	1.0393
3	3	4	10.29	0.9634	1.0141
4	4	5	8.64	0.948	0.9979
5	5	6	9.8	0.9172	0.9654
6	6	7	2.08	0.9072	0.9549
7	7	8	3.83	0.889	0.9357
8	8	9	8.11	0.8587	0.9039
9	9	10	5.76	0.8375	0.8816

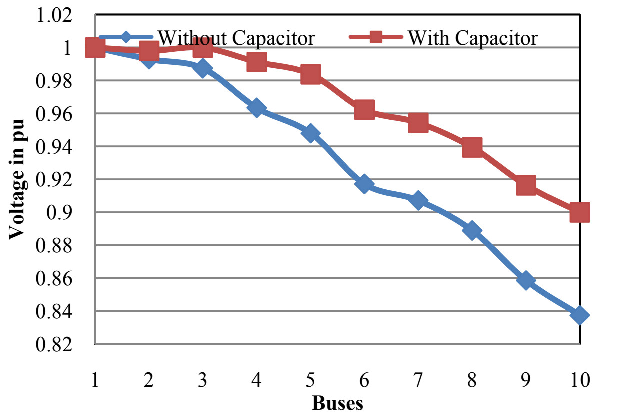

Fig. 3. Bus voltages of 10-bus RDS before and after capacitor placement

Table 2. Summary of results for 10-bus RDS

Evolutionary algorithms	Cross-Over Rate	Muta-tion	Popula-tion Size	Number of load flow executions	Loss in kW
Genetic algorithm (GA)	0.6	0.7	20	2182	694.93
Differential evolution (DE)	0.6	0.7	20	1482	694.93
Hybrid differential evolution (HDE)	0.6	0.7	10	766	694.93
Self adaptive hybrid differential evolution (SaHDE)	NA	NA	5	378	694.93
Opposition based differential evolution (ODE)	0.7	0.6	5	172	694.93

The real power loss has been reduced from 783.77 kW to 694.93kW under initial load condition. The result of the proposed method has been compared with the other evolutionary algorithms and shown in Table 2. From the Table, all the algorithms bring global optimum and except SaHDE, all other evolutionary algorithms have taken larger population size even for the lesser number of variables.

Compared with SaHDE, the proposed ODE takes lesser number of load flow executions. The other methods in the literature are compared with the proposed method in Table 3. Proposed method ensures the global optimum. Also compared with PGSA, the proposed method solution methodology is simple.

5.2 IEEE 33-Bus RDS

The next system considered for implementation is the IEEE 33-bus radial distribution system [6]. This system is a 12.66kV system and it consists of 33 buses and five tie lines. The total load conditions are 3715kW and 2300kVAR. The initial operating cost of this system is 34,049.74 $/year. The buses 5, 27 and 28 are identified as candidate locations for capacitor location through sensitivity analysis. ODE tunes for the optimum capacitor

Table 3. Comparison with other methods in literature for 10-bus RDS

Parameters	Fuzzy Reasoning [12]	PSO [18]	PGSA [19]	Proposed
Final Configuration Loss (kW)	704.883	696.21	694.93	694.93
Total Capacitor size (kVAR)	4950	3186	3007	3007
Power Loss Cost ($/(KW-yr))	118420	116963	116748	116748
Capacitor Cost ($/yr)	999.656	1618.72	1592	1592
Total Annual Cost ($/yr)	119420	118582	118340	118340
%saving	9.31	9.94	10.13	10.13

Table 4. Summary results for33-bus RDS

Parameters	Proposed
Final Configuration Loss (kW)	159.89
Total Capacitor size (kVAR)	2940
Power Loss Cost ($/(KW-yr))	26861.59
Capacitor Cost ($/yr)	1529.87
Total Annual Cost ($/yr)	28,391.46
%saving	16.61

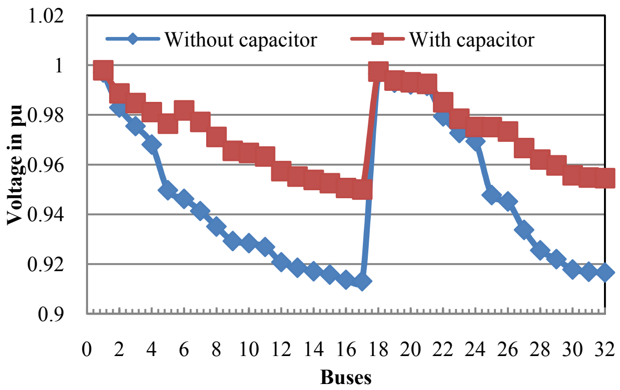

Fig. 4. Bus voltages of 33-bus RDS before and after capacitor placement

size for the identified locations.

The proposed method reduces the power loss from 202.67kW to 159.89kW, and maintains the bus voltages well above minimum value. The bus voltages before and after capacitor placement have been shown in the Fig. 4. From the Fig. 4, it is observed that all the bus voltages are maintained above 0.95 pu. The details of the results received are shown in Table 4. It is found that through the proposed algorithm 16.61 % of cost saving has been achieved.

5.3 34-Bus RDS

The proposed method has been tested with34-bus balanced radial distribution system [24]. The initial uncompensated system annual cost is 37,241 $/year. As per the sensitivity analysis, the sensitive buses are identified. For this test system, buses 19, 22 and 20 are selected as optimal locations for the capacitor placement. The proposed method reduces the power loss from 221.67kW to 161.07kW, and maintains the bus voltages well above minimum value. The bus voltages before and after capacitor placement have been shown in the Fig. 5. The results are compared with previous works addressed for optimization and shown in Table 5.

5.4 85-Bus RDS

The proposed method has been validated further by implementing to 85-bus balanced radial distribution system

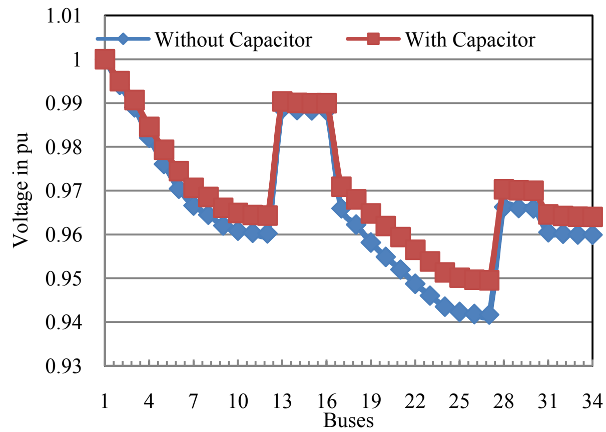

Fig. 5. Bus voltages of 34-bus RDS before and after capacitor placement

Table 5. Comparison with other methods in literature for 34-bus RDS

Parameters	PSO [18]	PGSA [19]	Proposed
Final Configuration Loss (kW)	168.8	161.07	161.07
Total Capacitor size (kVAR)	2063	2039	2039
Power Loss Cost ($/(KW-yr))	28,358.4	27,059.76	27,059.76
Capacitor Cost ($/yr)	1577.6	1424.24	1424.24
Total Annual Cost ($/yr)	29,936	28,484	28,484
%saving	19.61	23.51	23.51

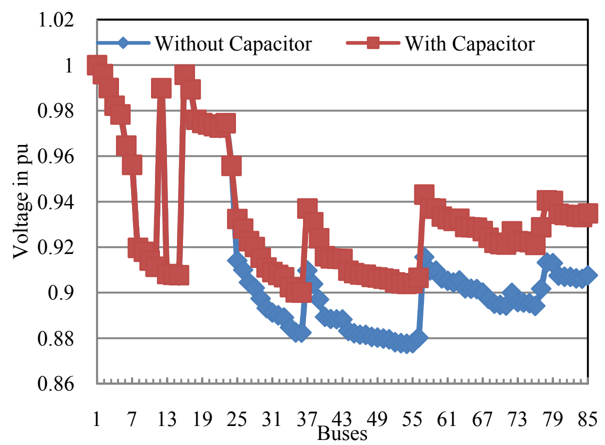

Fig. 6. Bus voltages of 85-bus RDS before and after capacitor placement

Table 6. Comparison with other methods in literature for 85-bus RDS

Parameters	PSO [18]	PGSA [19]	Proposed
Final Configuration Loss (kW)	163.32	161.4	161.4
Total Capacitor size (kVAR)	2474	2308	2308
Power Loss Cost ($/(KW-yr))	27,438	27,115	27,115
Capacitor Cost ($/yr)	1618.72	1592	1592
Total Annual Cost ($/yr)	118582	118340	118340
%saving	9.94	10.13	10.13

[25]. The sensitive buses 8, 58 and 7 were identified through sensitivity analysis. With the use of ODE, the capacitor sizes have been identified for those buses. The power loss is reduced from 315.714kW to 161.4kW.

The bus voltages before and after capacitor placement have been shown in the Fig. 6. The results are compared with previous works and shown in Table 6.

6. Conclusion

In this paper, distribution system optimization through capacitor placement has been handled through ODE along with sensitivity analysis. The optimal locations of the capacitors were identified through conventional sensitivity analysis. For finding the optimum capacitor sizes on the optimal locations, ODE has been proposed.

This combined effort of sensitivity analysis with ODE ensured global optimum and bus voltages has been maintained above the minimum limit. The proposed algorithm has been validated with four distribution systems of different sizes such as 10, 33, 34 and 85-bus radial distribution system. The results were compared with other papers referred in the literature.

7. Scope for Extension

This research work provides multiple directions for future work. This proposed method used conventional sensitivity analysis for finding the optimal location for the capacitors. Instead it can be carried out with suitable soft computing technique to improve the efficiency of searching or it can be combined with the proposed optimization technique used for finding optimum sizes of capacitor. The proposed algorithm handled only the balanced distribution systems; it can be tested with unbalanced distribution system. The proposed method applied only for capacitor placement, it can also be combined with reconfiguration and/or phase balancing.

Acknowledgement

The authors would like to thank the reviewers for their constructive suggestions which have helped to enhance the quality of this manuscript.

References

[1] Baran, ME & Wu, FF., 1989, “Network reconfiguretion in distribution systems for loss reduction and load balancing”, IEEE Trans. Power Del., Vol. 4, No. 1, pp. 401-1407.

[2] Civanlar, S., Grainger, J.J., Yin, H. & Lee, S. S. H., 1988, “Distribution feeder reconfiguration for loss reduction,” IEEE Trans. Power Del., Vol. 3, No. 3, pp. 1217-1223.

[3] Salazar, H., Gallego, R. & Romero, R., 2006, “Artificial neural networks and clustering techniques applied in the reconfiguration of distribution systems”, IEEE Trans. Power Del., Vol. 21, No. 3, pp. 1735-1742.

[4] Wang, C, and Cheng, H. Z., 2008, “Optimization of Network configuration in Large distribution systems using plant growth simulation algorithm,” IEEE Trans. Power Syst., vol. 23, No. 1, pp. 119-126.

[5] Whei-Min, L., & Hong-Chan, C., 1998, “A new approach for distribution feeder reconfiguration for loss reduction and service restoration”, IEEE Trans. Power Del., Vol. 13, No. 3, pp. 870-875.

[6] C. Wang and H.Z. Cheng “Optimization of Network configuration in Large distribution systems using plant growth simulation algorithm,” *IEEE Trans. Power Syst*., vol.23, No. 1, pp. 119-126, Feb. 2008.

[7] Venkatesh, B., Ranjan, R. & Gooi, H.B., 2004, “Optimal reconfiguration of radial distribution systems to maximize loadability”, IEEE Trans. Power Syst., Vol. 19, No. 1, pp. 260-266.

[8] Ying-Yi, H and Saw-Yu, H, 2006, “Determination of network configuration considering multi-objective in distribution systems using genetic algorithms”, IEEE Trans. on Power Sys., Vol. 20, No. 2, pp. 1062-1069.

[9] Schmill JV. Optimum size and location of shunt capacitors on distribution feeders. IEEE Trans Power Apparat Syst 1965; 84:825-32.

[10] Dura n H. Optimum number, location and size of shunt capacitors in radial distribution feeders: a dynamic programming approach. IEEE Trans Power Apparat Syst 1968; 87:1769-74.

[11] Grainger JJ, Lee SH. Optimum size and location of shunt capacitors for reduction of losses on distribution feeders. IEEE Trans Power Apparat Syst 1981 ; 100(3):1105-18.

[12] Su CT, Tsai CC. A new fuzzy reasoning approach to optimum capacitor allocation for primary distribution systems. In Proceeding of the IEEE on industrial technology conference; 1996. p. 237-41.

[13] Baran ME, Wu FF. Optimal capacitor placement on radial distribution system. IEEE Trans Power Deliv 1989;4(1):725-34.
[14] Baghzouz Y, Ertem S. Shunt capacitor sizing for radial distribution feeders with distorted substation voltages. IEEE Trans Power Deliv 1990; 5:650-7.
[15] H. A. Ferreira, B. A. Souza, and H. N. Alves, "Optimal capacitor allocation in electrical distribution systems using a genetic algorithm," in *Proc. IEEE Power Eng. Soc. T&D Latin Amer. Conf.*, Mar. 2002. Paper no. 188.
[16] Das D. Reactive power compensation for radial distribution networks using genetic algorithms. Electrical Power Energy Syst 2002; 24:573-81.
[17] B. A. Souza, H. N. Alves, and H. A. Ferreira, "Microgenetic algorithms and fuzzy logic applied to the optimal placement of capacitor banks in distribution networks," IEEE Trans. Power Syst., vol. 19, no. 2, pp. 942-947, May 2004.
[18] Prakash K, Sydulu M. Particle swarm optimization based capacitor placement on radial distribution systems. IEEE power engineering society general meeting; 2007. p. 1-5.
[19] Srinivasas Rao R, Narasimham S.V.L, Ramalingaraju M, Optimal capacitor placement in a radial distribution system using Plant Growth Simulation Algorithm. Electrical Power Energy Syst 2011; 33: 1133-1139.
[20] M. J. Kasaei and M. Gandomkar, Loss Reduction in Distribution Network Using Simultaneous Capacitor Placement and Reconfiguration With Ant Colony Algorithm, IEEE Proceeding, 2010, DOI: 978-1-4244-4813-5/10.
[21] Farahai, Behrooz and Hossein, "Reconfiguration and capacitor placement simultaneously for energy loss reduction based on an improved recon-figuration method," IEEE Trans. Power Syst., vol. 27, no. 2, pp. 587-595, May 2012
[22] Shahryar Rahnamayan, Hamid R. Tizhoosh, and Magdy M. A. Salama, Opposition-Based Differential Evolution, IEEE Trans on Evolutionary computation, Feb'2008; vol. 12, no. 1, 64-79.
[23] Baghzouz Y, Ertem S. Shunt capacitor sizing for radial distribution feeders with distorted substation voltages. IEEE Trans Power Deliv 1990;5:650-7.
[24] Chis M, Salama MMA, Jayaram S. Capacitor placement in distribution system using heuristic search strategies. IEE Proc-Gener Transm Distrib. 1997; 144(3):225-30.
[25] Das D, Kothari DP, Kalam A. Simple and efficient method for load flow solution of radial distribution network. Electrical Power Energy Syst. 1995; 17(5):335-46.

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