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Optimal Capacitor Allocation for the Reconfigured Network using Ant Lion Optimization Algorithm

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Abstract

This paper presents an Ant Lion Optimization (ALO) algorithm for optimal allocations and sizing of capacitors for the original and reconfigured distribution systems. Feeder reconfiguration is the process of changing the distribution network topology by changing the status of sectional and tie switches. First the candidate buses for installing capacitors are identified using Fuzzy Approach. Then the proposed ALO algorithm is to find the size of capacitors. The main objective is to reduce the total real loss and consequently, to increase the net energy savings per year. The attained results via the proposed ALO algorithm are compared with original network to highlight their benefits. The proposed algorithm is to minimize the losses and total cost and to enhance the voltage profiles and net saving for various distribution systems. The proposed ALO algorithm has been tested on a standard IEEE 33- bus and 69-bus test system for capacitor placement for original and reconfigured network to reduce the power loss and energy savings.

Keywords: Ant Lion Optimization, Energy savings, Optimal Capacitor Placement, Radiality Constraint, Simultaneous Reconfiguration.

INTRODUCTION

In power distribution system (PDS) planning, the major challenge is to supply uninterrupted power within allowable limits. In primary distribution systems, the sectional switches are used for both protection (to isolate a fault) and for configure management to reconfigure the network. A power distribution network consists of radial feeders which can be connected together by several tie switches. Power loss reduction major concern of electrical distribution utilities. Among conventional methods, optimal reconfiguration and capacitor placement are the two successful techniques which can be applied on the network. However, the configuration is changed during switching operation by changing the status of sectional and tie switches.

Reconfiguration (RCG) of radial distribution systems is a very successful and efficient to reduce losses, improvement of voltage profile and enhance system reliability. Distribution networks are generally structured in mesh but operated in a radial configuration for effective coordination of their protective schemes and to reduce the fault level. The aim of network reconfiguration is to obtain a radial operating configuration that minimizes real power loss while satisfying all the operational constraints without the islanding of any node.

A number of research papers have been emerged on the general topic of feeder reconfiguration, there is still a need to develop more appropriate and effective techniques for the network reconfiguration under reliable operating conditions. Many recent researches on distribution feeder reconfiguration on reducing the power losses. Merlin[1] offered the sequential opening algorithm. Simplicity is the main advantage of heuristic methods. Das[2] proposed a simple and efficient method for solving radial distribution networks, which involves only the evaluation of a simple algebraic expression of voltage magnitudes and no trigonometric functions as opposed to the standard load flow case. Shirmohammadi[3] described a technique for the reconfiguration of distribution networks to reduce their resistive line losses.

Goswami[4] presented a heuristic algorithm for feeder reconfiguration. Jeon[5] presented the simulated annealing with tabu search algorithm for loss reduction by switching operation in distribution systems. Venkatesh[6] proposed a novel algorithm based on fuzzy adaption of evvolutionary programming to optimal network reconfiguration to achieve the minimal kW losses and best voltage profile. Yuji[7] proposed tabu search to reconfiguration for an open loop radial distribution network with distributed generators to minimize the total line losses subjected to the line or transformer capacity constraints and voltage constraint. Damodar Reddy[8] proposed a fuzzy multi-objective approach used for the capacitor placement in the reconfigured network. In addition to loss reduction, simultaneously as reconfiguration also improves the nodal voltage deviations and branch current limit violation.

Mirjalili[9], proposed novel nature inspired algorithm is called Ant Lion Optimizer (ALO). The ALO algorithm mimics the hunting mechanism of antlions in nature, implemented in 2015. Sudhakara Reddy[10] proposed PSO algorithm with an objective of reducing power losses by using Network reconfiguration by simultaneous switching Method. Sudhakar Reddy[11] described the dragonfly algorithm exclusively for network reconfiguration problem. Singh[12] proposed a bit shift based Particle Swarm Optimization to solve the problem of feeder reconfiguration for different load models in a power distribution system.

Damodar Reddy[13] described an Particle Swarm Optimization (PSO) for maximum savings using capacitor

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placements and locations are identified by fuzzy approach. El-Fergany[14] proposed an evolutionary algorithm of optimal capacitor allocation for annual net savings. Satish[15] proposed Bat Algorithm(BA) and Cuckoo Search (CS) algorithm for the placement of fixed size and variable size of capacitors for real loss minimization and maximum network savings. Hamed[16] proposed an competent algorithm is called graph theory striking a mixed integer programming for reconfiguration problem with radiality constraint. Mostafa[17], described to solve Network reconfiguration problem and capacitor placement are used to decrease real power losses and to maintain voltage profiles within acceptable limits in distribution networks. Gnanasekaran[18], presented a new efficient technique is called Shark Smell Optimization (SSO) algorithm used to find optimal size and position of shunt capacitors with the objective of reducing the cost due to energy loss and reactive power compensation.

This paper proposes(i) Reconfiguration using simultaneous switching (ii) Capacitor installations for the original network. (iii) Capacitor allocations for the reconfigured network using fuzzy and ALO algorithm The proposed ALO algorithm has been tested on a standard IEEE 33- bus and 69-bus test systems.

PROBLEM FORMULATION

The complex power injected into the bus n is given [13] by

$$S_{L,n} = P_{L,n} + jQ_{L,n} = V_n . I_{L,n}^{*}$$

The load current at any bus n is given by

$$I_{L,n} = \left(\frac{P_{L,n} + jQ_{L,n}}{V_n} \right)^{*} = \frac{P_{L,n} - jQ_{L,n}}{V_n^{*}} \tag{1}$$

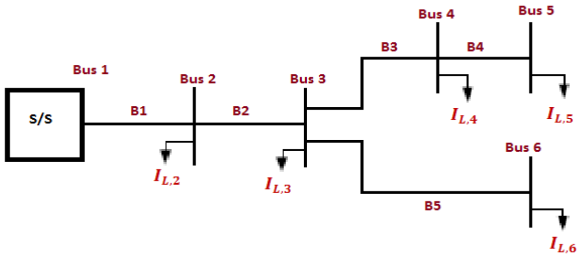

Figure 1: A Simple 6-bus radial distribution system

B. Load Flow Solution:

The relation[14] between load currents and branch currents can be found by using KCL equations as follows.

$$I_{B1} = I_{L2} + I_{B2} \tag{2}$$

$$I_{B2} = I_{L3} + I_{B3} + I_{B5} \tag{3}$$

$$I_{B3} = I_{L4} + I_{B4} \tag{4}$$

$$I_{B4} = I_{L5} \tag{5}$$

$$I_{B5} = I_{L6} \tag{6}$$

Thus, the relationship between load currents and branch currents can be expressed in matrix form as shown below.

$$[I_B] = [BIBC].[I_L] \tag{7}$$

C. Forward sweep

The receiving end voltages can be premeditated by forward sweeping across the line by subtracting the line section drop from the sending end voltages of the line section.

$$V_q(k) = V_p(k) - I_B(k) * Z_B(k) \tag{8}$$

D. Radiality constraint

All load buses must be connected to the source node. According to graph theory a tree satisfies the following equation.

$$N_{br} = N_{no} - 1 \tag{9}$$

Where, N_{br} is the number of branches and N_{no} is the number of nodes.

The proposed ALO algorithm is used for solving distribution network reconfiguration based on switching loops LSW33 [10] and LSW69 [11] for the checking radial structure of distribution network has been used in this approach.

E. Power losses:

The power losses in the distribution systems are real power loss and reactive power loss. The total real power loss in a balanced radial distribution system consisting of B branches can be written as

$$P_{LT} = \sum_{k=1}^{B} I_k^2 . R_k \tag{10}$$

F. Objective Function:

The objective function of the problem is formulated to exploit the power loss reduction in the radial distributed system, which is given by

$$Fitness\_Function = \min \{ P_{Loss} \} \tag{11}$$

The cost[14] related to capacitor compensation for the original and reconfigured network are calculated. On the other hand, the benefits due to peak power loss reduction of transmitted power in cables and transformers are neglected. Here, switching losses in the reconfiguration process are also neglected. The maximum annual savings per year is given by

$$S_N = C_1 * \Delta P_{LR} * T - C_2 * N_{\dim} - C_3 * \sum_{k=1}^{\dim} Q_C(k) \tag{12}$$

Where, S_N is the net savings in \$/year,

C_1 is a factor the energy losses converted into dollars,

C_2 is the installation cost of capacitors in dollars,

C_3 is a factor to convert the rating of capacitors into dollars,

T is the Total time period for an year in hours,

ΔP_{LR} is the system real power loss reduction in KiloWatts,

$N_{\dim}$ is the number of candidate buses for capacitors,

$Q_C(k)$ is the capacitor bank rating at bus k.

NETWORK RECONFIGURATION

The fundamental loops are determined for the meshed distribution network by closing all tie or secure switches. The number of fundamental loops on the meshed distribution network is equal to the number of tie-switches of the system and are given by the relation [3].

$$N_{li} = N_{ele} - N_{br} + 1 \tag{13}$$

Where,

N_{li} is the total number of links (Tie switches) for the distribution network. N_{ele} is the total number of elements i.e., sectionalizing plus tie-switches. N_{br} is the total number of branches. From Table 1, switching loops is designed by considering the real power loss constraint.

Basic configuration for 33-bus system = [33 34 35 36 37] and

Basic configuration for 69-bus system= [69 70 71 72 73] .

Table 1: Simultaneous Reconfiguration for 33 Bus

Test System	Loops corresponding to Possible Switchings				
	SW_1	SW_2	SW_3	SW_4	SW_5
33 Bus System	33	35	36	37	34
	6	8	15	22	12
	7	9	16	23	13
	--	10	17	24	14
	--	11	29	25	--
	--	--	30	26	--
	--	--	31	27	--
	--	--	32	28	--
Test System	Loops corresponding to Possible Switchings				
	SW_1	SW_2	SW_3	SW_4	SW_5
69 Bus System	72	71	73	69	70
	46	11	21	9	15
	47	12	22	10	16
	48	13	23	--	17
	49	14	24	--	18
	52	--	25	--	19
	53	--	26	--	20
	54	--	59	--	--
	55	--	60	--	--
	56	--	61	--	--
	57	--	62	--	--
	58	--	63	--	--
	--	--	64	--	--

Here, LSW is used for the optimal switching corresponding to minimum loss in each loop while maintain the radial structure in the distribution systems [13].

ANT LION OPTIMIZATION (ALO)

This manuscript also proposed a new algorithm called Ant Lion Optimizer [9] as an alternative approach for solving optimization problems. As its name implies, the ALO algorithm imitates the intelligent exploits of antlions in hunting ants in environment.

Antlions (doodlebugs) belong to the Myrmeleontidae family and Neuroptera order (net-winged creatures). The lifecycle of antlions includes two main phases: larvae and adult. A natural total lifespan can take up to 3 years, which mostly occurs in larvae (only 3–5 weeks for adulthood). Antlions undergo metamorphosis in a cocoon to become adult. They mostly hunt in larvae and the adulthood period is for reproduction.

The ALO algorithm mimics relations between antlions and ants in the trap. To mould such dealingss, ants are essential to move over the search space, and antlions are authorized to hunt them and grow to be fitter using traps. Since ants travel stochastically in nature when searching for food, a random walk using rolette wheel is chosen for modelling ants movement. In order to keep the random walks inside the search space, they are normalized min–max normalization using the following equation.

$$X = \left[0, CumSum\left(2*\left(rand\left(\max\_iter,1\right)>0.5\right)-1\right)\right]$$

$$RW\left(i\right) = X(i) = \frac{\left(\left(X-a\right).*\left(d-c\right)\right)}{\left(b-a\right)} + c \tag{14}$$

Where $a = \min\left(RandomWalk\right)$

$b = \max\left(RandomWalk\right)$

$c = lb\left(dim\right)$

$d = ub\left(dim\right)$

Implementation of the Projected ALO Algorithm:

Step 1: Initialize the parameters. Initialize the positions of antlions and ants.

Step 2: Set boundaries (upper bound and lower bound) and dimensions to the parameters that are to be optimized.

Step 3: Initialize variables to save the position of elite, sorted antlions to the parameters.

Step 4: Calculate the fitness of initial antlions and sort them.

Step 5: Run the basic load flow to obtain the real and reactive power losses and voltage profile before optimization.

Step 6: Calculate the initial fitness for antlions and sort them.

Step 7: Main loop started from the second iteration since the first iteration was dedicated to calculating the fitness of antlions.

Step 8: Main loop is simulate random walks. Select ant lions based on their fitness i.e., the better anlion having the higher chance of catching ant.

Step 9: The ant position can be calculated as

$$ant\_position(i) = \frac{\left[RA\left(C_{it}\right) + RE\left(C_{it}\right)\right]}{2} \tag{14}$$

Where, RA is the random walk around the selected antlion and RE is the random walk around the elite by rolette wheel.

Step 10: Check the Boundaries for position. Bring back the antlions of ants inside search space, if they go beyond the boundaries. Update the ant position by eq.(15).

$$ant\_position(i) = \left(ant\_position(i).*\left(\sim\left(Flag4ub + Flag4lb\right)\right)\right) \\ + ub.*Flag4ub + lb.*Flag4lb \qquad (15)$$

Step 11: Update antlion positions and fitnesses based on the ants, if an ant becomes fitter than an antlion we assume it was cought by the antlion and the antlion update goes to its position to build the trap.

Step 12: Update the Convergence curve upto max iterations.

Step 13: Display the best score which gives the optimum result with respect to best ant position.

Table 2: Control Parameters for ALO algorithm

parameters	ALO
SearchAgents	40
Max no of iter	50
No.of dim	5
Lower Bound	1
Upper Bound	8 (for 33-bus) 13 (for 69-bus)
Best Score	Elite antlion fitness
Best Position	Elite antlion position

RESULTS

Optimal locations of capacitors are identified using fuzzy approach and ALO method is used to find the sizes of the capacitors for original and reconfigured networks. These methods are applied to standard IEEE 33-bus and 69-bus systems. In all calculations the control parameters are, $C_1 = \$0.06 / kWh; C_2 = \$1000 / each\_Location; C_3 = \$3 / kVAr$ $T = 8760 hours / year$.

Optimal Location of Shunt Capacitor:

Fuzzy approach is used to identify the capacitor locations[8]. For the 33-bus sytem, the capacitor placement suitability index (CPSI) value greater than or equal to 0.75 are considered for capacitor location. Node 30 is selected for the optimal capacitor placement. For the 69-bus sytem, the capacitor placement suitability index (CPSI) value greater than or equal to 0.75 are considered for capacitor location. Node 61 is selected for the optimal capacitor placement for the original and reconfigured network.

IEEE 33-Bus test system:

The 33 bus system of 100MVA, 12.66KV, IEEE 33-bus test system with 37 branches, 32 sectionalizing switches and 5 tie switches. The total substation loads for the basic configuration are 4715 kW and 2300 kVAr [8]. By using fuzzy approach, the top ten locations obtained according to the CPSI values are [30, 32, 31, 8, 29, 7, 14, 18, 33, 6]. Here, the capacitors are installed based on CPSI values which is greater than or equal to 0.75 for 33-bus system, which are shown in Table 3. The simultaneous reconfiguration results for 33-bus system are shown in Table 4.

Table 3: Capacitor Results for 33 bus system

Bus Number	30
Capacitor Size in kVAr	1314.8803
Total Real Power Loss before capacitor placement in kW	369.2558
Total Real Power Loss before capacitor placement in kW	297.9886
Loss Reduction	71.2672
% Loss Reduction	19.30 %

Table 4: Simultaneous Reconfiguration for 33 bus system

Total real power loss of the original network	369.2558 kW
Optimal Switchings for Reconfiguration	7, 9, 31, 28, 14
Total real power loss of the reconfigured network	238.2888 kW
Loss reduction after optimal reconfiguration	35.47 %
Location of capacitors for RCG network	30
Size of capacitor (kVAr)	1112.5776
Total real power loss after capacitor placement for the reconfigured network	203.1939 kW
% Loss reduction after capacitor placement for the reconfigured network	44.97 %

From Table 2, the real power loss for the original network was **369.2558 kW** and after capacitor placement by using the projected ALO algorithm, power loss is reduced to **297.9886 kW**. From Table 3, the real power loss for reconfigured network was **238.2888 kW** and after capacitor placement for the reconfigured network the power loss is reduced to **203.1939 kW**. The comparison of loss reduction, Energy savings[14] and net savings of capacitor placement for the original and reconfigured network are shown in Table 5. The annual energy savings are \$ 37,458 and \$ 87,282 with capacitor installations for the original and reconfigured network for 33-bus system. Moreover, the annual net benefits are \$ 32,513 and \$ 82,944 with capacitor installations for the original and reconfigured network for 33-bus system.

Table 5: Final Results of 33-Bus System

Point of comparison	Capacitors for original network	Capacitors for reconfigured network
Initial Loss	369.2558 kW	238.2888 kW
Final Loss	297.9886 kW	203.1939 kW
Loss Reduction	71.2672 kW	166.0619 kW
Energy Savings	$ 37,458	$ 87, 282
Compensation	$ 4,945	$ 4,338
Net Savings	$ 32,513	$ 82,944

IEEE 69-Bus test system

The final configuration of the 100MVA, 12.66kV, IEEE 69-bus test system with 73 branches, 68 sectionalizing switches and 5 tie switches as shown in fig 4. The total substation loads for the basic configuration are 3.8022 MW and 2.6946 MVAr [4]. By using fuzzy approach, the top ten locations obtained according to the CPSI values are [61, 64, 59, 65, 62, 58, 25, 17, 18, 19]. Here, the capacitors are installed based on CPSI values which is greater than or equal to 0.75, which are shown in Table 6. The simultaneous reconfiguration results are shown in Table 7.

Table 6: Capacitor Results for 69 bus system

Bus Number	61
Capacitor Size in kVAr	1329.9980
Total Real Power Loss before capacitor placement in kW	225.0044
Total Real Power Loss before capacitor placement in kW	152.0446
Loss Reduction	72.9598
% Loss Reduction	32.43 %

Table 7: Simultaneous Reconfiguration for 69 bus system

Total real power loss of the original network	225.0044 kW
Optimal Switchings for Reconfiguration	57,14,61,69,70
Total real power loss of the reconfigured network	99.6216 kW
Loss reduction after optimal reconfiguration	55.72 %
Location of capacitors for RCG network	61
Size of capacitor (kVAr)	1049.9715
Total real power loss after capacitor placement for the reconfigured network	73.5478
% Loss reduction after capacitor placement for the reconfigured network	67.31 %

From Table 5, the real power loss for the original network was **225.0044 kW** and after capacitor placement by using the projected ALO algorithm, power loss is reduced to **152.0446 kW**. From Table 6, the power loss for reconfigured network was **99.6216 kW** and after capacitor placement for the reconfigured network the power loss reduced to **73.5478 kW**. The comparison of loss reduction, Energy savings[14] and net savings of capacitor placement for the original and reconfigured network are shown in Table 8.

Table 8: Final Results of 69-Bus System

Point of comparison	Capacitors for original network	Capacitors for reconfigured network
Initial Loss	225.0044 kW	99.6216 kW
Final Loss	152.0446 kW	73.5478 kW
Loss Reduction	72.9598 kW	151.4566 kW
Energy Savings	$ 38,348	$ 79,606
Compensation	$ 4,990	$ 4,150
Net Savings	$ 33,358	$ 75,456

The annual energy savings are $38,348 and $79,606 with capacitor installations for the original and reconfigured network for 69-bus system. Moreover, the annual net benefits are $ 33,358 and $ 75,456 with capacitor installations for the original and reconfigured network for 69-bus system.

CONCLUSION

In this paper, Reconfiguration using simultaneous switching is implemented. The Capacitor installations for the original and reconfigured network applied sucessfully. The reduction in power losses leads to energy savings with capacitor placement for the original and reconfigured network. In this paper, the Ant Line Optimization algorithm is successively applied to capacitor allocation for original and reconfigured network. The power loss reduction for the original network is 19.3% and 32.43% with capacitor installation for 33-bus and 69-bus respectively. The power loss reduction is 44.97% and 67.31% with capacitor installation for the reconfigured network of 33-bus and 69-bus respectively. Results show the considerable reduction in losses and significant increase in the energy savings of the original and reconfigured network.

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REFERENCES

[1] A. Merlin, H. Back: "Search for a minimal-loss operating spanning tree configuration in an urban power distribution system," *5th Power System Computation Conf. (PSCC),* Cambridge, U.K., 1975, pp. 1–18.

[2] D.Das, D.P.Kothari and A.Kalam, "Simple and efficient method for load flow solution of Radial distribution networks", *Electrical Power & Energy Systems,* vol.17, no.5, pp.335-346, 1995.

[3] D. Shirmohammadi and H. W. Hong, "Reconfiguration of electric distribution networks for resistive line losses reduction" *IEEE Trans. Power Del.,* vol. 4, no. 2, pp. 1492–1498, Apr. 1989.

[4] S. K. Goswami and S. K. Basu, "A new algorithm for the reconfiguration of distribution feeders for loss minimization" *IEEE Trans.Power Del.,* Vol.7, No.3, pp1484-1491, July1992.

[5] Y. J. Jeon and J. C. Kim, "Network reconfiguration in radial distribution system using simulated annealing and tabu search", in *IEEE Power Eng.soc.* Winter Meeting, 2000.

[6] B.Venkatesh, Rakesh Ranjan "Optimal radial distribution system reconfiguration using fuzzy adaption of evolutionary programming", *Electrical Power and Energy Systems* 25, pp.775–780, 2003.

[7] Yuji Mishima, Koichi Nara, Taiji Satoh, Takamitsu Ito, "Method for Minimum-Loss Reconfiguration of Distribution System by Tabu Search", *Electrical Engineering in Japan*, Vol. 152, No. 2, 2005 p.p. 1149-1155, March 2005.

[8] M. Damodar Reddy, Prof. V.C.Veera Reddy "A two-stage methodology of optimal capacitor placement for the reconfigured network", *Indian Journal of Engineering and Material Sciences*, ISSN: 1819-6608, Vol-17, p.p. 105-112, March 2008.

[9] Seyedali Mirjalili, "The Ant Lion Optimizer", *Advances in Engineering Software*, 83, pp.80–98, 2015.

[10] A. V. Sudhakara Reddy, Prof. M. Damodar Reddy, "Optimization of network reconfiguration by using particle swarm optimization", *IEEE,* 2016.

[11] A. V. Sudhakara Reddy, Prof. M. Damodar Reddy, "Optimization of distribution network reconfiguration using dragonfly algorithm", *Journal of Electrical Engineering,* Vol.16, Edition.4, No.30, pp.273-282, ISSN:1582-4594, Mar 2017.

[12] Akansha Singh, Sudhansu Kumar Mishra, Deepak Kumar and Rakesh Chandra Jha, "Optimal Reconfiguration of Primary power Distribution System using Modified Teaching Learning based Optimization Algorithm", *IEEE*, 2016.

[13] M. Damodar Reddy and V.C. Veera Reddy, "Capacitor placement using fuzzy and Particle Swarm Optimization method for maximum annual savings" *ARPN Journal of Engineering and Applied Sciences*, Vol-3, No-3, p.p. 25-30, June – 2008.

[14] Attia El-Fergany "Optimal Capacitor Allocations using evolutionary algorithms", *IET Generation, Transmission & Distribution*, pp.593-601, 2013.

[15] Satish Kumar Injeti, Vinod Kumar Thunuguntla, Meera Shareef, "Optimal allocation of capacitor banks in radial distribution systems for minimization of real power loss and maximization of network savings using bio-inspired optimization algorithms", *Electrical Power and Energy Systems,* 69, pp.441–455, 2015.

[16] Hamed Ahmadi, José R. Martí, "Mathematical representation of radiality constraint in distribution system reconfiguration problem", *Electrical Power and Energy Systems,* 64, pp.293–299, 2015.

[17] Mostafa Sedighizadeh, Reza Bakhtiary, "Optimal multi-objective reconfiguration and capacitor placement of distribution systems with the Hybrid Big Bang–Big Crunch algorithm in the fuzzy framework", *Ain Shams Engineering Journal,* 7, pp.113–129, 2016.

[18] N. Gnanasekaran, S. Chandramohan, P. Sathish Kumar, A. Mohamed Imran, "Optimal placement of capacitors in radial distribution system using shark smell optimization algorithm", *Ain Shams Engineering Journal,* 2016.