International Journal of Emerging Technology in Computer Science & Electronics (IJETCSE)
ISSN: 0976-1353 Volume 20 Issue 2 – FEBRUARY 2016.

OPTIMAL LOCATION OF CAPACITORS AND CAPACITOR SIZING IN A RADIAL DISTRIBUTION SYSTEM USING KRILLHERD ALGORITHM

SA.ChithraDevi[#] and Dr. L. Lakshminarasimman[*]

[#]Research Scholar, [*]Associate Professor, Department of Electrical Engineering, Annamalai University,
Annamalai Nagar, India

***Abstract* - This paper presents a new meta-heuristic technique, krillherd algorithm for solving capacitor placement problem in radial distribution system (RDS). The algorithm predicted the optimal size of the capacitors and should be placed at the proper location for loss minimization and hence improvement in voltage. The krillherd algorithm is established along the biological herding behavior of krills. The method is implemented in 10 and 85 bus RDS test systems and the results are compared with other algorithms from the literature. The outcomes reveal the potency of the algorithm. The simulation is taken away on the MATLAB environment.**

***Keywords*: Capacitor placement, Krillherd algorithm, Power loss minimization, Radial distribution system (RDS),**

I. INTRODUCTION

From the studies, at the distribution side 13% of the total power is exhausted as ohmic losses caused by reactive current flowing in the network. Shunt capacitors are used for the reduction of reactive currents which consequences in loss minimization, power factor improvement, system security and better voltage regulation. The main steps of capacitor problem are (i) optimal location of capacitor units and (ii) sizing of capacitor units. Hence, getting the optimal position and size of capacitors plays a significant part in the planning and operation of an electrical system.

In [1], the authors gave a brief survey about the shunt capacitor problem in radial distribution system from the year 1956 to 2013.

The authors of [2] presented the overview of optimum shunt capacitor placement in distribution system based upon the techniques that is (i) analytical method (ii) numerical programming method (iii) heuristic method (iv) artificial intelligence methods (v) multidimensional problems. The authors also compared the results with Particle Swarm Optimization (PSO) on the basis of power losses reduction, voltage profile improvement, maximizing loadability and line limit constraint.

The authors of [3] gave a brief introduction and discussed various works done on the Shunt Capacitor Problem (SCP) till 2014. Also, they used two methods, namely sensitivity analysis for searching suitable locality of capacitors and gravitational search algorithm for selecting the size of capacitors.

From 2015, Artificial Bee Colony (ABC) algorithm [4], HCODEQ method [5], Bacterial Foraging Optimization Algorithm (BFOA) [6], monkey search optimization algorithm [7], Bat and Cuckoo search algorithm [8], Particle Swarm Optimization (PSO) [9], [10] and flower pollination optimization algorithm [11] are applied for solving optimal capacitor placement and sizing in the RDS.

The main drawback in all the above methods is poor convergence speed and obtaining near optimal solutions. This is overcome by presenting one of the new bio – inspired algorithm, namely Krill herd algorithm is used for solving the capacitor optimization problem. RDS active power loss minimization is taken as an objective function subjected to various constraints namely voltage limit, reactive power limit and capacitor location and an optimum solution is obtained using KH algorithm.

In this proposed approach, the following assumptions are taken:

- Harmonics effect is neglected.
- The system is within the acceptable balance tolerance.
- Bus 1 is always considered as slack/swing

II. OBJECTIVE FUNCTION & CONSTRAINTS

Minimization of the system power loss is the main objective function which subject to various equality and inequality constraints of a distribution network, by determining the optimal placement and sizing of Capacitor using KHA.

Minimization of loss

Objective function $F = \min(P_{Loss})$

$P_{loss} = P_{inj} - \Sigma P_D$

Constraints

1. Voltage limit

$V_a^{min} < V_a < V_a^{max}$

2. Reactive power limit

$$Q_{a,min}^{Cap} \le Q_a^{Cap} \le Q_{a,max}^{Cap}$$

3. Capacitor location

$1 < Cap_{loc} < n$; n = number of buses

III. PROBLEM FORMULATION & ALGORITHM

A. Load flow equations

The radial distribution system has high R/X ratio. Due to that the classical load flow techniques Newton - Raphson and Gauss - Seidal methods are not suited for solving RDS load flow problem. From [12], basic formulation of Kirchhoff's laws is used for finding out the power flow in the system. RDS Load flow solution method steps:

1. Read system data.
2. Assuming a flat voltage profile for the initial voltages at all other nodes.
3. Calculate specified power injection at node a, $S_a = P_D^a + j\, Q_D^a$ for a = 1 to n. n – Number of nodes.
4. Set iteration count iter = 1 and I_{max} is the maximum number of iterations.
5. Calculate the nodal current (Bus current).

$$I_a^{iter} = \left[\frac{S_a}{V_a^{iter-1}}\right]^*$$

6. Backward Sweep:
   Calculate the branch currents. Starting from the last layer and moving towards the first node, the current at branch B is given by,

$$i_B^{iter} = -I_{B2}^{iter} + \sum currents\ in\ branches\ originatig\ from\ node\ B2.$$

$$where\ B = b, b-1, \ldots..1$$

   I_{B2} current injection at node B2
7. Forward Sweep:
   Calculate the node voltage.

$$V_{B2}^{iter} = V_{B1}^{iter} - Z_B i_B^{iter}$$

$$where\ B = 1, 2, \ldots\ldots b\ number\ of\ branches$$

   Z_B – Series impedance of branch B
8. Increment the iteration count iter = iter+1 until iter reaches I_{max}.
9. Calculate the power injection at bus 1.

$$S_{inj}^1 = V_{inj}^1 \left(I_{inj}^1\right)^*$$

10. Calculate
    P_{inj} = real (S_{inj})
    Q_{inj} = imag (S_{inj})
    $P_{loss} = P_{inj} - \Sigma P_D$
    $Q_{loss} = Q_{inj} - \Sigma Q_D$
11. Print the results.

B. Overview of krillherd algorithm

Krillherd Algorithm is a biologically inspired swarm intelligence algorithm which is proposed by Gandomi and Alavi in [13]. In this population based algorithm, each krill individual has a fitness function which is defined by its distances from food and highest density of the swarm. Each krill individuals modify its position using 3 processes, namely (i) movement induced by other krill individuals (local) (ii) foraging motion (global) (iii) random physical diffusion. The fitness (imaginary distances) is the value of the objective function.

The n dimensional decision space is given by

$$\frac{dX_i}{dt} = N_i + F_i + D_i \qquad \textbf{(1)}$$

where, N_i - movement induced by other krill individuals
F_i - foraging activity
D_i - random diffusion

To find N_i:

For each krill individual the movement is given by,

$$N_i^{new} = \left[N^{max} \left\{\sum_{j=1}^{NN} \left[\frac{K_i - K_j}{K_{worst} - K_{best}}\right] \left[\frac{X_j - X_i}{\|X_j - X_i\| + \varepsilon}\right]\right\} \left\{2 \left(rand + \right.\right.\right.$$

IImaxKi,bestXi,best+ ωnNiold

(2)

To find F_i:

The foraging motion depends on food location and previous experience about food location.

$$F_i = V_f \left\{2 \left(1 - \frac{I}{I_{max}}\right) \widehat{K_{i,food}}\, \widehat{X_{i,food}} + \widehat{K_{i,best}}\, \widehat{X_{i,best}} \right\} + \omega_f F_i^{old} \qquad \textbf{(3)}$$

To find D_i:

The physical diffusion of the krill individual is a random process.

$$D_i = D^{max} \left(1 - \frac{I}{I_{max}}\right) \delta \qquad \textbf{(4)}$$

Motion process of KHA:

The position vector is given by

$$X_i(t + \Delta t) = X_i(t) + \Delta t \frac{dx_i}{dt}$$

(5)

where $\Delta t = C_t \sum_{j=1}^{NV} (UB_j - LB_j)$

$\frac{dX_i}{dt} = N_i + F_i + D_i$ from equation (1).

If the related fitness value of each of the above mentioned effective vector (K_i, K^{best}, K^{food} or K_i^{best}) is better than the fitness of the ith krill it has an attractive effect else repulsive effect.

Genetic Operators:

1. *Crossover:*

$$X_{i,m} = \begin{cases} X_{r,m} & rand_{i,m} < C_r \\ X_{i,m} & else \end{cases} \qquad \textbf{(6)}$$

$$C_r = 0.2\, \widehat{K_{i,best}}$$

r ϵ{1,2, …i-1,i+1, …N}

2. *Mutation:*

$$X_{i,m} = \begin{cases} X_{gbest,m} + \mu(X_{p,m} - X_{q,m}) & rand_{i,m} < \\ X_{i,m} & \end{cases} \quad (7)$$

$$Mu = 0.05/\widehat{\mathrm{K}_{\mathrm{i,best}}}$$

p,q ϵ{1,2, …i-1,i+1, …K} and μ is between 0 and 1

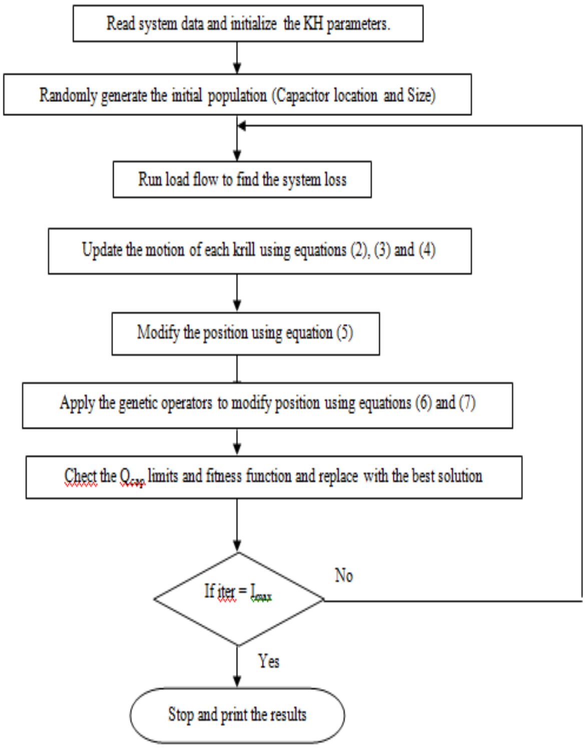
C. Application of the krillherd algorithm to the OCP problem

In [14], the authors used the krillherd algorithm for the solution of the economic load dispatch problem.

1. Read system data, dimension of the problem, KHA parameters and number of iterations.
2. Randomly generate the initial population of the size and location of capacitors and regularized between the maximum and minimum limits.
3. Run the load flow in order to find the system losses.
4. Update motion of each krill individual by induced motion, foraging motion and random diffusion using the equations (1), (2) and (3) respectively.
5. Modify the position of each krill individual using equation (5).
6. Applying crossover and mutation to modify the position of each krill individual using equations (6) and (7) respectively.
7. Check for the limits of individual Capacitor – size variables; if it violates then set the minimum or maximum value.
8. Check the fitness function; the unfeasible solution is replaced by the solution with the best previously visited position.
9. Go to step 3 and repeat the procedure from step 3 to 8 until the maximum number of iterations is reached.

Here the stopping criterion is the number of iterations.

D. Flowchart for the krill herd algorithm application to capacitor problem



IV. TEST CASE AND RESULT COMPARISON

The krillherd algorithm is implemented on the 10 and 85 IEEE radial test system. The software program is developed in the MATLAB 2009a environment and executed on Intel Core processor i3 – 2120 CPU with 3.30GHz. The results are enlightened below in detail.

Case 1: 10 bus system

23kV RDS has 10 buses and 9 branches with a total load of (12.368 + j 4.186) MVA is taken from [15] is the first test system. The uncompensated system losses are 783.7895 kW. After the application of proposed algorithm, the system is compensated with 4908.8396 kVAr and the system losses decreased to 682.7651 kVAr. From Table (1), it is revealed that the results are efficient when compared to PSO algorithm [10]. Fig. (1) shows the power loss reduction with respect to iterations and Fig. (2) illustrates the voltage improvement after the capacitor compensation.

Table (1)

Items	Un - compensated	Compensated
	Proposed method	
Total losses (kW)	**783.7895**	**682.7651**
% Loss reduction	–	**12.89**
Minimum voltage	0.8375/10	0.8807/10
Capacitor location & size (kVAr)	–	5/3297.6421 9/499.6666 6/1111.5309
Total kVAr	–	4908.8396

PSO [10]		
Total losses (kW)	**787.778**	**698.14**
% Loss reduction	–	**11.38**
Total kVAr	–	4050

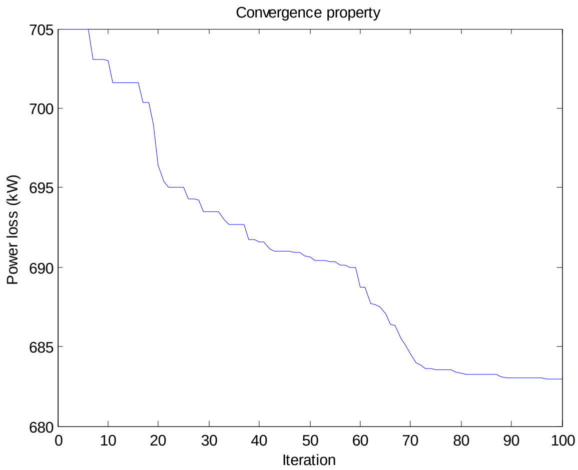


Fig. (1) Power loss reduction for 10 bus system

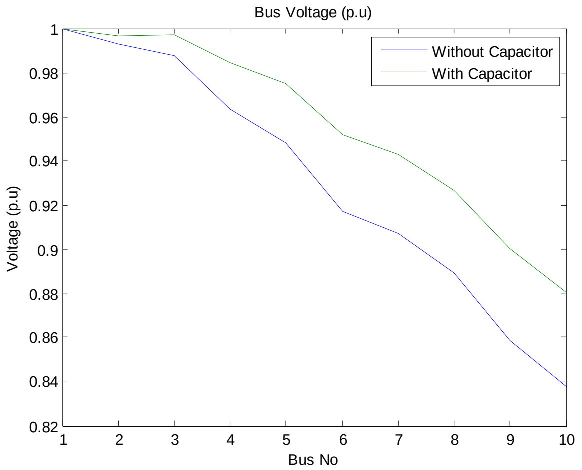


Fig. (2) Bus voltage improvement with and without capacitor

Case 2: 85 bus system

11kV rural RDS having 85 buses with total load of (2549.56 + j 2601.066) kVA is taken as large scale test system from (16). The total losses without capacitor compensation are 311.4145 kW. Network losses get reduced to 142.7877kW after the application of capacitors with a total capacity of 2322.6632kVAr at various nodes. The results are given in Table (2) and made a comparison with GSA [3] and bio-inspired algorithm [8]. Fig. (3) explains the convergence property and Fig. (4) point up the voltage improvement after the capacitor compensation.

Table (2)

Items	Un - compensated	Compensated
Proposed method		
Total losses (kW)	**311.4145**	**142.7877**
% Loss reduction	–	**54.15**
Minimum voltage	0.8707/54	0.9213/54
Capacitor location & size (kVAr)	–	23/141.155 58/316.752 8/155.6012 80/347.245 48/288.1133 68/340.3576 33/370.6198 26/362.8193
Total kVAr	–	2322.6632
GSA [3]		
Total losses (kW)	**315.714**	**143.019**
% Loss reduction	–	**54.69**
Total kVAr	–	1050 (at 6 locations)
Bio-inspired algorithm [8]		
Total losses (kW)	**316.84**	**145.743**
% Loss reduction	–	**54.0**
Total kVAr	–	2250 (at 8 locations)

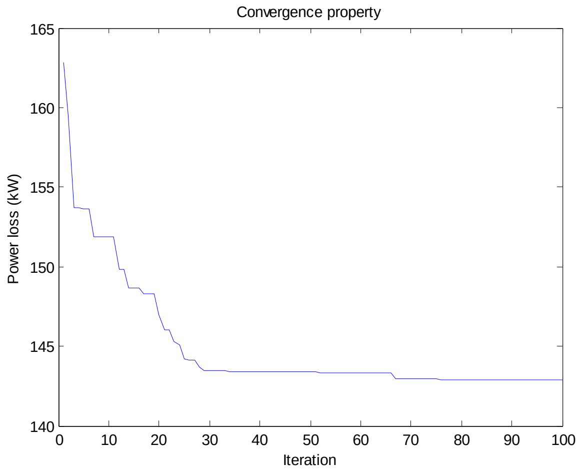


Fig. (3) Power loss reduction for 85 bus system

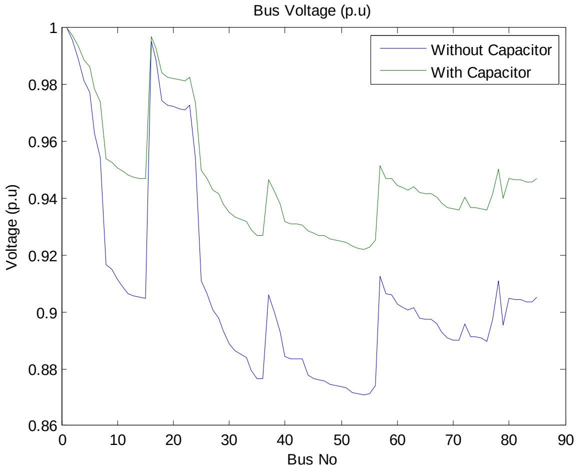


Fig. (4) Bus voltage improvement with and without capacitor

CONCLUSION

This paper has presented krillherd algorithm for capacitor placement and sizing problem in radial distribution system. From the results it is revealed that the algorithm gives the optimal solution when compared to ther methods from literature. Reconfiguration and including system cost as an objective with loss are the future scopes for this work.

REFERENCES

[1] Shilpa Kalambe , Ganga Agnihotri, "Loss minimization techniques used in distribution network: bibliographical survey," *Renewable and Sustainable Energy Reviews*, vol. 29, pp.184–200, 2014.

[2] M.M. Aman , G.B.Jasmon , A.H.A.Bakar , H.Mokhlis , M.Karimi , "Optimum shunt capacitor placement in distribution system — A review and comparative study," *Renewable and Sustainable Energy Reviews*, vol. 30, pp. 429 – 439, 2014.

[3] Y. Mohamed Shuaib, M. Surya Kalavathi , C. Christober Asir Rajan, "Optimal capacitor placement in radial distribution system using Gravitational Search Algorithm," *Electrical Power and Energy Systems*, vol. 64, pp.384 – 397, 2015.

[4] Marjan Tavakoli , Mahdi Mozaffari Legha, Sajad Salehi, Sarbijan, Mehran Montazer, "Capacitor placement in radial distribution system for improve voltage profile and loss reduction using artificial bee colony," *WALIA journal*, vol. 31(S3), pp. 44 – 49, 2015.

[5] Ji-Pyng Chiou, Chung-Fu Chang, "Development of a novel algorithm for optimal capacitor placementin distribution systems," *Electrical Power and Energy Systems*, vol. 73, pp. 684 – 690, 2015.

[6] K.R. Devabalaji, K. Ravi, D.P. Kothari, "Optimal location and sizing of capacitor placement in radial distribution system using Bacterial Foraging Optimization Algorithm," *Electrical Power and Energy Systems*, vol. 71, pp. 383 – 390, 2015.

[7] Felipe G. Duque, Leonardo W. de Oliveira , Edimar J. de Oliveira, André L.M. Marcato, Ivo C. Silva Jr., "Allocation of capacitor banks in distribution systems through a modified monkey search optimization technique," *Electrical Power and Energy Systems*, vol. 73, pp. 420 – 432, 2015.

[8] 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 for minimization of real power loss and maximization of network savings using bio-inspired optimization algorithms," *Electrical Power and Energy Systems*, vol. 69, pp. 441 – 455, 2015.

[9] Neeraj Kanwar, Nikhil Gupta, Anil Swarnkar, K. R. Niazi, R.C. Bansal, "New Sensitivity based Approach for Optimal Allocation of Shunt Capacitors in Distribution Networks using PSO," *Energy Procedia*, vol. 75, pp. 1153 – 1158, 2015.

[10] Chu-Sheng Lee, Helon Vicente Hultmann Ayala, Leandro dos Santos Coelho, "Capacitor placement of distribution systems using particle swarm optimization approaches," *Electrical Power and Energy Systems*, vol. 64, pp. 839 – 851, 2015.

[11] A.Y. Abdelaziz, E.S. Ali, S.M. Abd Elazim, "Optimal sizing and locations of capacitors in radial distribution systems via flower pollination optimization algorithm and power loss index," *Engineering Science and Technology, an International Journal* , 2015.

[12] D. Shirmoharmnadi H. W. Hong A**.** Semlyen G. X. Luo, "A Compensation based power flow method for weakly meshed distribution and transmission networks," *IEEE Transactions on Power Systems*, vol. 3, pp. 753 – 762, May 1988

[13] Amir Hossein Gandomi, Amir Hossein Alavi, " Krill herd: A new bio-inspired optimization algorithm," *International journal on Communications in Nonlinear Science and Numerical Simulation*, vol. 17, pp. 4831–4845, 2012.

[14] Barun Mandal, Provas Kumar Roy, Sanjoy Mandal, "Economic load dispatch using krill herd algorithm," *Electrical Power and Energy Systems*, vol. 57,pp. 1–10, 2014.

[15] S.K. Goswami, T. Ghose, S.K. Basu, "An approximate method for capacitor placement in distribution system using heuristics and greedy search technique," *Electric Power Systems Research*, vol. 51, pp. 143–151, 1999.

[16] D. Das, D.P. Kothari, A. Kalam, "Simple and efficient method for load flow solution of radial distribution network," *Electrical Power and Energy Systems*, vol. 17 (5), pp. 335–346, 1995.

NOMENCLATURE

K_i – fitness value of the ith krill individual (i = 1 to nk)
K_j – fitness value of the neighbor (j =1 to NN)
K_{worst} , K_{best} – worst and best fitness value of the krill individual
X – related position of the krill individual
ε – small positive number
N^{max} – maximum induced speed in ms^{-1}
I – actual iteration count
I_{max} – maximum iteration count
$\widehat{K_{i,best}}$ – best fitness value of ith krill
$\widehat{X_{i,best}}$ – position corresponds to $\widehat{K_{i,best}}$ of ith krill
ω_n – inertia weight of the motion induced, in the range of (0,1)
N_i^{old} – last motion induced
rand – random number between 0 and 1
N – number of krill individuals
V_f – foraging sped, ms^{-1}
ω_f – inertia weight of the foraging motion in the range (0, 1)
F_i^{old} – last foraging motion
D^{max} – maximum diffusion speed, $D^{max} \epsilon$ [0.01, 0.02] ms^{-1}
δ – random directional vector [-1 &1]
NV – total number of variables
C_t – constant between [0, 2]
UB, LB – upper and lower bound of the variables