ISSN 2229-5518

Simultaneous Reconfiguration and Optimal Capacitor Placement for Loss and Cost Reduction in Radial Distribution System

S.Anitha

Abstract—Power delivered to the consumers faces many disturbances in the distribution path. Power loss reduction and improvisation in voltage profile is necessary to provide power with good power quality. Individual network reconfiguration or capacitor placement cannot be effective during heavy loads. In this paper, Simultaneous reconfiguration and capacitor allocation in radial distribution system is carried out to minimize the real power loss and operating cost by using Johnson's and Modified Whale's Algorithm. Therefore, the proposed method is tested on standard IEEE 33 and 69 bus systems and their performances are compared with results obtained by Harmony Search and Simulated Annealing Algorithm.

Keywords—Network Reconfiguration, Johnson's algorithm, Optimal Capacitor Placement, Modified Whale's algorithm, Power loss reduction, Operating cost minimization.

I. Introduction

Distribution system is very essential to deliver power without any interruption. But due to its shorter line length the value of reactance is less than value of resistance with large R/X value, which leads to huge real power loss. Hence, it is necessary to minimize the loss in the distribution network to provide optimal power. Various methods have been used to minimize the real power loss. Network Reconfiguration and Optimal capacitor placement are among the different ways to minimize loss. Hence, switching of tie lines and utilization of shunt capacitors in radial distribution system helps to reduce the power loss and operating cost. Though the aim of the above two methods are same, they operate in different manner. But for heavy power loads individual reconfiguration and reactive power compensation (capacitor allocation) cannot be effective. If these two techniques are combined together, better results can be obtained than that of any one method.

In general, Reconfiguration is done by switching on the tie lines in order to alter the network structure. And the placing of shunt capacitor in network helps in reactive power compensation. Both methods help to increase the power quality and efficiency. Few authors worked only on network reconfiguration [1]-[5] without considering capacitor placement by using many shortest path algorithm. In [1] and [2] Kruskal's, Dijkstra's and Depth First search algorithms were used to create feasible radial topology. In [3], [4] and [5] various minimum spanning tree algorithms were used for reconfiguration in order to reduce the power loss and to improve the voltage profile. Usually individual reconfiguration results in 20% reduction in power loss.

Most researchers worked only on optimal sizing and locating of capacitor without considering network reconfiguration [6]-[11] by using many optimization techniques. In [6],[7] and [8] different optimization algorithm such as Genetic, Direct Search and Harmony Search algorithms were used to obtain 25% reduction in power loss and their results are compared with proposed technique for IEEE 33 bus system. In [9,[10] and [11] novel techniques such as Particle Swarm Optimization, Analytical and Evolutionary algorithms were used to attain 30% power loss reduction and their performance are compared with proposed method for IEEE 69 bus system. And also these methods results in minimization of operating cost.

Only few author worked with simultaneous reconfiguration and capacitor placement [12]-[18] by modified optimization techniques. In [12], [13], [14] and [15] combined reconfiguration and capacitor placement is done by techniques such as CB based Genetic, Ordinal optimization, sequential and Big Bang approach and In [16], [17] and [18] ordinary optimization technique such as Harmony Search, Simulated Annealing and Ant Colony algorithms were used for optimal placement. The above algorithms helps in 40% power loss and operating cost reduction.

Loss Sensitivity Analysis is one way to select most suitable bus for capacitor location. Many papers were published using LSI based optimization [19]-[23].Different techniques like Plant Growth Simulation, Backtracking Search were used in [19] and [20].In [21],[22] and [23] normal optimization algorithms like Flower Pollination, Ant Colony and Improved HS algorithms were used for locating shunt compensation. In [24] and [25] new optimization technique called Whale optimization algorithm are used for optimization. Thus, from the literature survey it is clear that combined reconfiguration with capacitor placement yields better loss reduction.

In this paper, Simultaneous reconfiguration and Capacitor placement of radial distribution network is implemented using two algorithms. Impedance based network reconfiguration is

Anitha.S, Assistant Professor, Department of Electrical and Electronics Engineering, IFET College of Engineering, Villupuram.

carried out using Johnson's algorithm and Whale's optimization algorithm is used for optimal capacitor placement. Here, Optimization is two-step process. In first step, Loss Sensitivity Indices is implemented to select most convenient bus for locating capacitor. In second step, Whale Optimization algorithm is employed to find the optimal location and sizing capacitor which includes minimization of power loss and capacitor cost.

This paper is organised as follows. Section II describes the Mathematical modelling. Section III explains about the Solution Methodology. Section IV explains the implementation of proposed work. And finally, Section V described the Results and Discussion.

II. MATHEMATICAL MODELLING

A. *Power flow calculation*

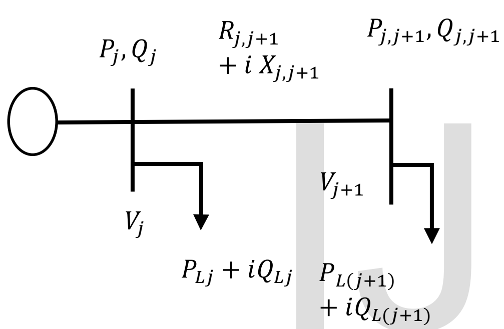


Fig 1.Simple Radial Distribution System

Power flow is very important in radial distribution system. To compute the power loss consider the single line diagram shown in Fig.1 where *j* is sending end node and *j+1* is receiving end node. The following set of equations describes the real and reactive power flows Equ. (1) and Equ. (2).

$$P_{j+1} = P_j - P_{L(j+1)} - R_{j,j+1} * \frac{\left(P_j^2 + Q_j^2\right)}{\left|V_j\right|^2} \quad (1)$$

$$Q_{j+1} = Q_j - Q_{L(j+1)} - X_{j,j+1} * \frac{\left(P_j^2 + Q_j^2\right)}{\left|V_j\right|^2} \quad (2)$$

The real power loss in the line can be calculated by using Equ.(3)

$$P_{loss}(j, j+1) = R_{j,j+1} * \frac{\left(P_j^2 + Q_j^2\right)}{\left|V_j\right|^2} \quad (3)$$

The Total power loss in the distribution system can be calculated by adding all the individual line losses as shown in Equ (4)

$$P_{Tloss} = \sum_{p=1}^{n-1} P_{loss}(j, j+1) \quad (4)$$

B. *Objective Function*

Generally, the objective function decides the optimization. In proposed work, the main objective is to minimize the real power loss and operating cost. The objective function is described in following equation

(a) Minimization of Real Power Loss

$$f_1 = \min\left(P_{Tloss}\right) = \min\left(\sum_{p=1}^{n-1} P_{loss}(j, j+1)\right) \quad (5)$$

(b) Minimization of Operating Cost

$$f_2 = \min\ (\cos t)$$

$$= \min\left(k_p \times P_{Tloss} + D\left(k_1 \times CB + k_c \times \sum_{i=1}^{CB} Q_{ci}\right) + k_o \times CB\right) \quad (6)$$

(c) Constraints

(i) Voltage limits

$$V_{\min} \le \left|V_j\right| \le V_{\max} \quad (7)$$

(ii) Capacitor limits

$$Q_{ci} \le \sum_{j=1}^{n} Q_{Lj} \quad (8)$$

C. *Loss Sensitivity Indices*

Loss Sensitivity Indices is used to list the load buses according to their vulnerability in finding the most suitable load buses for installing capacitors. It helps to avoid the necessity to check each load bus for locating capacitor. Loss Sensitivity Index can be obtained by taking first derivative of P_{loss} with respect to $Q_{L(j+1)}$ which results in following equation (9).

$$LSI = \frac{\partial P_{loss(j+1)}}{\partial Q_{L(j+1)}} = \frac{2 * Q_{L(j+1)} * R_{j,j+1}}{V_{j+1}^2} \quad (9)$$

The buses that contains highest values of LSI are considered as most suitable buses for capacitor allocation. The buses presented at the top of the list are more sensitive for reactive power compensation.

Thus, optimal location of capacitor can be done within reduced search space using Loss Sensitivity Index and sizing is based on power flow in algorithm.

NOMENCLATURE

P_j	*real power at sending node*
P_{j+1}	*real power at receiving node*
Q_j	*reactive power at sending node*
Q_{j+1}	*reactive Power at receiving node*
P_{Lj}	*real power load at sending node*
Q_{Lj}	*reactive power load at sending node*
P_{Lj+1}	*real power load at receiving node*
Q_{Lj+1}	*reactive power load at receiving node*
$R_{j,j+1}$	*resistance between j and j+1*
$X_{j,j+1}$	*reactance between j and j+1*
V_j	*voltage at node j*
P_{loss}	*real power loss between j and j+1*
P_{Tloss}	*Total real power loss*
K_p	*Cost per kwhour*
D	*Depreciation factor*
K_1	*Cost per installation*
CB	*Number of compensated bus*
K_c	*Cost per k var*
Q_{ci}	*Value of installed reactive power*
K_o	*Operating Cost*

III. SOLUTION METHODOLGY

Simultaneous reconfiguration and optimization is possible by following two algorithms. It includes Johnson's (shortest path) and Modified Whale's (optimization) algorithms.

A. *Johnson's Algorithm*

Johnson's algorithm is used to find the shortest path between all edges by considering their impedance.It is the combination of both Bellman-Ford and Dijkstra's algorithms.

The following are the steps involved in Johnson's algorithm

Step 1. Add a new node with zero weight edge and connect it to all other node.

Step 2. Run Bellman–Ford algorithm for each node at least once and the shortest path can be calculated using

Distance [V]>Distance [U] +Distance [U, V]

Step 3. Reweight every edge by using following formula to have all positive weight edge.

W (u, v) =W (u, v) +h (u)-h (v)

Step 4. Run Dijkstra's algorithm on each node using reweighted function with a condition that all the edges should be visited at least once.

Thus, network reconfiguration for loss minimization can be performed using Johnson's algorithm.

B. *Modified Whale's Algorithm*

The modified whale's algorithm is based on whale optimization algorithm.Here, Optimization is done by using special hunting mechanism. This technique creates spiral shaped bubbles by using upcoming mechanisms.

- Encircling Prey
- Bubble-net Attacking

✓ Encircling Prey

Humpback whales recognize the prey location and encircle them. This algorithm consider the current position as the best solution. After the best search agents are found, other search agents update their position towards best solution by using following equation

$$D = \left| C.X^*(t) - X(t) \right| \quad (10)$$

$$X(t+1) = X^*(t) - A.D \quad (11)$$

Where, t is the current iteration, A is co-efficient vector which is equal to *2.a.r-a* ,X is the current position and X^* is the best position. Here, a is linearly decreased from 2 to 0 and r is random vector [0 1].

✓ Bubble-net Attacking

In this mechanism, the distance between the whale and prey location is calculated and the helical shape is created by using equation (12)

$$X(t+1) = D^{'}.e^{bl}.\cos(2\prod l) + X^*(t) \quad (12)$$

Where,D' is the distance between whale and prey and b, l are constant value equal to 1.

The humpback whale swim around the prey using above two mechanism. To model this simultaneous behavior it is assumed with 50% probability to choose either mechanism to update the position of whales during optimization. The following is the mathematical model of this optimization technique.

$$X(t+1) = \begin{cases} X^*(t) - A.D & if \;\; p < 0.5 \\ D.e^{bl}.\cos(2\prod l) + X^*(t) & if \;\; p \geq 0.5 \end{cases} \quad (13)$$

ISSN 2229-5518

At each iteration, search agents update their positions with respect to best solution.

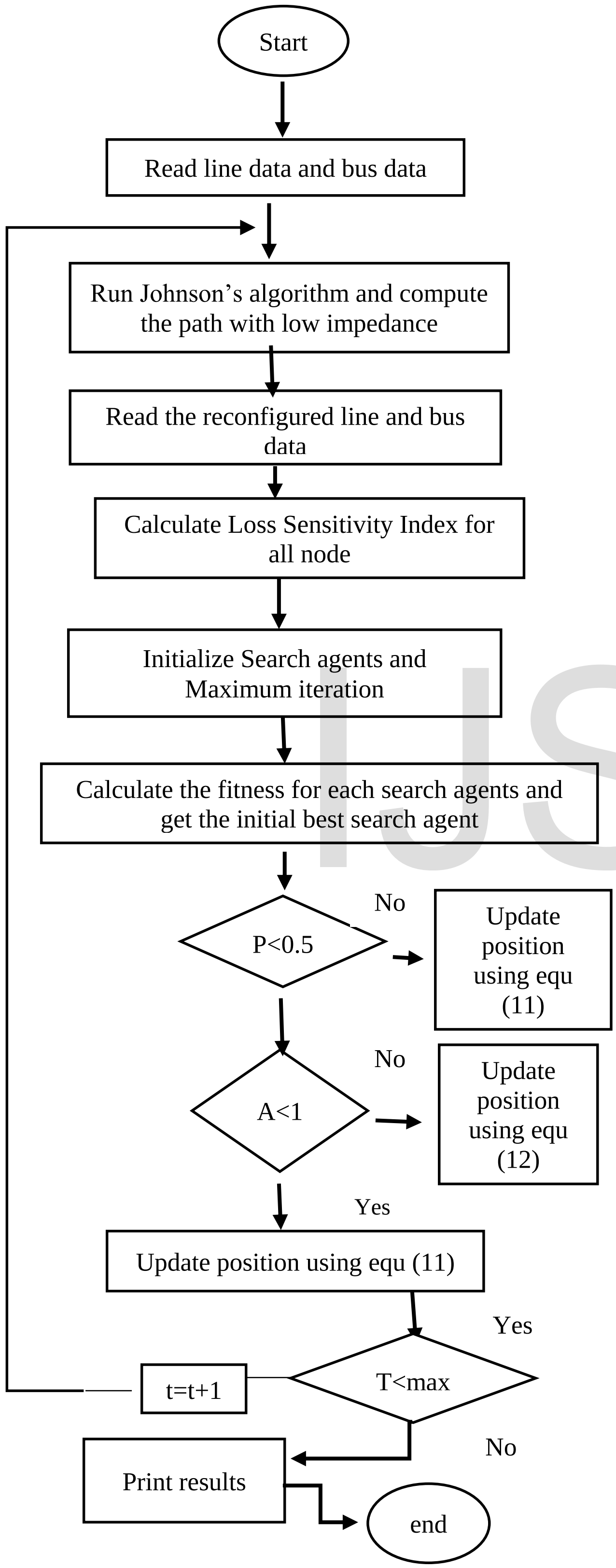


Fig.2.Flowchart of proposed work

Depends on the value of *p*, the algorithm switch between either spiral or circular movement.

IV. PROPOSED WORK

The Modified Whale Optimization Algorithm can be applied to find the optimal placement for capacitors using following steps:

Step 1: Initialize the input data's such as line impedance and load power.

Step 2: Calculate the total power loss, Operating cost and Voltage before compensation.

Step 3: Reconfiguration of network by tie line switches was done by using Johnson's algorithm and the path with low impedance path can be obtained. (For Case 1 and Case3 only, otherwise go to step 4)

Step 4: Initialize the search agents and maximum iterations for optimization.

Step 5: Calculate the fitness for each search agents and get the initial best search agent.

Step 6: Update *a, A, C, l and p* for each search agents

Step 7: Create the search space for capacitor location by considering Loss Sensitivity Index.

Step 8: Initially each whale is positioned at the starting bus and then decides the next node to be visited for optimal capacitor placement by using LSI

Step 9: If $p<0.5$ the go to step 10 otherwise go to step 12.

Step 10: If $|A|<1$, then update the position of the current search agent by using equation (10) and (11)

Step 11: If $|A|>1$ and $p>0.5$, Then calculate the new search agent and update its position using equation (12)

Step 12: Update the position of the current search agent by using equation (13)

Step 13: Go to *step 14*, if maximum iteration is reached, Else calculate the fitness function until counter is reached.

Step 14: Print the optimal solution.

Thus, individual and simultaneous reconfiguration and capacitor placement for loss minimization can be done by obeying above algorithmic steps.

In this algorithm, for case 2 step 3 is eliminated for optimal placement.

V. RESULTS AND DISCUSSIONS

The proposed methodology is implemented in two standard radial distribution system with different cases for loss minimization and optimization. Each system is examined with following three cases:

Case 1: Only reconfiguration.

Case 2: Only Optimal Capacitor Placement.

Case 3: Simultaneous Reconfiguration and Capacitor Placement.

A. *IEEE 33 BUS SYSTEM*

The IEEE-33 radial distribution system consists of 33 nodes, 37 edges with base kV 12.66 and base MVA 100.The Figure 3 shows the Single line diagram of IEEE-33 radial distribution system. The following tables describe about the performance of 33 bus system with three cases. The Table I shows the results of base system.

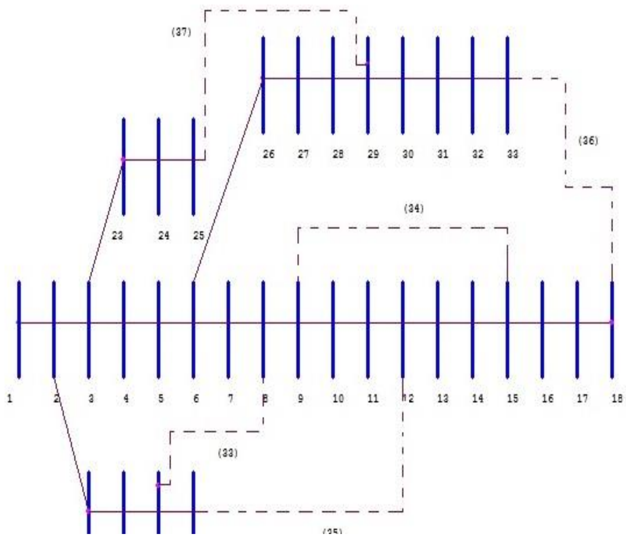


Fig 3.Single line diagram of IEEE 33 Radial distribution System

TABLE I 33-bus system: Base Case

Parameters	Results
Open Switches	33,34,35,36,37
Real Power loss (KW)	168.95
Voltage (p.u)	0.8867
Total Operating Cost($/Kvar)	95,661

From the Table I it is clear that Initially the system operates only with sectionalizing switches and all tie line switches are closed.It operates with total impedance of 10.819.

The results obtained after Case 1 : Only Reconfiguration is shown in Table II and the total minimum impedance obtained is 6.216 and results in 20.68% power loss reduction.In this case,36 sectionalizing switches and 1 tie line switches are closed and other tie line switches in intial configuration are opened.

TABLE II 33-bus system: Only Reconfiguration

Parameters	Results
Open Switches	33,34,35,36,37
Real Power loss (KW)	137.28
% Reduction in Power loss	20.68
Voltage (p.u)	0.9068

The results obtained after Case 2 : Only Capacitor placement is shown in Table III.It results with 21.82% power loss reduction and 19,217($/kvar) savings in Total operating cost. In this case,capacitors are placed at three different locations for loss and cost minimization.

TABLE III 33-bus system: Only Capacitor placement

Parameters	Results
Open Switches	33,34,35,36,37
Optimal Size (bus)	150 (24) 50 (25) 150 (30)
Real Power loss (KW)	135.718
% Reduction in Power loss	21.82
Voltage (p.u)	0.9032
Total Operating Cost ($/Kvar)	76,443
Savings ($/year)	19,217

The results obtained after Case 3: Simultaneous Reconfiguration and Capacitor placement is shown in Table IV.It results with 32.68% power loss reduction and 25,946 ($/kvar) savings in Total operating cost.In this case,Intially the network is reconfigured as in case 1 and then capacitor is

ISSN 2229-5518

placed at three optimal positions as in case 2.Thus MATLAB program is performed with simultaneous reconfiguration and capacitor.

TABLE IV 33-bus system: Simultaneous reconfiguration and capacitor placement

Parameters	Results
Open Switches	33,34,35,36,25
Optimal Size (bus)	400 (24) 250 (25) 150 (30)
Real Power loss (KW)	121.4956
% Reduction in Power loss	32.68
Voltage (p.u)	0.9163
Total Operating Cost ($/Kvar)	69,715
Savings ($/year)	25,946

The Figure 4 shows the voltage profile of all the above cases and frrom the figure it is clear that Voltage is well improved in case 3 than other cases.

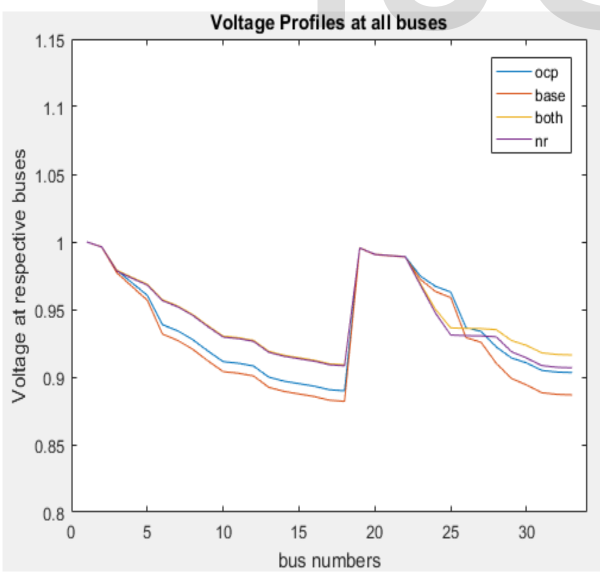


Fig 4. Voltage Profile of 33 bus system

B. IEEE-69 BUS SYSTEM

The IEEE-69 radial distribution system consists of 69 nodes and 68 edges with base MVA 100 and base KV 11. The Figure 5 shows the Single line diagram of IEEE-69 radial distribution system. The following tables describe about the performance of 69 bus system with three cases. The Table V shows the results of base system.

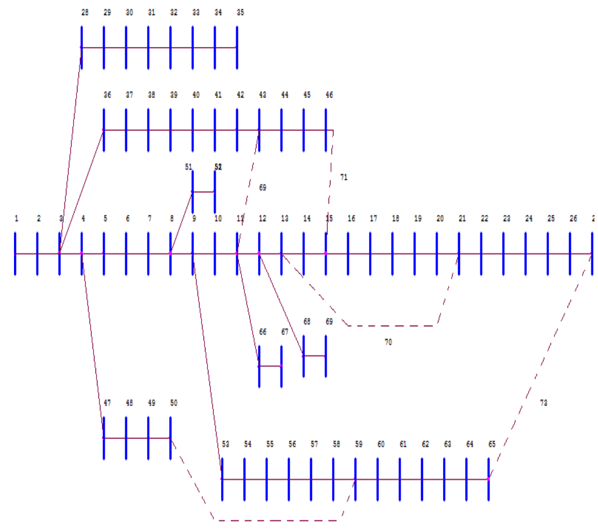


Fig 5.Single line diagram of IEEE 69 radial distribution system

TABLE V 69-bus system: Base Case

Parameters	Results
Open Switches	69,70,71,72,73
Real Power loss (KW)	202.36
Voltage (p.u)	0.9576
Total Operating Cost($/Kvar)	1,15,408

From the Table V it is clear that Initially the system operates only with sectionalizing switches and all tie line switches are closed.It operates with total impedance of 8.461

The results obtained after Case 1 : Only Reconfiguration is shown in Table VI and the total minimum impedance obtained is 3.639 and results in 7.06% power loss reduction.In this case,68 sectionalizing switches and 1 tie line switches are closed and other tie line switches in intial configuration are opened.

The results obtained after Case 2 : Only Capacitor placement is shown in Table VII.It results with 31.7% power loss reduction

TABLE VI 69-bus system: Only Reconfiguration

Parameters	**Results**
Open Switches	69,13,71,72,73
Real Power loss (KW)	188.56
% Reduction in Power loss	7.06
Voltage (p.u)	0.9628

and 29,556($/kvar) savings in Total operating cost. In this case,capacitors are placed at three different locations for loss and cost minimization.

The results obtained after Case 3: Simultaneous Reconfiguration and Capacitor placement is shown in Table VIII.It results with 41.72% power loss reduction and 41,400 ($/kvar) savings in Total operating cost.In this case,Intially the network is reconfigured as in case 1 and then capacitor is placed at three optimal positions as in case 2. Thus MATLAB program is performed with simultaneous reconfiguration and capacitor.

TABLE VII 69-bus system: Only Capacitor placement

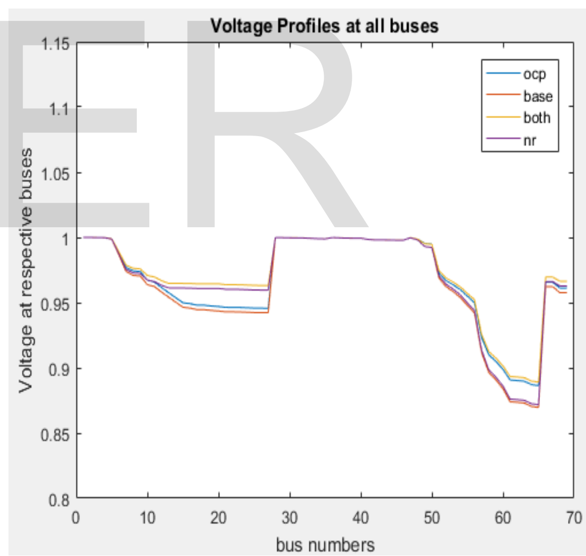
Parameters	**Results**
Open Switches	69,70,71,72,73
Optimal Size (bus)	150 (49) 150 (50) 1050 (61)
Real Power loss (KW)	146.96
% Reduction in Power loss	31.7
Voltage (p.u)	0.9611
Total Operating Cost ($/Kvar)	85,852
Savings ($/year)	29,556

The Figure 6 shows the voltage profile of all the above cases and frrom the figure it is clear that Voltage is well improved in case 3 than other cases.

TABLE VIII 69-bus system: Simultaneous reconfiguration and capacitor placement

Parameters	**Results**
Open Switches	69,13,71,72,73
Optimal Size (bus)	150 (49) 125 (50) 138 (61)
Real Power loss (KW)	133.341
% Reduction in Power loss	41.72
Voltage (p.u)	0.9664
Total Operating Cost ($/Kvar)	74,008
Savings ($/year)	41,400

Fig 6. Voltage profile of 69-bus system



The following Table IX explains about comparative analysis of proposed methodology with Stimulated Annealing Algorithm for 33 bus system.

VI. CONCLUSION

Thus in this paper, Johnson's and Modified Whale's Optimization Algorithm is proposed for loss and Operating cost minimization for all three cases. It also enhances the voltage profile and improves the power factor. Finally, the results of IEEE-33 radial distribution system are compared with the performance of Simulated Annealing. It can be concluded that Simultaneous reconfiguration and capacitor placement is more effective than individual reconfiguration and capacitor placement.

TABLE IX Comparison of proposed method with Stimulated Annealing

Parameters	Proposed Methodology			Stimulated Annealing		
	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Open Switch	33,34, 35,36, 25	33,34, 35,36, 37	33,34, 35,36, 25	7,14, 9,32, 37	33,34, 35,36, 37	7,14, 9,32, 37
Optimal Size (bus)	-	150(24) 50(25) 150(30)	400(24) 250(25) 150(30)	-	1050 (6) 450 (28) 300 (29) 300 (30)	1050 (6) 450 (28) 300 (29) 300 (30) 150 (19)
Real Power loss (KW)	137.28	135.718	121.495	142.60	136.11	124.29
% Reduction in Power loss	20.68	21.82	32.68	16.9	21.5	30.46
Cost($/kvar)	-	76,443	69,715	-	84,519	79,676
Savings ($/yr)	-	19,217	25,946	-	11,142	15,985

REFERENCES

[1] Diana P Montoya and Juan, "A minimal spanning tree algorithms for distribution networks configuration," Power and Energy Society,2012.

[2] B.Moradzadeh and K.Tomsovic,"Mixed Integer Programming-Based Reconfiguration of a Distribution System with Battery Storage", In Proc.North America Power Symp (NAPS),2012, pp 1-6..

[3] T.D.Sudhakar,"Prim's Algorithm for Loss minimization and Service restoration in Distribution Networks", In Int.Journal of Electrical and Computer Engineering, 2010, vol. 2, pp 43-62..

[4] T.D.Sudhakar,"Power Restoration in Distribution Networks using MST algorithms", new frontiers in graph theory,2012.

[5] S.K.Gautami and S.K.Basu,"A new algorithm for reconfiguration of distribution feeders for loss minimization", IEEE transactions on Power Delivery,1992.

[6] D. Ramakrishna and G. Vasu, "Optimal placement and sizing of capacitor and Distributed Generator in radial distribution system", International Journal for Modern Trends in Science and Technology,2016, vol 2, issue 09,pp 2455-3778.

[7] S.Chandrashekhar Reddy P.V.N.Prasad and A.Jaya Laxmi.,"Placement of Distributed Generator, Capacitor and DG and Capacitor in Distribution System for Loss reduction and Reliability Improvement,"Journal of Electrical Engineering.

[8] R.Srinivasa Rao,"A hybrid approach for loss reduction in distribution systems using Harmony Search Algorithm,"International Journal of Eclectric and Comp Engineering,2010, vol 4,issue 3.

[9] K.Prakash and M.Sydulu,"Particle Swarm Optimization based capacitor placement on Radial distribution systems," IEEE,2007.

[10] S. P. Singh and P.Vijay Babu," Capacitor allocation in radial distribution system for maximal energy savings,"IEEE 2016.

[11] Attia. El-Fergany,"Optimal capacitor allocations using Evolutionary algorithm,"IET Gen.,Trans.,Dist.,2013, vol 7,pp 593-601.

[12] Marcos and Carlos,"An Efficient method for distribution systems reconfiguration and capacitor placement using the Chu-Beasley based Genetic algorithm,"IEEE PowerTech,2011.

[13] R.El.Ramli and M.Awrd,"Ordinal Optimization for optimal capacitor placement and Network Reconfiguration in Radial Distribution Networks,"IEEE,2012.

[14] Mostafa and Reza,"Optimal multi objective reconfiguration and capacitor placement of distribution systems with Hybrid Big- Bang Crunch algorithm in fuzzy framework,"Ain Shams Engineering Journal,2016.

[15] L.W. Oliveira, S. Carneiro, E.J. Oliveira, J.L.R. Pereira, I. Silva, J.S. Costa,"Optimal reconfiguration and capacitor allocation in radial distribution systems for energy losses minimization," Int. J. Electr. Power Energy Syst. ,2010,pp 840–848.

[16] R.Srinivasa Rao,"A hybrid approach for loss reduction in distribution systems using Harmony Search Algorithm,"International Journal of Eclectric and Comp Engineering,2010, vol 4,issue 3.

[17] Ching-Su and Chu-Lee,"Feeder reconfiguration and capacitor setting for loss reduction of Distribution systems,"Electr Power System Research,2001.

[18] M.J.Kasaei and M.Gandomkar,"Loss reduction in Distribution network using Simultaneous capacitor placement and Reconfiguration with Ant Colony algorithm,"IEEE,2010.

[19] R. Srinivasas Rao, S.V.L. Narasimham and M.Ramalingaraju,"Optimal capacitor placement in radial distribution system using Plant Growth Simulation Algorithm,"International Journal on Electrical and Power Energy System,2011, vol 33,pp 1133-1139.

[20] Attia. El-Fergany,"Optimal allocation of multi-type distributed generators using backtracking search optimization algorithm,"Int. J. Electr. Power Energy Syst. 64 ,2015,pp 1197–1205.

[21] Almoataz Y. Abdelaziz, Ehab S. Ali, Sahar M. Abd Elazim,"Flower pollination algorithm for optimal capacitor placement and sizing in distribution systems,"Electr. Power Compon. Syst.,2016,pp 544–555.

[22] Adel Ali Ela,Ragab A.Sehiemy and Mohamed Taha,"Optimal capacitor placement in distribution systems for power loss reduction and voltage profile improvement," IET Generation,Transmission and Distribution,2015,vol 10,issue 5,pp 1209-1221.

[23] E.S.Ali,S.M.Abd-Elazim,A.Y.Abdelaziz,"Improved Harmony Algorithm for optimal locations and sizing of capacitors in radial distribution systems," Int. J. Electr. Power Energy Syst.,2016,pp 275–284.

[24] Seyedali Mirjalili, Andrew Lewis,"The Whale Optimization Algorithm," Adv. Eng. Software,2016,pp 51–67.

[25] D.B. Prakash and C. Lakshmi Narayana,"Optimal siting of capacitors in radial distribution network using Whale Optimization Algorithm,"Alexandria Engineering Journal, 2017,vol 56,issue 4,pp 499-509.

ISSN 2229-5518