OPTIMAL NETWORK RECONFIGURATION AND CAPACITOR PLACEMENT FOR IMPROVING VOLTAGE STABILITY AND NET SAVINGS IN RADIAL DISTRIBUTED SYSTEMS.

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Abstract: - Reducing power losses and regulating voltage stability within the limits of Radial Distribution Systems (RDS) are essential processes to provide quality power to consumers. The power loss minimization and voltage profile improvement are effectively done by optimum network reconfiguration and the placement of the capacitors in RDS. This paper presents the combined methodology of Capacitor placement and Network reconfiguration is properly applied to maximize the net saving cost, minimize the power loss and improve the voltage profile. The size and location of capacitors and tie-line switches of nodes are optimally allocated by the effectual Moth-Flame Optimization (MFO) algorithm. The MFO is an effective nature-inspired algorithm based on the chemical effect of light on moths as an animal with bilateral symmetry. This algorithm provides a better solution with less computational time by two searching operators of Moth and Flame. The Performance of the MOF is analyzed by a standard test system of 33 and 69-node RDS. The best simulation results of loss reduction, voltage enhancement, and cost-saving are numerically and graphically reported. The dominance of the obtained results is compared with other soft computing methods available in the literature.

Keywords — Distribution system, Optimal location and size capacitor, Power loss minimization, net saving cost maximization, MFO algorithm

1. INTRODUCTION

One of the major issues affecting the quality of electric power being delivered to the distribution system is power losses. Now a day's more industries are developed, and the consumers of electrical power are guaranteed a good quality of power which means within a certain tolerance of voltage (±5%), frequency (±0.5%) with minimum harmonics, and with as possible interruption time. In an uncompensated distribution system, the reactive power demand is usually met by the source, thus burdening the system and resulting in a poor voltage profile and an increase in losses. If the reactive power demand can be met locally then the transmitting of reactive power from the source to the reactive elements can be reduced. Localized meeting of reactive power demand can be achieved by installing either switchable capacitors or fixed capacitors. Network reconfiguration in distribution systems is best for reducing distribution losses by finding the best (optimal) configuration of switches.

Over the last few years, a lot of research work has been carried out on capacitor placement problems in the radial distribution system. Many researchers focused on the analytical approach Ng, H.N. et al., to decide the optimum location and capacity of the capacitors in a radial distribution system [1]. Jabr, R.A proposed a conic and mixed integer linear programming approach (MILP) to optimize the capacitor to reduce the costs related to capacitor banks, peak power, and energy losses [2].

Various approaches for improving the voltage stability and cost saving of RDS. In [3, 4], the author has presented the reactive power planning problem for a system that is allocated and evaluated the ability of the reactive power resources. Hamedani M.E and Arefifar S. A [5] has been proposed the comprehensive planning problem and which is solved by using the tabu search (TS) algorithm with the effects of minimizing the cost of power and energy losses and total required reactive power during the planning period. In [6], discussed improving the real power transfer capability of the system by injection of reactive power using the predictor-corrector optimization scheme. The various soft computing techniques have been documented by the researchers, such as Teaching-learning-based optimization [7], ABC algorithm [8], Bacterial Foraging [9], Improved Harmony Algorithm [10], Oppositional krill algorithm [11] also been used to solve the capacitance placement problem.

Many researchers had solved the network reconfiguration problem using different methods with the objective of voltage profile improvement and reducing the power loss in power distribution networks. Author [12] extends the reach of relaxations to reconfiguration problems by binary decision variables, such as minimal power loss, load balancing, and power supply restoration. A cuckoo search algorithm (CSA) is used for minimizing power loss and improving voltage magnitude by reconfiguration methodology [13]. The Author has proposed reconfiguration techniques under different practical considerations used for service restoration in distribution systems [14]. Various approaches for reconfiguration in radial distribution include, Meta-heuristic Particle Swarm Optimization (PSO) is used to reconfigure and identify the finest tie switches for reducing the real power loss in an RDN [15], Improved Selective Binary Particle Swarm Optimization (IS-BPSO) [16], GA [17], runner-root algorithm (RRA) [18]. The combined methodology of network reconfiguration and capacitor placement simultaneously to reduce power losses and improve the system reliability using Binary Gravitational Search Algorithm (BGSA) [19], Modified Flower Pollination Algorithm [20], and binary particle swarm optimization [21].

2. PROBLEM FORMULATION

2.1 Voltage stability Indices (VSI)

The VSI is a numerical value that helps the operator to monitor how close the system is to a stable state. The main objective of VSI is to find the distance from the current operating point to the marginally stable point. When the system operates in a stable state the determined value of VSI is nearby unity, otherwise insecure occurs. The VSI for the node can be mathematically represented using the following equation [9]

$$VSI(m2) = |V(m1)|^4 - 4.0\,\{P(m2)\,x(jj) - Q(m2)\,r(jj)\}^2 - 4.0\,\{P(m2)\,r(jj) + Q(m2)\,x(jj)\}|V(m1)|^2 \quad (1)$$

2.2 Objective function

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The prime objective of the proposed work is to maximize the net saving cost of the RDS. The savings of the RDS mainly depends on the reconfiguration process, power loss, and optimal allocation and value of capacitors. The MFO algorithm-based net saving maximization is mathematically formulated as,

$$\max f = C_E\left(P_{LB} - P_{LA}\right)T - \beta\left(C_I N_B + C_P \sum_{i=1}^{N_B} Q_{ci}\right) - C_o N_B \quad (2)$$

Equality and inequality Constraints

Real and Reactive power limits

The active and reactive power of RDS are mathematically represented as follows

$$P_{SS} = \sum_{i=2}^{NB} P_D(i) + \sum_{j=1}^{NL} P_{loss}(j) \quad (3)$$

$$Q_{SS} = \sum_{i=2}^{NB} Q_D(i) + \sum_{j=1}^{NL} Q_{loss}(j) - \sum_{k=1}^{NC} Q_C(k) \quad (4)$$

Reactive Power Compensation Limits

The reactive power delivered by each switched capacitor is limited by its lower and upper limits as,

$$0 \le Q_{Ci} \le Q_{Ci}^{\max} \quad (5)$$

The acceptable capacitor range 0 to 1500 KVAr with step of 50 KVAr.

Voltage Profile Limits

The voltage magnitude of each node in the radial distribution system is strictly maintained as,

$$V_i^{\min} \le V_i \le V_i^{\max} \quad (6)$$

Line thermal Limits

The current flows in the branches should not go beyond the thermal capacity of the line.

$$I_{(i,j)} \le I_{(i,j)}^{\max} \quad (7)$$

3. SOLUTION METHODOLOGY

3.1 Overview of Moth – Flame Optimization (MFO) Technique

Generally, optimization algorithms have been confined to the local optimum which curtails the algorithm from attaining its original optimal solution and other flaws are huge computational burden and time consumption [13, 14]. One of the recently introduced evolutionary algorithms, namely the Moth fly optimization algorithm was introduced by Mirjalili in 2015. It has received wider attention among researchers and has been applied to solve multi-objective optimization algorithms. It exhibits a competitive performance over other algorithms because of its good convergence attitude. This technique is formulated based on the biological behavior of moths fighting flames in the field. The MFO technique uses a community of moths to do the optimization process and every moth needs to upgrade their position regarding the flame. It protects the moth to evade the entrapment of local optima and to regain its inspection process in the search space. More specifically, its performance is on the virtue of the transverse orientation process. The navigating nature of the moth has inspired researchers to carry out this kind of optimization problem.

3.2 Implementation of MFO Algorithm

The following steps are used for optimal allocation and sizing of capacitor with network configuration to enhance the voltage profile using MFO algorithm.

1. Read the line, bus, and load data of RDS,
2. Run the distribution power flow and calculate the loss using the exact loss formula for the base case.
3. Fix a number of Capacitors that are to be used in the Radial Distribution System.
4. Initialize the parameters of the MFO algorithm such as Population, dimension, maximum no of iteration number, lower bound, and upper bound (node and size of Capacitor respectively).
5. Set iteration=1
6. Calculate fitness (i.e. loss in a network) for each moth by placing DG and Capacitor at their respective buses using Eqn. (15).
7. Evaluate the objective functions of each moth and determine the net savings of RDS...
8. Update the position of flame and save the best fitness values in an array corresponding to Eqn. (16)
9. Update the record of flames and the flames are arranged using Eqn. (17) based on their fitness values
10. Compute the present position of moths.
11. Check that all constraints are satisfied, if yes move to the next step, else go to step 6.
12. Check If the number of iteration processes is equal to a maximum number of iterations, go to step 13. Otherwise, go to step 5.
13. Display the global best solution of net saving cost and voltage profile and STOP the program.

4. RESULTS AND DISCUSSIONS

In this study two standard test systems of 33 and 69 node RDS are considered to determine the superior performance of the proposed MFO algorithm. The base 100 MVA with 12.66 KV is engaged to solve the two test cases. The system and load data of the 33 node RDS are adapted from [1] and

69 node RDS is taken from [3]. The control parameters of the applied MFO are number of search agents = 40, maximum number of iterations = 500 and number of dimensional parameter = 11 for both test cases.

Test case 1: 33 node RDS

This test system has one main feeder and three laterals are interconnected in this network. The maximum capacity of the real and reactive power loads is 3715 KW and 2300 KVAr, respectively. Initially, the distribution load flow methodology is applied and finds the base case values of the voltage violations, VSI, and power loss of given RDS. Enhance the voltage stability and minimize the transmission losses by optimally allocating the tie-line switches and capacitors in proper locations in RDS. The projected MFO simultaneously identifies the best location with a value of the three capacitors and five tie-line switches for network reconfiguration. The best tie line switches are 34, 35,36,37 and the optimal locations of the capacitors are 13, 32, and 25. with values are 200 KVr, 200 KVr, and 650 KVr respectively. The one-line diagram of Network Reconfiguration with capacitors for 33-node RDS is shown in fig. 1. The enhanced voltage for each node is compared to base case voltage and graphically displayed in fig 2 and obtained VSI also compared with fig. 3.

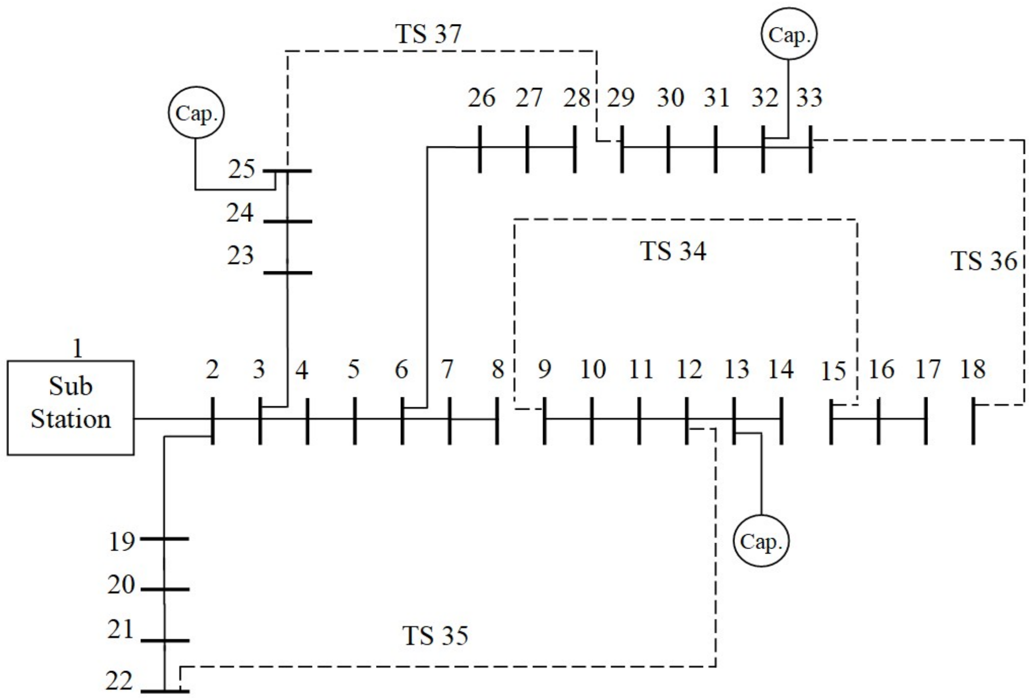

Fig 1. Network Reconfiguration with capacitors for 33-node RDS

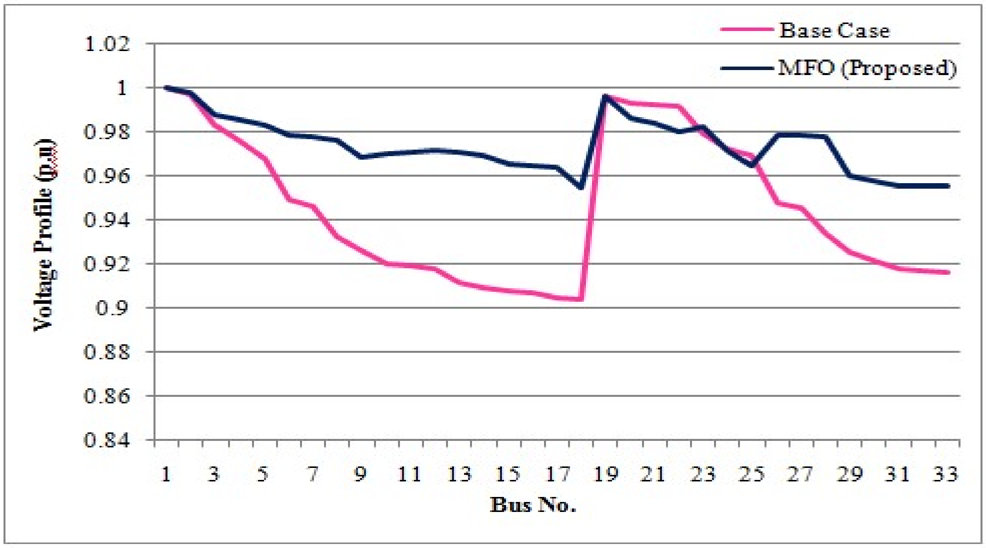

Fig.2. Comparison of Voltage profile of base case and proposed MFO

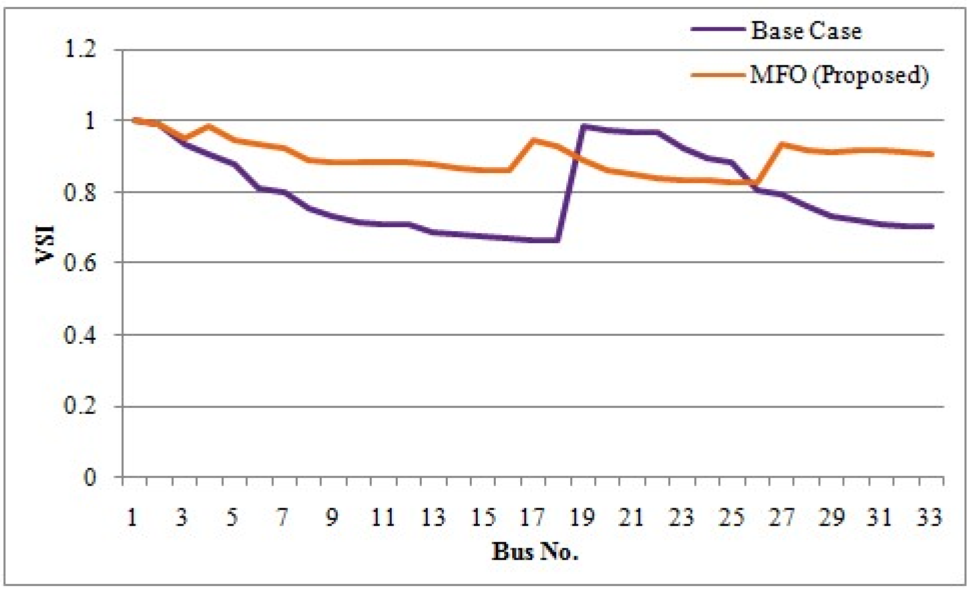

Fig.3. Comparison of VSI of base case and proposed MFO

Table 1. Simulation results of 33- node with network reconfiguration

Parameters	Optimal Value
Open switches	8 28 17 33 14
Tie-line switches	34, 35,36,37
Optimal location of Capacitor	13 32 25
Optimal sizing of Capacitor	200 kVAr 500 kVAr 650 kVAr
Minimum Voltage (p.u)	0.95517
Minimum Voltage stability index (p.u)	0.83083
Power loss (KW)	103.66
Annual saving (Rs)	43431.3653

Table 2: Comparisons of numerical results in various methods for 33-node system

Method	Switches opened	P_{loss} (KW)	VSI_{min}	V_{min} (p.u.)	Node no.	Capacitor size (KVAr)	Loss reduction (%)
Base case	33,34,35,36,37	202.67	0.6951	0.9131	-	-	-
SA [12]	7,14,9,32,37	107.89	0.8235	0.9526	6 28 29 30 9	1050 450 300 300 150	46.77
HSA [12]	33,14,8,32,28	108.45	0.8208	0.9519	6 28 29 30 9	900 300 600 300 300	46.49
MFO (proposed)	8, 28, 17,33 14	103.66	0.83083	0.95517	13 32 25	200 500 650	49.78

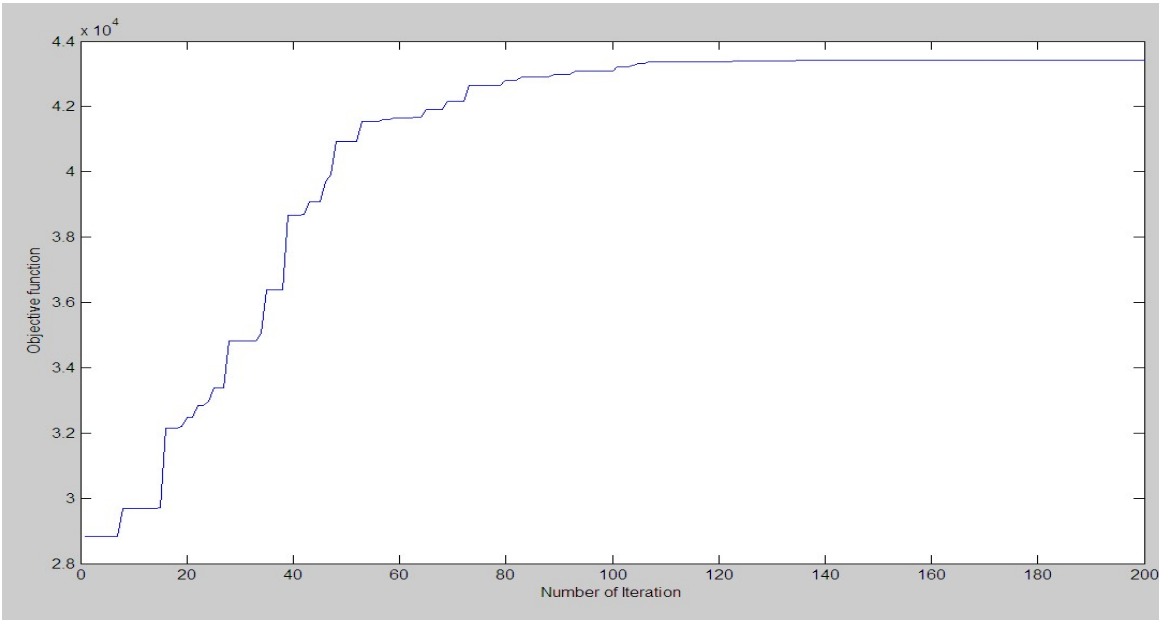

Fig. 4: Convergence characteristics of 33-node test system

The simulation results of the proposed 33 node RDS by The MFO algorithm are reported in Table 1. This table includes several open and tie-line switches, the best location and size of the three capacitors, minimum voltage and VSI, power loss, and net savings of the RDS per year. The power loss of the system is 103.66 KW and the annual saving is Rs 43431.3653. The Convergence characteristic of the proposed test system is displayed in fig. 3. The simulation results are compared with other available methods and reported in Table 2. From the table, the MFO is the best global optimization algorithm competed with similar techniques available in the literature.

Test case 1 : 69 node RDS

In the second case, the large-scale system of 69 node is considered to find the ability of the projected MFO algorithm. The reconfiguration process and capacitor allocation are implemented in this test system. This algorithm is well suited for the solution of large-scale systems to obtain the best numerical solutions. The parameter setting of MFO is population size = 50, a number of variables =7, and a maximum number of iterations =500. Using this parameter setting, the projected algorithm effectively does the best Reconfiguration process and simultaneously identifies the optimum location and compensated value of capacitor banks. Network Reconfiguration for IEEE 69-bus test system with DG placement is shown in fig 5.

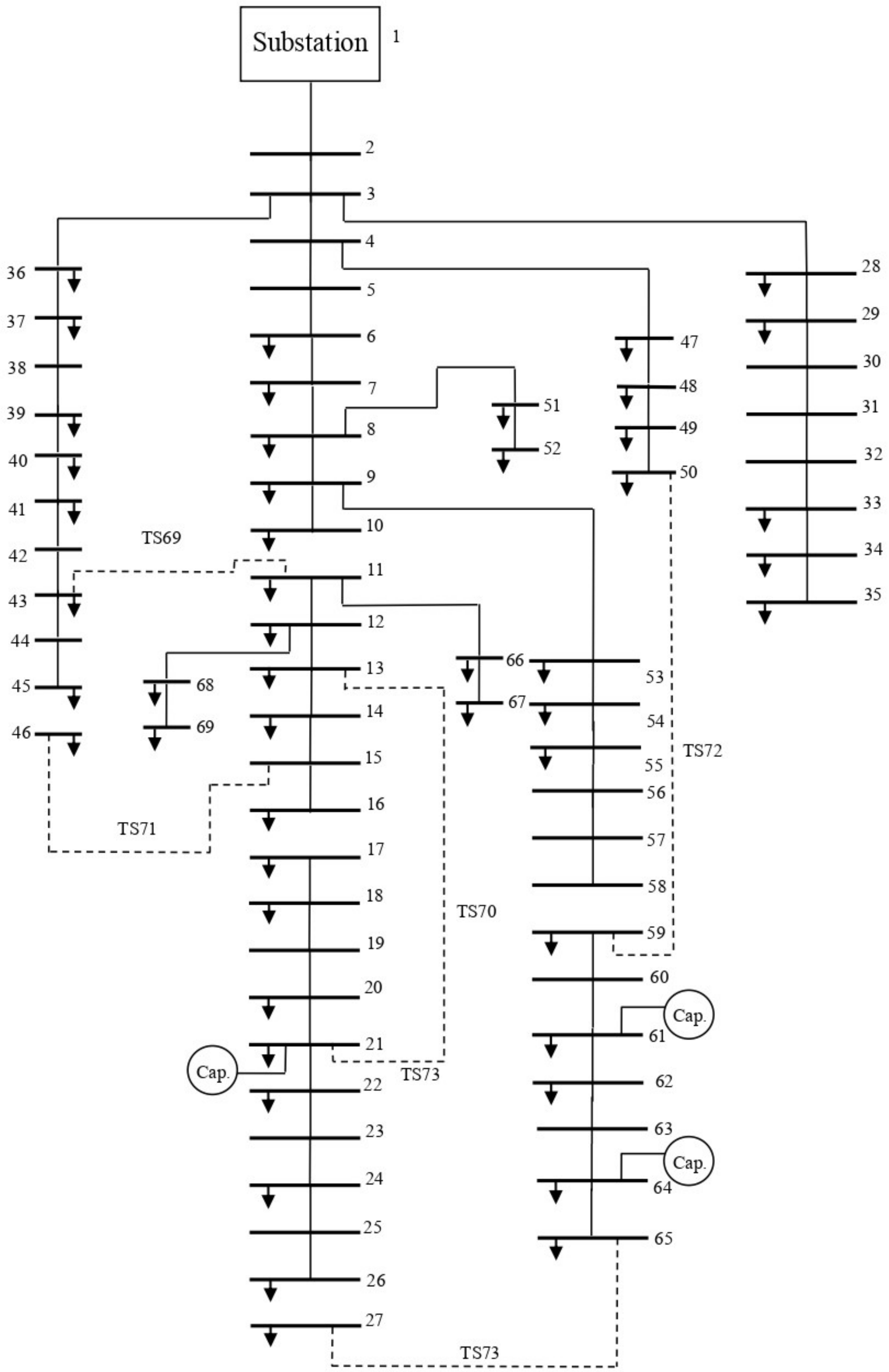

Fig 5. Network Reconfiguration with capacitors for 69-node RDS

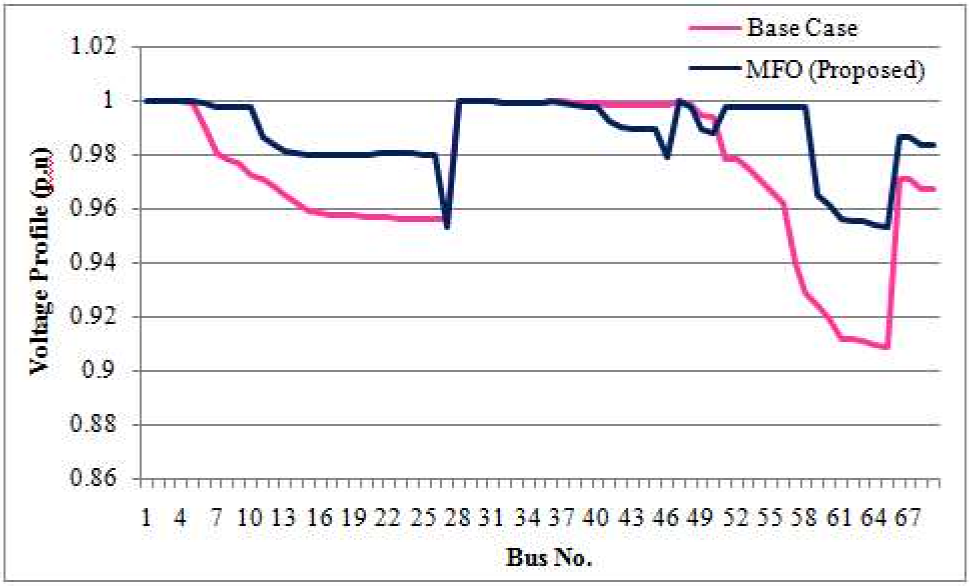

Fig. 6 Voltage profile for base case and Reconfiguration with placement of capacitor in 69-bus test system

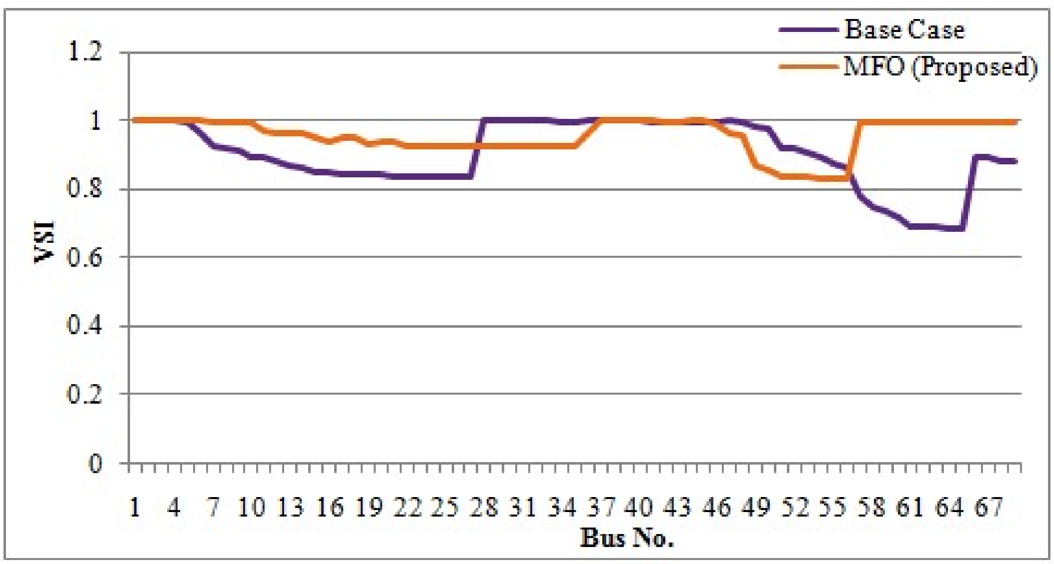

Fig. 7 VSI for base case and Reconfiguration with placement of capacitor in 69-bus test system

Table 3: Comparisons of numerical results in various methods for 69-node system

Method	Switches opened	P_{loss} (KW)	VSI_{min}	V_{min} (p.u.)	Node no.	Capacitor size (KVAr)	Loss reduction (%)
Base case	69,70,71,72,73	224.97	0.6833	0.9090	-	-	-

MFPA[12]	10,68,60,44,15	153.93	0.7494	0.9305	64 63 62	350 600 250	31.58
MFO (Proposed)	**26, 45, 58, 16, 10**	**85.793**	**0.82688**	**0.95359**	**61 64 21**	**900 200 250**	**61.86**

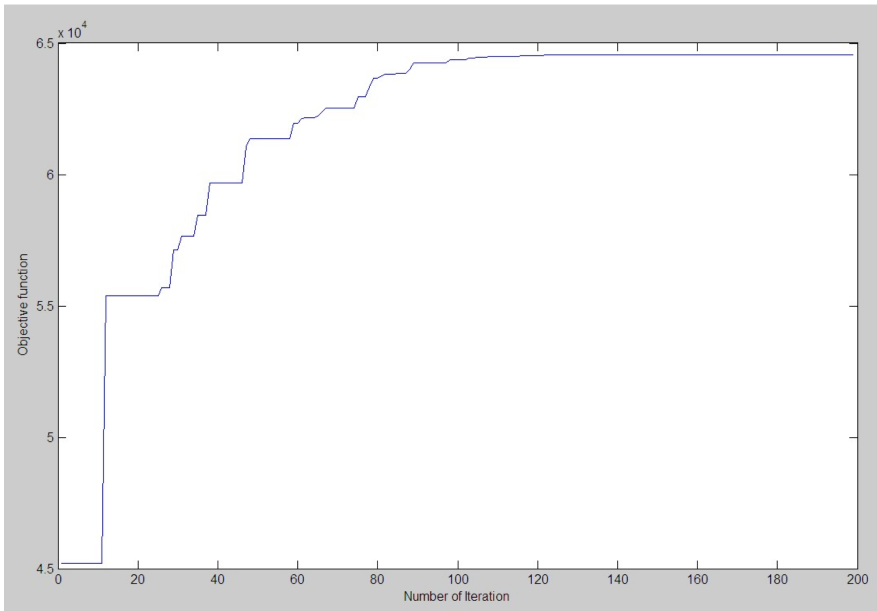

Fig. 8: Convergence characteristics of 69-node test system

The optimized capacitor place and value is 61, 64, 21 and 900 MVAr, 200 MVAr and 250 MVAr respectively. The open and tie-line switches of 69 bus test system are 26 45 58 16 10 and 69, 70,71,72,73 respectively. The node voltage and VSI for base case and after reconfiguration with capacitor are graphically reported in fig.6 and fig. 7. The simulation results of IEEE 69 bus test system by proposed method are compared with other methods and reported inTable 3.. Here, the minimized real power loss is 85.793 KW respectively. A convergence characteristic of 69-node test system is displayed in fig.8. From the comparison, the MFO approach provides best reconfiguration with capacitor allocation, minimized power loss and improved voltage profile.

5. Conclusion

In this research work, a simple and best tuning optimization algorithm of MFO has been proposed to solve the stability problem in regulated RDS. Network reconfiguration and capacitors placement are considered to enhance the voltage profile, reduce the network losses and improve the net saving cost of RDS. The projected algorithm optimally changes the structure of an existing system by using the tie-line switches and finding out the best location and sizing of capacitors. The capacitors inject the reactive power to the weakness bus of the proposed system and do the compensation process to achieve the improved voltage profile. In this study 33 and 69 node test systems are taken into account to test the performance of the MFO. This algorithm effectively maximizes the net saving cost, minimizes power loss, and improves the stability of the system. From the results, it can be concluded that it is a most excellent and robust algorithm for solving all engineering optimization problems.

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