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Distribution Network Reconfiguration for Maximum Loss Reduction Using Moth Flame Optimization

A. V. Sudhakara Reddy
Department of Electrical & Electronics Engineering, Sri Venkateswara University, Tirupati, India.

M. Damodar Reddy
Department of Electrical & Electronics Engineering, Sri Venkateswara University, Tirupati, India.

Abstract – This paper presents an application of a Moth Flame Optimization (MFO) for feeder reconfiguration of the primary distribution system based on step by step reconfiguration. The purpose of reconfiguration is the minimization of power losses or maximization of system loss reduction. The main objective of optimizing of feeder reconfiguration is to find the best promising switching of network reconfiguration in terms of maximum reduction in real power loss while maintaining the radial structure in distribution systems without islanding of any nodes. Network reconfiguration is a method of modifing the system topology by altering the ON or OFF status of both the secure as well as sectional switches. MFO algorithm can be used as one of the approaches for finding the most favorable configuration by solving Kirchhoff's Laws, by maintain radial structure of the distribution system. Moth position has been incorporated with the spiral movement in search space to change the position of tie switches after each iteration, such that the MFO algorithm moves towards the direction of finding the objective as best moth fitness. The proposed Moth Flame Optimization has been illustrated on IEEE 16- node and 69-node test systems.

Index Terms – Maximum loss reduction, Moth Flame Optimization, Distribution system, Network Reconfiguration, Radiality Constraint.

1. INTRODUCTION

Network reconfiguration (RCG) is the tree organization of feeders or laterals by changing the switching (ON-OFF) status of sectional and tie switches with lowest loss, by preserving the radial nature in distribution systems. "The different types of loss reduction techniques in the distribution system are (i).Network reconfiguration, (ii).Construction of a new substation, (iii).Compensation Techniques, (iv).High Voltage distribution system, (v).Distributed Generation placement, (vi).Selection of Conductor material, (vii).Automatic voltage regulators [20]".

Many articles have been developed on the broad theme of network reconfiguration, there is still require to develop more suitable and efficient techniques for the system reconfiguration under reliable operating provisions. Merlin [1] offered the sequential opening algorithm to operate spanning tree based on minimal loss. Simplicity is the main benefit of heuristic methods. Shirmohammadi [2] proposed the reconfiguration problem to reduce the resistive losses. The main drawback is that final reconfiguration is dependent on the primary significance of open switches.

Goswami [3] described a algorithm for the reconfiguration of feeder laterals with minimum loss configuration. The optimum power flow pattern which is obtained by solving KCL and KVL laws. Kim [4] proposed network reconfiguration and to identify the final configuration which curtails the power loss depending on the load levels. Taleski [5] described a power summation method to find out the network reconfiguration to reduce the energy losses based on statistical representation of variations in load. Moorthy [6] explained the hybrid algorithm of multi objective ant colony optimization (MACO) and bacterial foraging optimization (BAFO) for reconfiguration to curtails the power losses.

Venkatesh [7] proposed a novel algorithm; Fuzzy based Evolutionary Programming technique (FEP) for the best combination of switches with respect to optimal reconfiguration under the umbrella of SCADA to achieve the minimal kW losses and improve the Voltage Deviation Index (VDI). Gomes [8] described a heuristic optimization technique suited for network reconfiguration with different topologies in step by step manner to minimize total system losses in the distribution system. Chiou [9] proposed differential evolution (DE) to crack the reconfiguration problem for power loss diminution and nodal voltage enrichment in power delivery systems. Damodar Reddy [10] explained a fuzzy inference system used to the capacitor placement of the original and reconfigured networks. In addition to loss reduction, also improves the voltage deviations at every node and branch current boundary violation.

Ghosh [11] described an competent algorithm for reconfiguration to condense the number of switching operations and run or processing time by initiating the heuristic rules. Olamaei [12] proposed feeder reconfiguration quandary using modified honey bee mating optimization algorithm for reducing power losses. Srinivasa Rao [13] described an efficient nature inspired harmony search algorithm (HSA) to optimize the reconfiguration problem and identify the best placements and the installation of dispersed generation units at different load levels. Abdelaziz [14] proposed two heuristic algorithms, namely ant colony optimization inspired based on real time ant behaviour and harmony search algorithm inspired based on musician behaviour with operational constraints.

Moth Flame Optimization algorithm firstly implemented in 2015 by Mirjalili [15]. Sudhakar Reddy [17] explained PSO for reconfiguration to reduce total system losses. Archana [17] suggested a Modified Teaching Learning Based (MTLBO) Optimization to solve the reconfiguration predicament of various load replicas to reduce operational cost in the power distribution system. Sudhakar Reddy [18] described a dragonfly algorithm (DA) is exclusively to the network reconfiguration problem based on step by step and simultaneous switching.

The proposed MFO technique tested on standard IEEE 16-node and 69- node systems to reduce the total I^2R loss, without islanding of any node of the initial network. To find real power loss, a suitable power flow method is required. In this manuscript, backward-forward load flow method is employed.

2. 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

$$P_{L,Real} = \sum_{B=1}^{i} I_B^2 * R_B \tag{1}$$

The branch current I_i is the active part of the branch Current I_a and reactive part of branch current I_r from the network can be obtained from the load flow solution of the network. The total I^2R loss P_{LT} can be estranged keen on two sections P_{LA} and P_{LR} based on the active and reactive components of branch currents. The power loss components can be defined as

$$\begin{aligned} P_{TL,Real} &= \sum_{B=1}^{i} I_B^2 * R_B \\ P_{TL,Reactive} &= \sum_{B=1}^{i} I_B^2 * X_B \end{aligned} \tag{2}$$

3. NETWORK RECONFIGURATION

3.1. Reconfiguration Process

The basic loops are decided for the closed loop distribution network is equal to the number of tie-switches of the meshed system and is given by

$$N_{li} = N_{ele} - N_{br} + 1$$

Where, N_{li} is the total number of links (Tie switches) for the distribution network.

N_{ele} is the total number of elements (sectionalizing plus tie-switches).

N_{br} is the total number of branches.

In the proposed work, loop vectors are designed and implemented for network reconfiguration by simultaneous switching which is given in Table.1.

Table 1 Loop Vectors of 16-node system

Loops corresponding to Maximum Possible Switching (L_{SW})					
SW_1	14	8	7	2	--
SW_2	15	12	6	--	--
SW_3	16	13	11	4	3

From Table 1, switching loops are designed by considering the real, reactive power loss and minimum voltage constraints [11]". The Tie-switches are normally opened for the original network {TS-14, TS-15, TS-16} for 16-node and {TS-69, TS-70, TS-71, TS-72, TS-73} for 69-node systems respectively and shown as green colour (Entire First Column) highlighted in Table 1.

3.2. Radiality Constraint

Any distribution network with 'n' nodes and 'b' branches are said to be a radial network if it obey the two constraints.

1. The total number of branches 'b' is given by

$$N_{br} = (N_{no} - 1) - (N_f - 1) \tag{3}$$

$$\begin{aligned} &Where,\quad N_f \rightarrow represents\ the\ number\ of\ feeders\ and \\ &\qquad N_{no} \rightarrow represents\ the\ number\ of\ nodes \end{aligned}$$

2. The network should satisfy the conservation of power flow constraint, i.e. every node should be linked to the substation node by one path such that every load must be energized.

3.3. 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

$$Objective\_Function = min\{P_{TL,Real}\} \tag{4}$$

4. MOTH-FLAME OPTİMİZATİON (MFO)

The Moth Flame Optimizer (MFO) has proved its competitiveness with many other optimization algorithms. It is inspired by physical phenomena in nature. The main inspiration of this algorithm is the transverse orientation, which is the navigating mechanism of moths in nature [15, 19]. Moths fly at hours of darkness by sustaining a fixed angle with respect to the moon, a very effective mechanism for travelling in a straight line for longer spaces. However, these fancy pests are cornered in an inadequate or noxious spiral conduit in the region of artificial lights. This MFO, mathematically models this behaviour to achieve optimization. Moths are fancy pests used for flight at nights using moonlight, having an exceptional navigation technique for travelling in a straight line over longer distances.

Moths tend to move by sustaining a fixed angle with respect to the moon; permit them to fly in a straight light. The main stimulation of this method is the routing of moths in natural environment called transverse orientation. MFO is a population based algorithm in which moths and flames, both are the solutions. Moths are actual search agents, while the flames are the best moth positions and objective as moth fitness. The updating mechanism of the positions around flames is projected by a Spiral movement shown in Fig.1. With this mechanism, a moth can never lose its best solution. In Fig.1, M_k indicates the moth 'k', F_i indicates the flame, and D_k indicates the distance of the moth k for the flame *i*.

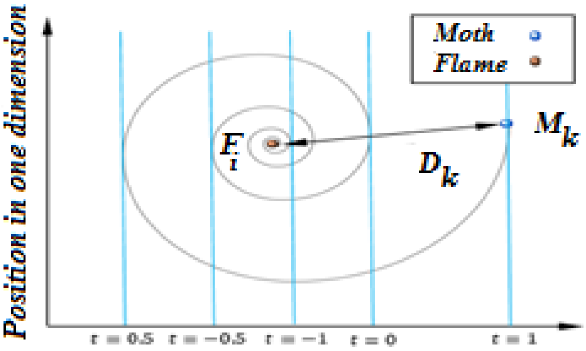

Figure 1 The spiral in search around a flame and moth with respect to time

4.1. Implementation of the Projected MFO

Step 1: Initialize the all constraints.

Step 2: Set boundaries to the parameters that are to be optimized.

Step 3: Initialize lower, upper boundaries and dimensions to the parameters.

Step 4: Perform the basic load flow to acquire the actual I^2R loss and voltages prior to the optimization.

Step 5: The optimal switching selection of network reconfiguration is taken based on moth position.

Step 6: Randomly generate an initial population.

Step 7: Set flame count given by the following equation (13).

$$Flame\_no = round\left(N_{fl} - C_{it} * \left(\frac{N_{fl}-1}{T_{it}}\right)\right) \quad (5)$$

Where C_{it} is the present or existing iteration; N_{fl} is the ceiling quantity of flames, and T_{it} is the ceiling quantity of iterations.

Step 8: Verify for the boundary conditions of moths in the search space and set them if out of boundary.

Step 9: Consider the fitness function as active power loss for evaluation.

Step 10: Sort the Moth fitness and assign it to the flame fitness.

Step 11: Update the position of best flame.

Step 12: Updating mechanism of the Moth position, based on spiral velocity corresponding to the flame given as

$$M_k = S\left(M_k, F_i\right) \quad (6)$$

Where, S is the spiral function.

Step 13: The logarithmic spiral task is as follows:

$$S\left(M_k, F_i\right) = D_k.e^{bt}.\cos\left(2 * pi * t\right) + F_i \quad (7)$$

Where, b is a invariable for the contour of spiral, and t is a arbitrary numeral between [-1, 1] which is as follows:

$$t = \left(a-1\right) * r_i + 1 \quad (8)$$

$$a = -1 + C_{it} * \left(\frac{-1}{N_{it,\max}}\right) \quad (9)$$

Step 14: Detachment of the moth to the light up, D_k is calculated as follows:

$$D_k = \left|F_i - M_k\right| \quad (10)$$

Step 15: Repeat the iterative process from step 7 to 14 as until the flame count terminates as per the equation (5) achieving optimum results.

Step 16: Display the best score of moth which gives the optimum result as power loss with respect to best moth position.

5. TEST RESULTS AND DISCUSSIONS

The proposed Moth Flame Optimization of maximum loss reduction by reconfiguration was tested with IEEE 16-node [8] & 69-node [10] radial networks. In the present work, the control parameters of Moth Flame Optimization as shown in Table 2.

5.1. IEEE 16-Node Test System

The configuration of the 100MVA, 23kV, IEEE 16-node test system with 16 branches, 13 sectional or closed and 3 ties or open switches are exposed in fig 2. From Fig 2, the red colour dotted lines represented as tie switches of the network; after reconfiguration, opened switches are of green colour solid lines. The comparative results for the initial and after optimal reconfiguration of 16-node system are presented in Table.2.

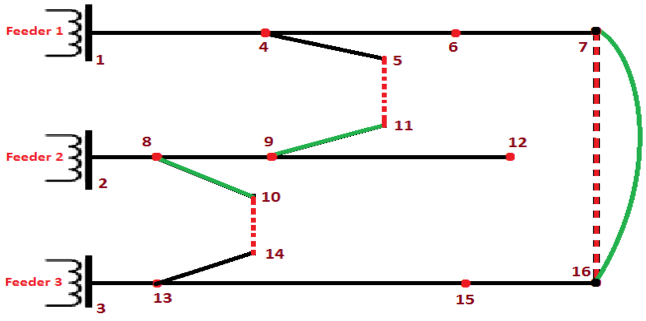

Figure 2 Final Reconfiguration of 16 node test system

Table 2 Network Reconfiguration Results of 16-node system

Switching	Branch closed	Branch opened	Real power loss, kW	Minimum Voltage
Base Case	----	----	511.4356	0.9693 (V_{12})
1	10 - 14	8 - 10	483.8688	0.9715 (V_{12})
2	5 - 11	9 - 11	466.1266	0.9716 (V_{12})

In the original network, the system I^2R loss is 511.4356 kW and after fnal reconfiguration with application of anticipated MFO, I^2R loss is reduced to 466.1266 kW with step by step switching process. The maximum reduction in power loss is 45.3090 kW.

5.2. IEEE 69-Node Test System

The Structure of 12.66 kV, 100 MVA, IEEE 69-node test system with 73 branches, 68 sectional switches and 5 tie or open switches as exposed in fig 3.

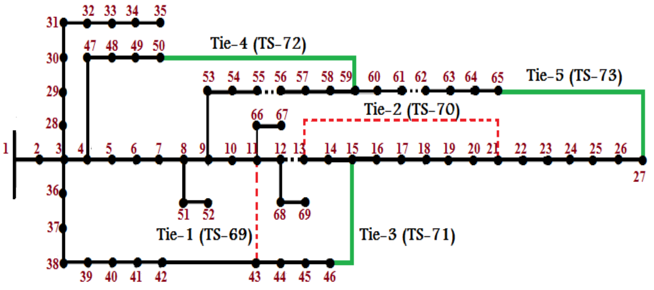

Figure 3 Final Reconfiguration of 69 node test system

The green colour solid lines are Tie- switches of the original network are closed during switching operation and after reconfiguration switches are opened indicated as block colour dotted lines, which is revealed in Fig 3. The total substation loads for the basic configuration are 3.8022 MW and 2.6946 MVAr. The simulation results of 69-node system for the initial and after optimal RCG are presented in Table 3.

Table 3 Network Reconfiguration Results of 69-node system

Switching	Strap-Branch closed	Branch opened	Real power loss, kW	Minimum Voltage
Base Case	-------	------	225.0044	0.9092 (V_{65})
1	50 - 59	57 - 58	134.0676	0.9263 (V_{65})
2	27 - 65	61 - 62	129.9221	0.9406 (V_{62})
3	15 - 46	12 - 13	99.8206	0.9428 (V_{61})

In the original network, the system loss is 225.0044 kW and after final reconfiguration with the application of anticipated MFO, network losses is condenced to 99.8206 kW with step by step switching process. The maximum power loss reduction is 125.1838kW with step by step switching of network reconfiguration.

The optimum switching for network reconfiguration of 16-node system is highlighted in green color, which is shown in Table 1. The convergence characteristics are shown in Fig. 4 and Fig. 5 for standard 16-node and 69-node system respectively.

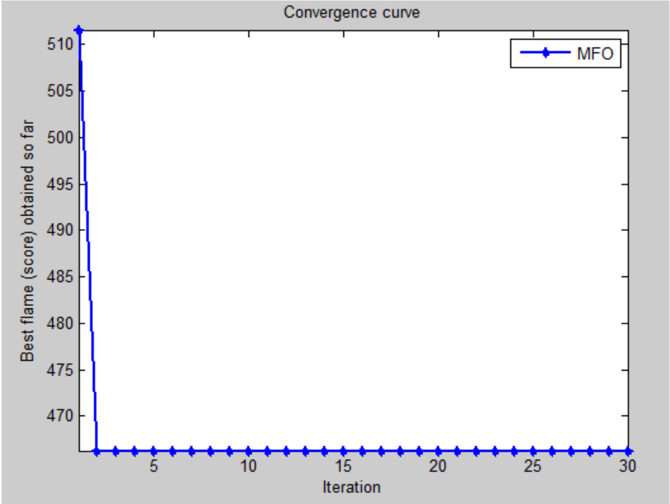

Figure 4 Convergence Characteristics of 16-node test system

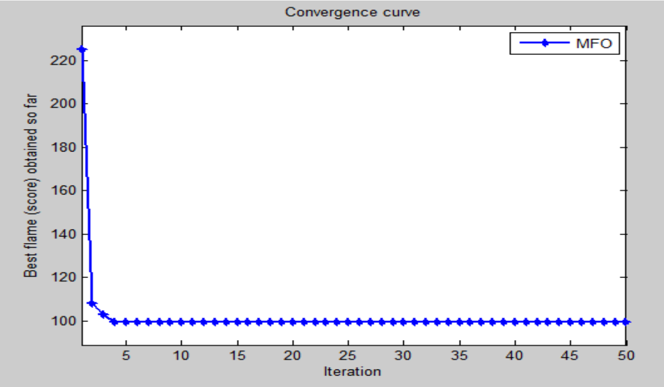

Figure 5 Convergence Characteristics of 69-node test system

6. CONCLUSION

Thus, in the proposed work, Moth Flame Optimization (MFO) technique is developed to find the best reconfigured route by satisfying all constraints. In this document, the Moth Flame Optimization (MFO) is successively applied to a distribution feeder reconfiguration. In optimization process, the maximum real power loss reduction is 45.3090 kW for 16-node and 125.1838 kW for 69-node systems, without violating radial nature of the given network based on switching vectors. The maximum percentage power loss reduction after optimal reconfiguration is 8.86% for 16-node and 55.64% for 69-node systems respectively. An efficacy of the Moth Flame Optimization algorithm demonstrated and performance is assessed on the standard IEEE 16-node and 69-node systems.

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Authors

A. V. Sudhakara Reddy has 8 years of experience in teaching and research. He has a Life Time Member of **ISTE**. **Six Times** Qualified in All India **GATE** entrance exam 2010, 2012, 2013, 2015, 2016 and 2017. Presently he is working as Research Scholar at S. V. University, Tirupati, India. He has published 14 Research Papers including IEEE conferences, Free, Scopus and UGC indexed Journals.

Prof. M. Damodar Reddy has 25 years of experience in teaching & Research. He has a Life Time Member of Indian Society for Technical Education. Presently he is working as a Professor at S. V. University, Tirupati, India. He has published 73 Research Papers (Journals-43, Conferences-30) including IEEE conferences, Free and Scopus indexed Journals. He has specialized in Power systems & Optimization Techniques.