OPTIMIZATION OF DISTRIBUTION NETWORK RECONFIGURATION USING DRAGONFLY ALGORITHM

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Abstract: *This manuscript explores feeder reconfiguration in balanced networks and presents an efficient method to optimize the radial distribution system by means of simultaneous reconfiguration. Network Reconfiguration of radial distribution system is a significant way of altering the power flow through the lines. This assessment presents a modern method to solve the network reconfiguration problem with an objective of minimizing real power loss and improving the voltage profile in radial distribution system (RDS). A precise and load flow algorithm is applied and the objective function is formulated to solve the problem which includes power loss minimization. A Meta-heuristic Dragon Fly Algorithm (DFA) is utilized to restructure and identify the optimal strap switches for minimization of real power loss in a distribution network.. The strategy has been tested on IEEE 16-bus, 33-bus and 69-bus systems to show the accomplishment and the adequacy of the proposed technique. The results demonstrate that a significant reduction in real power losses and improvement of voltage profiles.*

Index Terms: Radial distribution systems, load flow analysis, real power loss, Dragon fly Algorithm, voltage profile

1. Introduction

In primary distribution systems, sectionalizing switches are used for both protection, and for configuration regulation of the network. The numerical optimization methods, including numerical techniques and heuristic methods have been used for solving the distribution feeder reconfiguration problem. In planning, the main objective is to minimize the cost of construction. Distribution networks are configured radially. Their configurations may be varied with manual or automatic switching actions. So that the loads are supplied at the cost of possible minimum resistive line losses, and enhance power quality.

In order to reduce the power loss and enhance the service reliability, load transfer and power quality in a radial distribution network, the network configuration changed by altering the open or closed position of switches. Reconfiguration also mitigates the overloading of the network components. The power loss in the distribution network is more than that in the transmission system, because the currents available in the distribution side are generally much greater than that in the transmission path. In electric power distribution systems, about 10% of the produced electric power is vanished in distribution systems, so minimizing the power loss is one of the important problems related to electric distribution systems.

Optimal network reconfiguration is the topological structure of feeders by changing open/closed status of sectionalizing and strap switches with minimum loss. In general, distribution systems are reconfigured to decrease active power loss and to alleviate overloaded in the network. However, due to the dynamic nature of the loads, total system load is more than its generation competency that makes relieving of burden on the feeders not possible and hence the voltage profile of the system will not be improved to the required level.

Network reconfiguration in the distribution network is utilized to improve the voltage profile and to afford a minimum power loss by altering the topological structure of feeders by changing open/congested status of sectionalizing and strap switches. However, in the anticipated method, reconfiguration is used for improved loss minimization and voltage profile at various levels. The objective perspective, in addition to loss reduction, which is probably the main objectives of reconfiguration problem, other intents are relieving the overloads, enhancement of voltage profile, safety maximization, feeder load balancing and minimization of drawn reactive power compensation in radial distribution systems have been discussed.

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 reconfiguration under reliable operating conditions. Many recent researches on distribution feeder reconfiguration on reducing the power losses.. Merlin and Back [1] offered the sequential opening algorithm. Simplicity is the main advantage of heuristic methods. Baran [2] formulated a feeder reconfiguration problem for loss reduction and load balancing, the result involves a search over pertinent radial patterns by considering branching exchange type switching.

M. DamodarReddy [3] a fuzzy multi-objective approach is used for the capacitor placement in the reconfigured network. In addition to loss reduction, simultaneously as reconfiguration also improves supplementary operational parameters are nodal voltage deviations and branch current limit violation. Civanlar [4] which proposed a scheme, which utilizes feeder reconfiguration to restructure the primary feeders for loss reduction. This is done through the closing of a single tie switch and the opening of a single sectionalizing switch. Shirmohammadi [5] described a technique for the reconfiguration of distribution networks to reduce their resistive line losses. Chiang [6] proposed a two-stage solution methodology based on the modified simulated annealing algorithm for the network reconfiguration.

Seyedali Mirjalili [7] implemented dragon flies algorithm first time in 2015 for solving single-objective, discrete and multi-objective problems. Lubkeman [8] presented a proficient system using heuristic rules to minimize the search space for reducing the computation time. Goswami [9] presented a heuristic algorithm for the reconfiguration of feeders. Kochi Nara [10] proposed network reconfiguration techniques for minimum loss configuration using genetic algorithm (GA). Kim [11] proposed artificial neural networks with mapping capability and to identify the system topology that reduces the power loss according to the load pattern. Borozan [12] proposed an algorithm for determining Z_{loop} matrix used the ordered network elements.

Taleski [13] proposed a method to determine the network reconfiguration with minimization of energy losses based on statistical representation of load. Chin [14] presented a ranking index method to determine the network reconfiguration problem for loss reduction based on a two-stage solution methodology. Jeon [15] presented the simulated annealing with tabu search algorithm for loss reduction of the by switching operation in distribution systems. Morton [16] presented a brute force solution for determining a minimal-loss radial configuration. V.C.VeeraReddy [17] presented a two stage approach for determining the network reconfiguration, which involves determining the loop for maximum loss reduction.

Sivanagaraju [18] presented a scheme to resolve the voltage stability of radial distribution systems by network reconfiguration. Hong Ying-Yi [19] was described the network reconfiguration based on a multi-objective approach. D. Das [20], presented a fuzzy multi-objective approach for the allocation of losses to consumers connected to radial networks before and after network reconfiguration in a deregulated environment. Modified particle swarm optimization for solving distribution network reconfiguration is described in [21]; bus incidence matrix for the checking radial structure of distribution network has been used in this approach. Modified Honey Bee Mating Optimization technique for solving radial feeder reconfiguration in order to reduce the power losses and the voltage deviation is presented in [22].

Dynamic feeder reconfiguration using GA for reducing power losses is proposed in [23]. Mostafa Sedighizadeh [24] described optimal reconfiguration and capacitor placement was used to reduce power losses and keep the voltage within its acceptable intervals. B. Bhargav Reddy [25] described the network reconfiguration for real power loss reduction for different scenarios at different load levels. V. Usha Reddy [26] presented capacitor placement, a two stage approach to minimize the active power loss and improvement of the voltage profile using a differential evolution algorithm. S. Naveen [27] described the modified bacterial foraging algorithm and Sudhakar Reddy [28] described the dragonfly algorithm are exclusively to the network reconfiguration problem.

2. Problem Formulation

A. Calculation of load current:

The complex power injected into the bus n is given by

$$S_n = P_n + jQ_n = V_n \ \ I_n{}^*$$

The load current at any bus n is given by

$$I_{L,n} = \left(\frac{P_n + jQ_n}{V_n}\right)^* = \frac{P_n - jQ_n}{V_n^*} \qquad (1)$$

$$\text{Where } n = 1, 2, 3, \ldots \ldots \ldots \ N$$

Where N = total number of buses

$I_{L,n}$ = load currents@ bus n
P_n = real power demand@ bus n
Q_n = reactive power demand@ bus n
V_n = bus voltage@ bus n

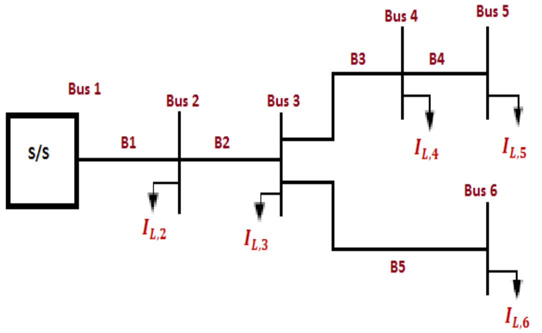

Fig 1: A Simple 6-bus radial distribution system

B. Formation of BIBC matrix:

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

$I_{B1} = I_{L2} + I_{L3} + I_{L4} + I_{L5} + I_{L6}$ (2)
$I_{B2} = I_{L3} + I_{L4} + I_{L5} + I_{L6}$ (3)
$I_{B3} = I_{L4} + I_{L5}$ (4)
$I_{B4} = I_{L5}$ (5)
$I_{B5} = I_{L6}$ (6)

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

$$\begin{bmatrix} I_{B1} \\ I_{B2} \\ I_{B3} \\ I_{B4} \\ I_{B5} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_{L2} \\ I_{L3} \\ I_{L4} \\ I_{L5} \\ I_{L6} \end{bmatrix} \qquad (7)$$

The above matrix is reduced to
[IB] = [BIBC] [IL] (8)

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.

$V_q\,(K) = V_p\,(K) - I_B\,(K)*Z_p\,(K)$ (9)

D. 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

$$P_{LT} = \sum_{i=1}^{b} I_i^2 \ R_i \qquad (10)$$

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

$$P_{LA} = \sum_{i=1}^{b} I_{ai}^2 \, R_i \qquad (11)$$

$$P_{LR} = \sum_{i=1}^{b} I_{ri}^2 \, R_i \qquad (12)$$

E. 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

$$\textit{Fitness function} = min\ \{\ P_{loss}\ \} \quad (13)$$

3. Anticipated Dragonfly Algorithm:

Dragonflies are considered as small predators that hunt almost all other small insects in nature. Nymph dragonflies also predate on other marine insects and even small fishes. The interesting fact about dragonflies is their unique and rare swarming behavior. Dragonflies swarm for only two purposes. They are hunting and migration. The former is called static swarm, and the latter is called dynamic swarm.

The primary stimulation of the DA algorithm originates from the static and dynamic swarming behaviors of dragonflies in nature. Two crucial phases of optimization, exploration and exploitation, are designed by modeling the social interaction of dragonflies in navigating, searching for foods, and avoiding enemies when swarming dynamically or statistically.Separation refers to the static collision avoidance of the individuals from other individuals in the neighborhood. Alignment, which indicates velocity matching of individuals to that of other individuals in neighbourhoods. Cohesion, which refers to the tendency of individuals towards the center of the mass of the neighborhood.

The main Objective of any swarm is endurance, so all of the individuals should be attracted towards food sources and distracted outwards enemies. Considering these two deeds, there are five focal factors in position updating of individuals in swarms.

Each of these behaviors is mathematically modeled as

1. Separation $S_i = -\sum_{j=1}^{N} X - X_j$ (14)

2. Alignment $A_i = \frac{\sum_{j=1}^{N} X_j}{N}$ (15)

3. Cohesion $C_i = \frac{\sum_{j=1}^{N} X_j}{N} - X$ (16)

4. Attraction towards a food source is calculated as $F_i = X^+ - X$ (17)

5. Distraction outwards an enemy is calculated as $F_i = X^- + X$ (18)

Where X is the position of the current individual, and X^+ and X^- signifies the position of the food source and enemy respectively.

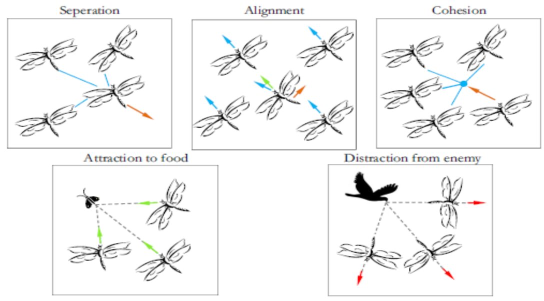

Fig1: Properties of dragon flies

To update the position of artificial dragonflies in a search space and simulate their movements, two vectors are considered: step (ΔX) and position (X). The step vector is analogous to the velocity vector in PSO, and the DA algorithm is developed based on the framework of the PSO algorithm. The step vector shows the direction of the movement of the dragonflies and defined as follows.

$$\Delta X_{t+1} = (sS_i + aA_i + cC_i + fF_i + eE_i) + w\Delta X_t \quad (19)$$

After calculating the step vector, the position vectors are calculated as follows.

$$X_{t+1} = X_t + \Delta X_{t+1} \quad (20)$$

As for now, dragonflies tend to align their flying while maintaining proper separation and cohesion in a dynamic swarm. In a static swarm, however, alignments are very low while cohesion is high to attack prey. For the transition between exploration and exploitation, the radii of neighbourhoods are increased proportional to the number of iterations. Another way to balance exploration and exploitation is to adaptively tune the swarming factors during optimization.

The dragonflies are required to change their weights adaptively for transiting from exploration to exploitation of the search space. It is also assumed that dragonflies tend to see more dragonflies to adjust the flying path as optimization process progresses. In other word, the neighboring area is increased as well whereby the swarm becomes one group at the final stage of optimization to converge to the global optimum.

To improve the randomness, stochastic behavior, and exploration of the artificial dragonflies, they are required to fly around the search space using a random walk when there are no neighboring solutions. In this case, the position of dragonflies is updated using the following equation.

$$X_{t+1} = X_t + \text{Levy}(d) * X_t \tag{21}$$

Where t is the current iteration and d is the dimension of the position vectors. The Levy flight is calculated as follows.

$$\text{Levy}(d) = 0.01 * \frac{r_1 * \sigma}{r_2^{1/\beta}} \tag{22}$$

Where r1, r2 are two random numbers in [0, 1], b is a constant, and σ is calculated as follows.

$$\sigma = \left(\frac{\Gamma(1+\beta) * \sin\left(\frac{\pi\beta}{2}\right)}{\Gamma\left(\frac{1+\beta}{2}\right) * \beta * 2^{\left(\frac{\beta-1}{2}\right)}} \right)^{1/\beta} \tag{23}$$

The DA algorithm starts optimization process by creating a set of random solutions for a given optimization problem. In each iteration, the position and step of each dragonfly are updated. For updating X and DX vectors, the neighborhood of each dragonfly is chosen by calculating the Euclidean distance between all the dragonflies and selecting N of them. The position updating process is continued iteratively until the convergence criterion is satisfied.

4. Results

In order to demonstrate the effectiveness of the anticipated method, DFA is tested on standard IEEE 16-bus, 33-bus and 69-bus systems.

4.1 IEEE 16-Bus test system

The final configuration of the 100MVA, 23kV, IEEE 16-bus test system with 16 branches, 13 sectionalizing switches and 3 tie switches as shown in fig 2. The dotted lines (red color) represented as tie switches of original network and tie switches of optimal reconfiguration are of green color solid lines, which are shown below.

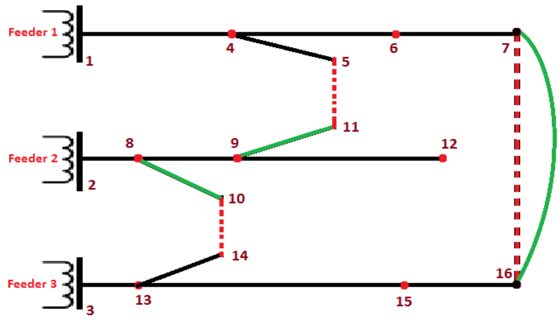

Fig2: Optimal Network Reconfiguration of 16 bus test system

Table 1: Network Reconfiguration Results of 16 bus system

Switching	Strap-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})
Optimal Case	----	----	466.1266	0.9716 (V_{12})

Table 2: Comparative Results of 16-bus system

1	Total real power loss of the original network	**511.4356 kW**
2	Minimum voltage of the original network	0.9693 p.u
3	Location of the minimum voltage	12
4	Total real power loss of the reconfigured network	**466.1266 kW**
5	Minimum voltage of the reconfigured network	0.9716 p.u
6	Location of the minimum voltage	12
7	Loss reduction after optimal reconfiguration	**8.86 %**

The comparative results of 16-bus test system for the original network and reconfigured network are presented in table-1 & table-2. In the basic configuration, power loss was **511. 4356 kW** and after reconfiguration by using the projected dragonfly algorithm, power loss is reduced to **466.1266 kW**.

4.1 IEEE 33-Bus test system

The final configuration of the 100MVA, 12.66KV, IEEE 33-bus test system with 37 branches, 32 sectionalizing switches and 5 tie switches as shown in fig 3. The total substation loads for the basic configuration are 4715 kW and 2300 kVAr [3]. The comparative 33-bus test results for the original network and reconfigured network are presented in table-3 & table-4.

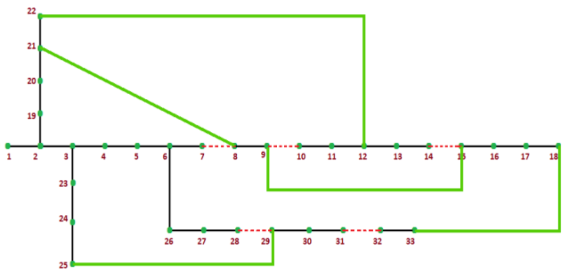

Fig3: Optimal Network Reconfiguration of 33 bus test system

Table 3: Network Reconfiguration Results of 33 bus system

Switching	Strap-Branch closed	Branch opened	Real power loss, kW	Minimum Voltage
Base Case	-------	------	369.2558	0.8785 (V_{33})
1	12 - 22	7 - 8	285.8260	0.8967 (V_{33})
2	25 - 29	28 - 29	269.0813	0.9100 (V_{33})
3	8 - 21	11 - 12	257.0505	0.9100 (V_{33})
4	18 - 33	31 - 32	244.6570	0.9148 (V_{32})
5	9 - 15	14 - 15	241.4075	0.9200 (V_{32})
Optimal Case	11 - 12	9 - 10	238.2888	0.9232 (V_{32})

In the basic configuration power loss was 369.2558 kW and after reconfiguration by using the projected dragonfly algorithm power loss is reduced to 238.2888 kW.

Table 4: Comparative Results of 33-bus system

1	Total real power loss of the original network	**369.2558 kW**
2	Minimum voltage of the original network	0.8785 p.u
3	Location of the minimum voltage	33
4	Total real power loss of the reconfigured network	**238.2888 kW**
5	Minimum voltage of the reconfigured network	0.9232 p.u
6	Location of the minimum voltage	32
7	Loss reduction after optimal reconfiguration	**35.47 %**

In the basic configuration, power loss was **369.2558 kW** and after reconfiguration by using the projected dragonfly algorithm power loss is reduced to **238.2888 kW.**

4.2 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 3802.2 kW and 2.6946 kVAr [3].

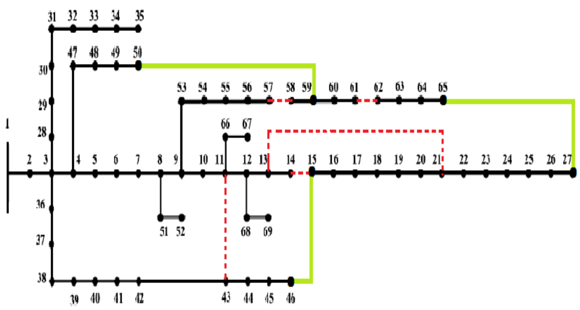

Fig4: Optimal Network Reconfiguration of 69 bus test system

The comparative 69-bus test results for the original network and reconfigured network are presented in table-5 & table-6. In the basic configuration power loss was **225.0044 kW** and after reconfiguration by using the projected dragonfly algorithm, power loss is reduced to **99.6216 kW.**

The optimal network reconfiguration is to find a superlative reconfiguration of radial network that gives lowest power loss while the obligatory operating constraints are satisfied, which are voltage profile of the system, the current capacity of the feeder and radial structure of the dissemination framework. The voltage profiles of original network and after optimal reconfiguration for IEEE 16-bus, 33-bus and 69-bus test systems are shown in fig.5, fig.6, fig.7, fig.8 and fig.9, fig.10 respectively.

Table 5: Network Reconfiguration Results of 69 bus 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	14 - 15	99.6216	0.9428 (V_{61})
Optimal Case	-------	------	99.6216	0.9428 (V_{61})

Table 6: Comparative Results of 69-bus system

1	Total real power loss of the original network	**225.0044 kW**
2	Minimum voltage of the original network	0.9092 p.u
3	Location of the minimum voltage	65
4	Total real power loss of the reconfigured network	**99.6216 kW**
5	Minimum voltage of the reconfigured network	0.9428 p.u
6	Location of the minimum voltage	61
7	Loss reduction after optimal reconfiguration	**55.72 %**

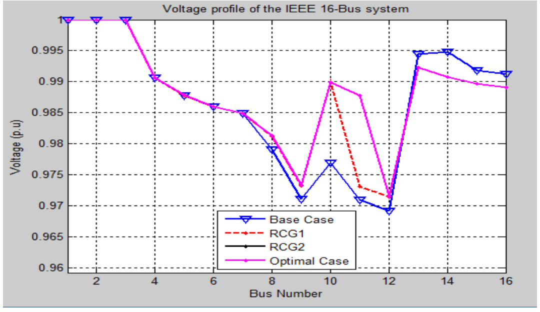

Fig. 5: Comparison of voltage profiles of different reconfigurations for IEEE 16-bus system

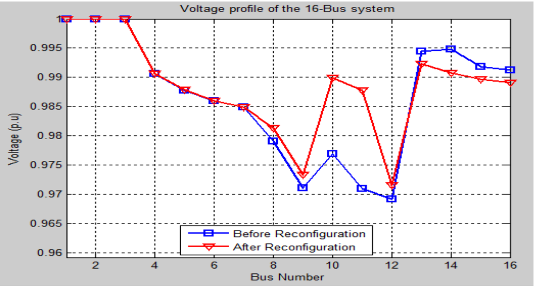

Fig. 6: Comparison of voltage profiles before and after optimal reconfiguration for 16-bus system

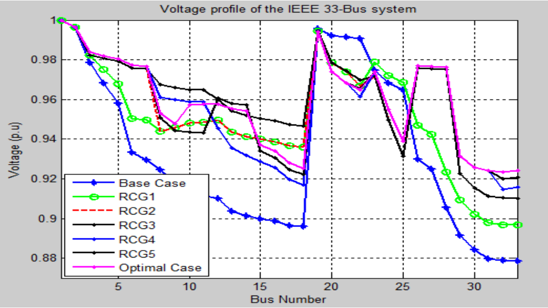

Fig. 7: Comparison of voltage profiles of different reconfigurations for IEEE 33-bus system

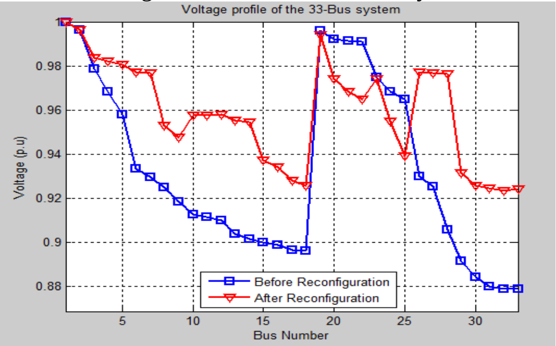

Fig. 8: Comparison of voltage profiles before and after optimal reconfiguration for 33-bus system

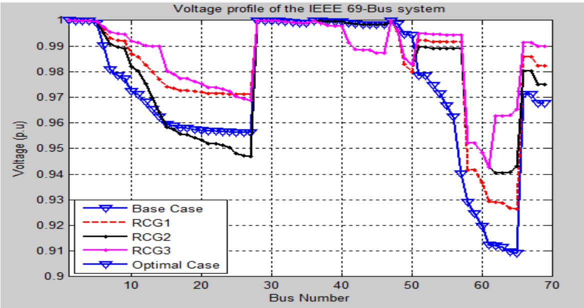

Fig. 9: Comparison of voltage profiles of different reconfigurations for IEEE 69-bus system

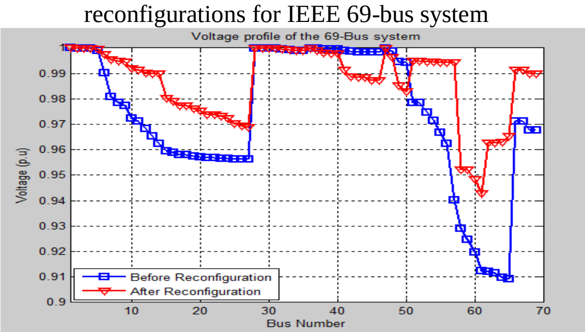

Fig. 10: Comparison of voltage profiles before and after optimal reconfiguration for 69-bus system

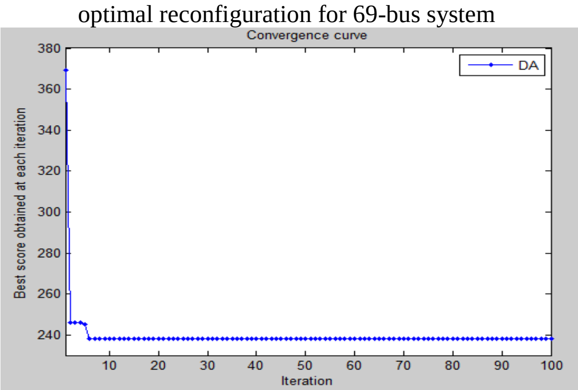

Fig. 11: Convergence curve for IEEE 33-bus system

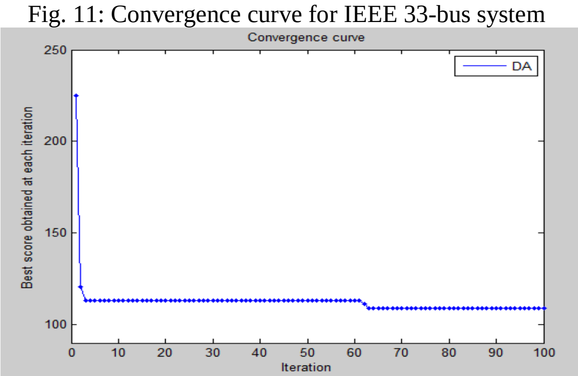

Fig. 12: Convergence curve for IEEE 69-bus system

In the present work,

Control parameters	DFA
Number of search agents	40
Max. number of iterations	100
No. of dimensions	3 (for 16-bus system)
	5 (for 33 & 69-bus)
Separation weight	S = rand*my_c
Alignment weight	A = rand*my_c
Cohesion weight	C = rand*my_c
Food attraction weight	F = rand
Enemy distraction weight	E = my_c
Best_score	Food_fitness
Best_position	Food_position

S. NO	Test System	LSW
1.	16 - Bus	2 5 8 9 0;7 11 14 0 0;3 4 16 15 13
2.	33 - Bus	9 10 11 35; 27 28 37 0;7 6 33 0;31 32 36 0; 13 14 34 0
3	69 - Bus	35 36 37 38 39 40 41 42 69 9 10 0 0;15 16 17 18 19 20 70 0 0 0 0 0 0;13 14 43 44 45 71 0 0 0 0 0 0 0; 46 47 48 49 72 52 53 54 55 56 57 58 0; 21 22 23 24 25 26 73 59 60 61 62 63 64

5. Conclusion

In this paper, the Dragon fly algorithm is successively applied to a distribution feeder problem. The objective to minimize the real power loss, while maintaining the radial structure of the network based on LSW16, LSW33 and LSW69 for 16 bus, 33 bus and 69 bus systems respectively. The effectiveness of the proposed method is demonstrated on 16-bus, 33-bus and 69-bus systems. The numerical results illustrates that the proposed algorithm is capable of finding optimal solution or the best score is obtained by using DFA. Thus, the final results of the proposed DFA method illustrates considerable loss reduction is possible as compared to previous reports of other researchers. The active power loss reduction for IEEE 16-bus, 33-bus and 69-bus systems are 8.86%, 35.47% and 55.72% respectively.

Appendix: 16-Bus Test System:

Line Number	Real Loss	Reactive Loss
1	61.6315	82.1754
2	7.5103	10.3267
3	11.9451	23.8903
4	1.5216	1.5216
5	278.3384	278.3384
6	2.0862	2.0862
7	87.0102	119.6390
8	0.7117	0.7117
9	19.7046	27.0938
10	29.0760	29.0760
11	7.8345	10.7724
12	2.0097	2.6796
13	2.0557	2.0557
Total Losses	**511.4356**	**590.3668**

Bus number	Voltage mag	Voltage ang
1	1.0000	0
2	1.0000	0
3	1.0000	0
4	0.9907	-0.3698
5	0.9878	-0.5443
6	0.9860	-0.6972
7	0.9849	-0.7043
8	0.9791	-0.7635
9	0.9711	-1.4523
10	0.9769	-0.7701
11	0.9710	-1.5259
12	**0.9693**	-1.8365
13	0.9944	-0.3293
14	0.9948	-0.4562
15	0.9918	-0.5228
16	0.9913	-0.5904

Acknowledgements

The authors would like to thank the Sri Venkateswara University College of Engineering, S V University, Tirupati, India, for providing the necessary facilities and encouragement to carry out this research work.

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