Optimum Distribution Network Reconfiguration Using Firefly Algorithm

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***Abstract*--The reconfiguration of the distribution system is used to minimize total power loss by providing good voltage profile. It is performed based on a metaheuristic optimization method, called firefly algorithm (FA). First, the algorithm was applied to the IEEE33- bus test system to find a new optimum configuration of the network by opening and closing the normally open switch and normally closed switches, keeping its radial structure and ensuring the supply of all connected loads. The application of the FA algorithm has achieved a good compromise efficiency and success rate compared to other highly recognized algorithms. Second, the algorithm was applied to a real distribution network of 112-bus with the aim to achieve optimal configuration and minimize the total power loss ensuring good voltage profile.**

***Index Terms*-- Distribution Network; Firefly Algorithm; Reconfiguration.**

1. INTRODUCTION

Two types of switches are generally known in the electrical system for the protection and network configuration. The first are normally closed switches (sectionalizing switches) and the second normally open (tie switches). By changing the state of these switches, the configuration of the distribution system is changed and the loads are transferred between the lines, so that the radial power configuration is maintained. This implementation is known as the reconfiguration of the power supply system [1].

In general, the process of reconfiguring a power distribution network is associated with the search for a new topology, allowing the distribution of power in the most efficient possible manner [2]. This topological search is achieved by optimizing the network under the objective of minimizing total losses of active power system and improving the voltage profile.

Some benefits are related to the reconfiguration [3] [4]:
-The ability to reduce the losses of active power;
-Increasing the capacity of the system;
-Ensuring the continuity of service for maintenance or system faults.

In this paper, the reconfiguration technique of distribution network is used to search the possible optimum configuration by the application of a metaheuristic method, called fireflies algorithm, applied firstly to the test system IEEE -33 bus to confirm the effectiveness of the algorithm and secondly on a real distribution network of 112-bus.

2. OPENING AND CLOSING OF THE SWITCHES

The main aim of an optimal reconfiguration (opening and closing of the switches) is to minimize active power loss. Therefore, the objective function of this study is:

$$\text{Minimise } \{P_{losses} = \sum_{l=i}^{n} | I_i |^2 \ R_i\} \quad (1)$$

where:
i = Number of lines in the system.
I_i = Line real active current.
R_i = Line resistance.

By providing [4]:
- Holding the radial structure of the network.
- The maximum and minimum amplitudes and phase angles of the voltages of the bus.
- The maintenance of the balance of power across the bus.
- The power supply of all loads connected to the network.

The closure of all switches in the network of radial distribution will create loops in the network determining the possible elements that must be opened. So the radial structure of the distribution system is maintained by the identification of these loops, ensuring that only one line segment is always switched open, which allows the generation of eligible topologies delimiting the search space to evaluate the configuration process.

Then each identified loop determines, among all its elements, the element to disconnect to form a radial network. Figure 1 represents a network consisting of three loops where the components of each of them are determined as follows: [2]

Loop 1= [L_2 L_4 L_5]
Loop 2= [L_1 L_3 L_4]
Loop 3= [L_5 L_6 L_7]

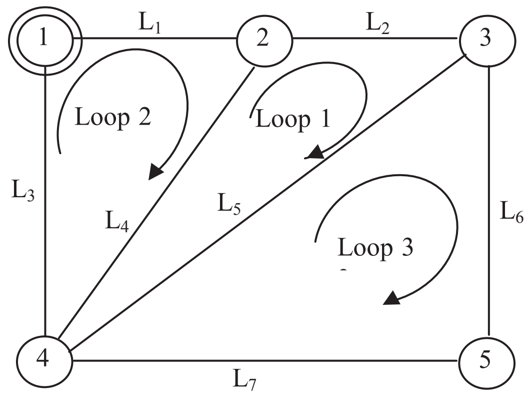

Fig. 1. Network consists of three loops.

Therefore, to design a feasible radial topology, items that will be disconnected are to be elected from the set of vectors, without common elements of basic loops. Combinatorial that can be obtained from these vectors provide all possible configurations of the system.

To get the best possible configuration respecting all constraints, a metaheuristic optimization method, called algorithm fireflies is applied, where the principle and its parameters are shown below.

3. Firefly algorithm

The firefly algorithm has three particular idealized rules which are based on some of the major flashing characteristics of real fireflies. These rules are the following [5]:

- All fireflies are unisex, and they move towards more attractive and brighter ones regardless their sex.
- The degree of attractiveness of a firefly is proportional to its brightness which decreases as the distance from the other firefly increases due to the fact that the air absorbs light. If there is not a brighter or more attractive firefly than a particular one, it will then move randomly.
- The brightness or light intensity of a firefly is determined by the value of the objective function of a given problem. For maximization problems, the light intensity is proportional to the value of the objective function.

A. Attractivenes

In the firefly algorithm, the form of attractiveness function of a firefly is the following monotonically decreasing function:

$$\beta_r = \beta_0 * \exp\left(-\gamma r_{ij}^m\right), \quad \text{with} \quad m \geq 1 \tag{3}$$

Where, r is the distance between any two fireflies, β0 is the initial attractiveness at r = 0, and γ is an absorption coefficient which controls the decrease of the light intensity.

B. Distance

The distance between any two fireflies i and j, at positions xi and xj , respectively, can be defined as a Cartesian or Euclidean distance as follows :

$$r_{ij} = \left\| x_i - x_j \right\| = \sqrt{\sum_{k=1}^{d} \left(x_{i,k} - x_{j,k}\right)^2} \tag{4}$$

Where xi,k is the kth component of the spatial coordinate xi of the ith firefly and d is the number of dimensions, for d = 2, we have:

$$r_{ij} = \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2} \tag{5}$$

However, the calculation of distance r can also be defined using other distance metrics, based on the nature of the problem, such as Manhattan distance or Mahalanobis distance.

C. Movement

The movement of a firefly i which is attracted by a more attractive (brighter) firefly j is given by the following equation:

$$x_i = x_i + \beta_0 * \exp\left(-\gamma r_{ij}^2\right) * \left(x_j - x_i\right) + \alpha * \left(rand - \frac{1}{2}\right) \tag{6}$$

Where the first term is the current position of a firefly, the second term is used for considering a firefly's attractiveness to light intensity seen by adjacent fireflies, and the third term is used for the random movement of a firefly in case there are no brighter ones.

The coefficient α is a randomization parameter determined by the problem of interest, while rand is a random number generator uniformly distributed in the space [0,1]. As we will see in this implementation of the algorithm, we will use $\beta_0 = 1.0$, $\alpha \in [0, 1]$ and the attractiveness or absorption coefficient $\gamma = 1.0$, which guarantees a quick convergence of the algorithm to the optimal solution [5].

4. Optimal reconfiguration by the application of FA

The problem of optimal reconfiguration to minimize active power losses has been addressed using metaheuristic firefly algorithm (FA). It works by first generating random solutions from space research imposed by the loops formed by closing all existing switches and evaluate them.

Finally, it consists in determining a new optimal topology of the distribution network through the application of this algorithm in finding the normally open switches to close, and branches with switches normally closed to open, corresponding to the best possible solution. The operation is done according to the flowchart in Figure 2.

The state vector corresponding to the reconfiguration of the network is given as follows:

$$X = [S_1 S_2 \ldots S_{NB}]_{(1xNB)} \tag{6}$$

S1, S2, ...S_{NB}: are switches selected to be open for a new configuration.

NB is the number of vectors or loops formed by the closing of the switches.

The application parameters of FA to solve the problem of the optimal configuration of the distribution network are given as follows: [6] [7] [8] [9]:

- Number of fireflies: 30;
- Maximum number of iterations: 30;
- Parameter distribution (α): 0.25;
- The minimum value of attractiveness (β): 0.2;
- Absorption coefficient (γ): 1.

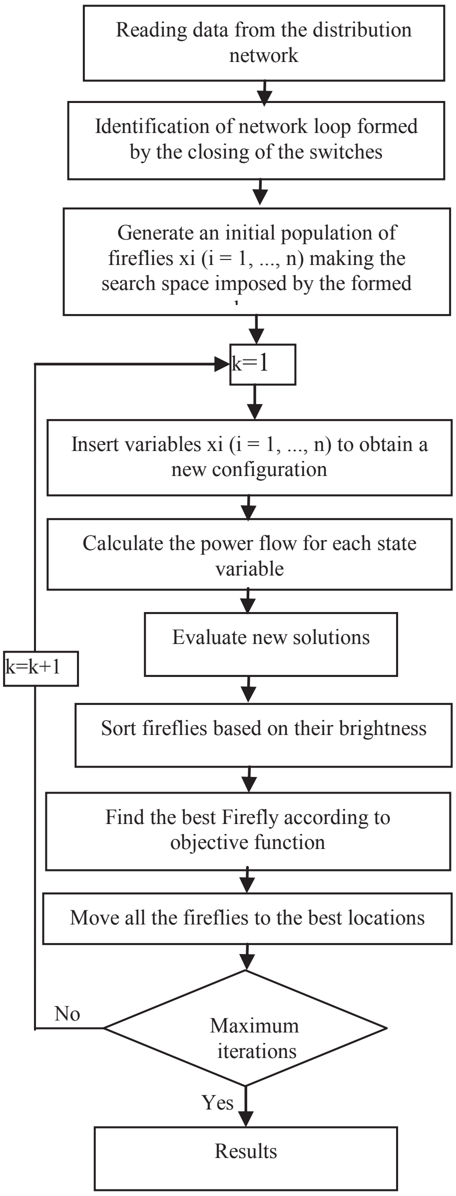

Fig. 2. Flowchart of the determination of the optimal topology of the distribution network

The problem is programmed in MATLAB and applied firstly on the network test IEEE 33-bus [10] shown in the figure 3 and secondly on the real distribution network 112-bus [11] shown in the figure 6.

A. IEEE 33-bus

In addition to the 32 branches, the network comprises five normally open switches (tie-switches) selected to be closed to insert new branches.

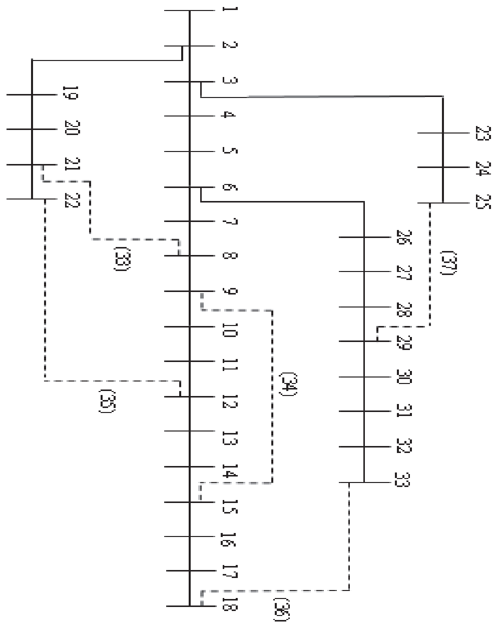

Fig. 3. IEEE33-bus with normally open switches (tie-switches)

Results and Discussion:

Table 1 shows the voltage at each bus for the optimal network configuration. Figure 4 represents the voltage profile before and after the reconfiguration of the network. The minimum voltage of 0.9134 pu with the initial configuration, where the switches 33, 34, 35, 36, 37 are open, is obtained at the bus 18. After completing the program, an optimal network topology is obtained with new branches open 7, 9, 14, 32, 37. A new voltage profile is obtained with a minimum value of 0.94237 pu at the bus 32 (Figure 4).

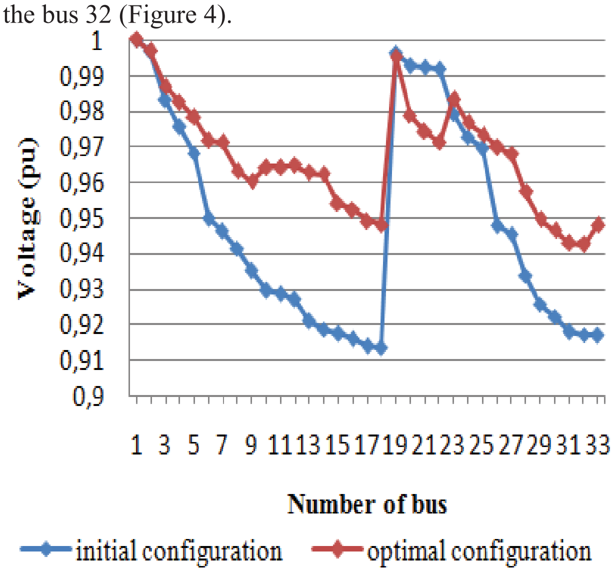

Fig. 4. Level voltage of each bus of the distribution IEEE33-bus before and after reconfiguration

TABLE I

Voltages before and after reconfiguration of the distribution system IEEE 33-bus

Bus number	V(pu)	
	Initial configuration	Optimal configuration
1	1.0000	1.0000
2	0.9970	0.9971
3	0.9830	0.9870
4	0.9755	0.9825
5	0.9682	0.9782
6	0.9498	0.9717
7	0.9463	0.9711
8	0.9415	0.9634
9	0.9352	0.9600
10	0.9294	0.9643
11	0.9286	0.9644
12	0.9271	0.9647
13	0.9210	0.9626
14	0.9187	0.9620
15	0.9173	0.9539
16	0.9160	0.9522
17	0.9140	0.9493
18	0.9134	0.9482
19	0.9965	0.9952
20	0.9929	0.9788
21	0.9922	0.9743
22	0.9916	0.9711
23	0.9794	0.9835
24	0.9727	0.9768
25	0.9694	0.9735
26	0.9479	0.9700
27	0.9453	0.9676
28	0.9339	0.9571
29	0.9257	0.9496
30	0.9222	0.9465
31	0.9180	0.9430
32	0.9171	0.9424
33	0.9168	0.9479

Table 2 shows the summary of the results before and after reconfiguration IEEE33-bus network by applying the FA algorithm. For the optimal configuration, the total losses are reduced from 201.89 kW to 136.14 kW with a reduction rate of 32.57%, which clearly reflects the impact of the optimal network reconfiguration on reducing total active power losses. Figure 5 gives the new optimal configuration obtained by applying the algorithm FA where the solid lines indicate the branches in service, and the broken lines indicate the branches out of service. The network is always radial and all connected loads are supplied.

TABLE II

Result of reconfiguration IEEE 33-bus network by FA

	Initial configuration	FA configuration
Operational switches	33,34,35,36,37	7,9,14,32,37
Power losses (kW)	201.89	136.14
Minimum voltage (pu)	0.9134	0.9423
Bus minimum voltage	18	32

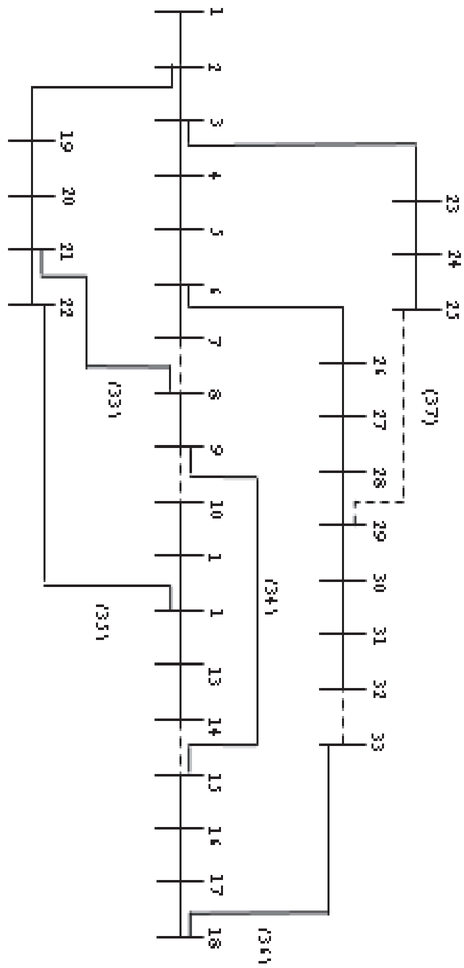

Fig. 5. IEEE33-bus network with the new optimal configuration obtained by FA

Table 3 shows a comparison between the results obtained by the FA algorithms (Fireflies Algorithm), ABC (Artificial Bees Algorithm), GA (Genetic Algorithm) [12] and TS (Tabu Search Algorithm) [13] made before and after reconfiguration.

TABLE III

Results obtained by FA compared to ABC, GA and TS

Algorithm	Operational switch	Total losses (kW)	Reduction of losses (%)
Initial configuration	33, 34, 35,36,37	201.89	-
ABC	8, 14, 28, 32, 33	139.52	30.90
GA	9, 28, 33, 34, 36	140.61	30.36
TS	6,11,14, 28, 31	136,47	32.40
FA	7, 9, 14, 32, 37	136,14	32.57

After reconfiguration of the network, we find that the value 136.14 kW of total loss of active power obtained by FA is less than those obtained by applying the algorithms GA (140.6 kW), ABC (139.5 kW) and TS (136.47 kW). These results reflect the effectiveness of the FA algorithm compared to GA, ABC and TS.

B. Real distribution network of 112- bus

In addition to the 111 branches, the network comprises seven normally open switches (tie-switches) selected to be closed to insert new branches.

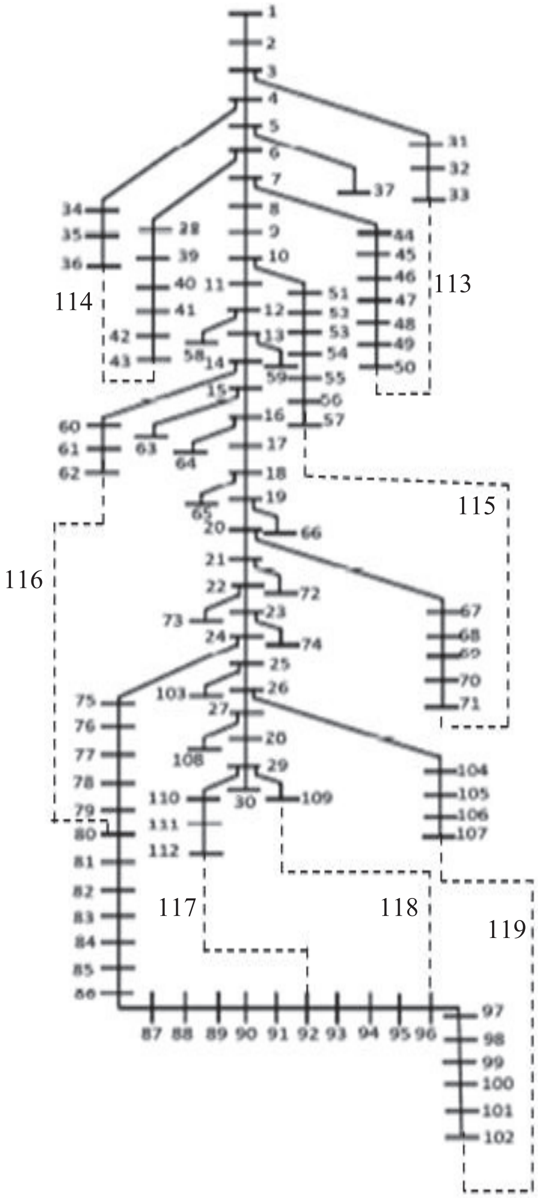

Fig. 6. Real distribution network 112-bus with normally open switches (tie-switches).

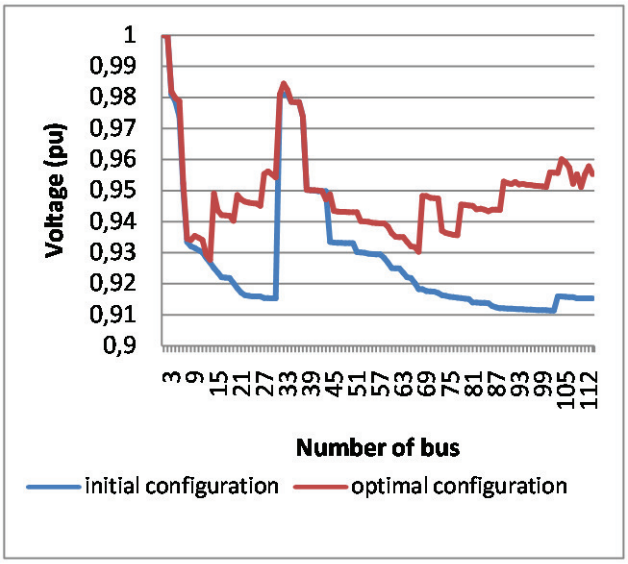

Fig. 7. Level voltage of each bus of the distribution real network 112-bus before and after reconfiguration

Table 6 shows the summary of the results before and after reconfiguration of real netowrk 112-bus by applying the FA algorithm. For the optimal configuration, the total losses are reduced from 309.84 kW to 224.48 kW with a reduction rate of 27.54%, which clearly reflects the impact of the optimal network reconfiguration on reducing total active power losses.

TABLE VI

Result before and after reconfiguration of real network 112-bus by FA

	Initial configuration	configuration
Operational switches	113,114,115,116	42,49,70,78
	117,118,119	88,94,101
Power losses (kW)	309.84	224.48
Reactive losses (KvaR)	288.88	162.04
Minimum voltage (pu)	0.9114	0.9304
Bus minimum voltage	102	66

5. CONCLUSION

The optimization method, based on the algorithm of the Fireflies FA, was used to find the most appropriate network topology distribution IEEE33-bus and real distribution network 112 -bus with the objective to have the minimum power loss with an eligible voltage profile. The optimal obtained configuration meets the requirements; keep the radial structure of the network, and ensure the supply of all loads connected to the network. The results have proven the effectiveness of the algorithm used FA compared with those obtained by the algorithms GA, ABC and TS.

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