RECONFIGURATION OF DISTRIBUTION SYSTEMS BY IMPLEMENTATION OF SHUFFLED FROG LEAPING ALGORITHM FOR LOSS REDUCTION

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ABSTRACT: *In this paper, a new approach for solving the reconfiguration problem in distribution systems with radial network structure is presented. Reconfiguration problem, in this work, considered as a special optimization problem which aims to reduce distribution losses and improvement of voltage profile. The result of this optimization determines the state of switches in distribution network. This reconfiguration problem is solved by employing Shuffled Frog Leaping Algorithm (SFLA) as an optimization tool. The proposed approach is tested on different distribution networks. The results indicate improvement in loss reduction and voltage profile in comparison to the other existing algorithm of reconfiguration.*

Key Words: *Reconfiguration, SFLA, distribution systems, loss reduction, radial network*

1. INTRODUCTION

Most distribution systems' topologies are radial. Distribution feeders contain a number of switches that are normally closed and switches that are normally open. The configuration may be varied by changing the status of switches. Choosing close switches should be in the way that radial structure remains. This constraint, radial structure, is because of relay coordination. Reconfiguration problem is finding the best configuration of system for some purposes. Such loss reduction, load balancing, improving voltage profile and reliability. But the main purpose in most literatures is loss reduction.

Loss reduction is center of attention since distribution losses not only conges the distribution system capacity and loadability, but also reduces the distribution's company's competitiveness in power market. In competitive environment, each participant try to maximize the benefits by reducing their costs and losses exert heavy expenses on distribution cost.

Reconfiguration of distribution systems for loss reduction was first presented by Civanlar [1]. In [2], Baran defined the problem as an integer programming problem for loss reduction and load balancing. Shirmohammadi and Hong [3] suggested a heuristic algorithm which closes all of the network switches and consider the system as a weakly meshed network, then open one after another so as to find best flow pattern in system.

In recent years artificial intelligent based algorithms are actively developed. [4]-[7] used fuzzy logic for loss reduction. In [8] fuzzy multiple objective optimization is employed with considering the node voltage deviation and branch current constraint. However, reconfiguration is an optimization with a wide spread search space, global search algorithms such as genetic algorithm (GA) [9]-[11], particle swarm optimization (PSO) are efficient tools [13]-[17]. Enacheanu et al. [12] modified genetic operators based on the graph and Metroid theories in order to improved more efficient operators which is mutation and crossover. The classical scheme of the PSO has been revisited in [18] in order to check radial configuration and operational constraints of distribution system in each iteration. Yang et al. [19] presented a stochastic optimization technique of PSO based on the multi-agent system to minimize the system loss. In [20] T. Sawa introduced mutation operation for discrete decimal problem to PSO.

In this paper, reconfiguration problem is defined as an optimization problem which tries to minimize losses in distribution system. Due to aforementioned advantage of evolutionary algorithms in comparison with other methods of reconfiguration, new evolutionary algorithm namely Shuffled Frog Leaping Algorithm (SFLA) is employed to solve the reconfiguration problem. The SFLA combines benefits of GA and PSO algorithm. In comparison with PSO, SFLA method in solving nonlinear is problem found better in terms of processing time [21]. Also Unlike PSO, in SFLA there is no parameter to tune.

The advantages of the proposed algorithm of reconfiguration by employing SFLA are as follows:

- Decreasing the total distribution losses in comparison to the methods
- Improvement in voltage profile
- Less calculation in comparison to the methods

The rest of this paper is organized as follows: section II describes the SFLA. Section III presents the mathematical formulation of reconfiguration problem for loss reduction. In section IV, application of SFLA on reconfiguration is presented. Case study demonstrates the capability of the proposed method in section V and section VI is devoted to conclusion.

2. SHUFFLED FROG LEAPING ALGORITHM

2.1. Conventional Shuffled Frog Leaping Algorithm

Many researchers are used different search algorithms for solving power system problems [22-28].

The SFLA has been developed as a population-based Meta heuristic random search algorithm which evolution of memes carried by interactive individuals and a global exchange of information among the frog population. It combines the benefits of the both the genetic-based memetic algorithm and the social behavior-based particle swarm optimization algorithm. In SFLA, there is a set of possible solutions defined by a set of virtual frogs that is partitioned into different groups named as memeplexes, each performing a local search. Within each memeplex, the individual frogs hold ideas that can be infected by the ideas of other frogs. After a defined number of local searches in each memeplex, ideas are passed between memeplexes in a shuffling process. The local search and the shuffling process continue until termination criteria are satisfied [29],[30].

First an initial population of P frogs is created randomly and the fitness function for each frog is calculated. Then the frogs are sorted in a descending order according to their fitness and partitioned into m different memeplexes. Each memeplex contains n frogs, which satisfy equation (P=m×n). In this process the first frog goes to the first memeplex, the second frog goes to the second memeplex, m-th frog goes to the m-th memeplex, and m+1-th frog goes back to the first memeplex, and so on. Both global and local search strategies are applied into memeplexes. Within each memeplex, an independent local search in each memeplex using a particle swarm optimization like method is applied to find the frogs with the best and worst fitness values in each cycle as Xbest and Xworst , respectively. Also, in each iteration the frog with global best fitness is identified as Xgbest. The i-th frog is represented as Xi=(x1, x2,…., xS), where S is the number of variables. In each memeplex the frog with the worst fitness is improved thorough below equations.

$$D_i = rand \times (X_{best} - X_{worst}) \qquad D_{min} \le D_i \le D_{max} \quad (1)$$

$$X_{newposition} = \text{current position } X_{worst} + D_i \quad (2)$$

Where Di is change in frog position and "rand" is a random number between 0 and 1; Dmin and Dmax is the maximum step size allowed for a frog. If the evolution produces a better solution, it replaces the worst frog. Otherwise, in this case the calculations in (1) and (2) are repeated but Xbest replaced by Xgbest. If no improvement becomes possible in this case, a new solution within the feasible space is randomly generated to replace the worst frog. The calculations then continue for a specific number of iterations [21],[29].

2.2. Adjustment of Conventional Shuffled Frog Leaping Algorithm

In this section, the presented conventional SFLA is adjusted. As equation (1) and (2) represents, the worst frog tries to find a better place by jumping toward the best frog. But as the random operator is within 0 and 1, only the space between the two frogs is searched. However, as the space beyond the best frog (the other side of the best frog) might be a suitable place of solution, there should be a possibility so that the frog could search that area as well. So the random operator is adjusted to rand (1, 1.6) in order to provide a chance to search the other side of the best frog. 1.6 is chosen according to the authors experiences in different problems.

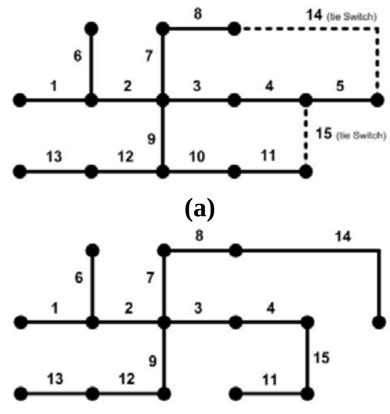

Figure 1. Example of network.

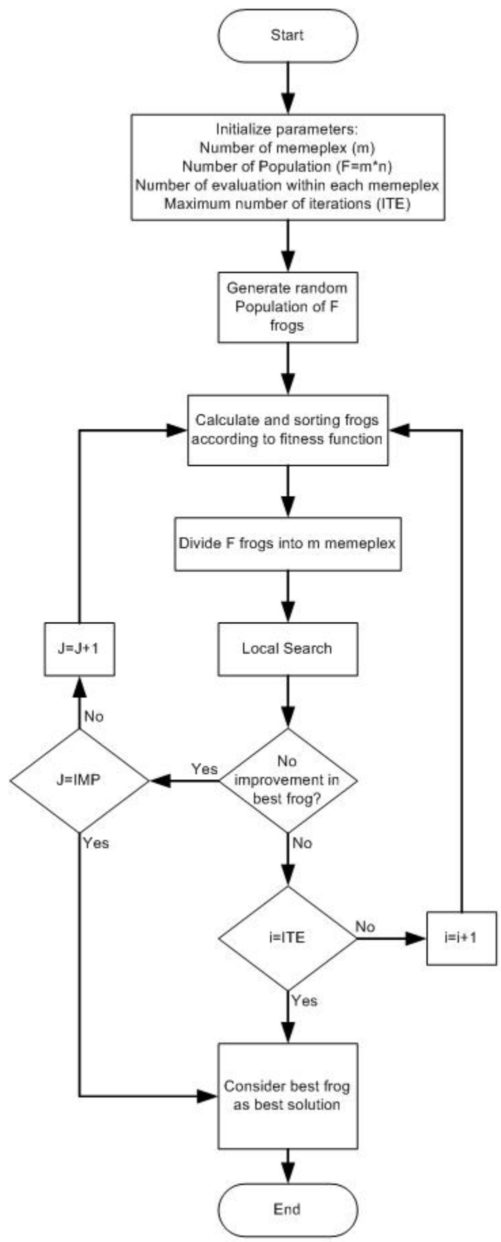

Figure 2. Flowchart of used SFLA for reconfiguration.

3. RECONFIGURATION PROBLEM FORMULATION

As described in the first section, the main objective of reconfiguration is to minimize the total distribution losses in the distribution network in order to improve different network features such as feeder load ability, network reliability and voltage profile improvement. The total distribution loss is defines according to Equation (3).

$$loss = \sum_{i=1}^{b} r_i \frac{P_i^2 + Q_i^2}{\left|V_i^2\right|} \qquad (3)$$

TABLE 1.
LOOK UP TABLE OF EXAMPLE NETWORK

Loops	Branches in loops
#1	3-4-15-11-10-9
#2	7-8-14-5

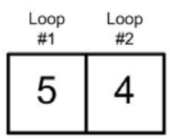

Figure 3. Frog variables for network in Figure 1(b).

This equation is subjected to different constraints which are listed below:

1) Maximum and minimum voltage at each bus

$$V_{imin} \le \left|V_i\right| \le V_{imax} \qquad (4)$$

2) Maximum eligible current at each branch

$$0 \le \left|I_{bi}\right| \le I_{bimax} \qquad (5)$$

where Pi and Qi are the active and reactive power flows through branch i, Vi the voltage magnitude at bus i, b is the number of branches in system and ri is the resistanse of branch i, Vmin and Vmax are respectively minimum and maximum voltage allowable for bus i and Ib nax is current limit through branch i.

3) Remaining the feasible structure: This constraint insures the radial structure during the optimization (reconfiguration process) process. Also, prevents from islanding in the network as result of wrong switches' status.

The final fitness function with considering maximum and minimum voltage constraint presented as below:

$$f = \sum_{i=1}^{b} r_i \frac{P_i^2 + Q_i^2}{\left|V_i^2\right|} + C(\left|V_i - V_{imin}\right|^2 + \left|V_{imax} - V_i\right|^2) \qquad (6)$$

Where C is a constant (~0.001).

4. APPLICATION OF SFLA ON RECONFIGURATION PROBLEM

4.1. Frog Definition

In different literatures, various methods for definition and simplification of network structure have been proposed. Switch state method, open branch and fixed loop method are the most popular methods according to [20]. In [15], switch state method has proposed which indicates the switches status as binary string. In open branch method the structure of network is defined by particles which the number of variables are equals to the number of open switches. However, among the described method, fixed loop method is superior to the others according to [20]. Although this method has a drawback in considering all feasible network structure, its advantages overweight to its drawbacks due to significant reduction in calculation and execution time.

TABLE 2.
RESULTS OF RECONFIGURATION FOR 33 BUS SYSTEM OF FIGURE 4

		Original Network	Optimum State	
		Venkatesh [30]	Proposed Method	
Open Switches	33-34-35-36-37	06-14-09-32-37	28-31-07-09-14	Open Switches
Total loss (kW)	211.22	128.26	121.83	Total loss (kW)
Minimum Voltage (p.u.)	0.9038	0.9378	0.9434	Minimum Voltage (p.u.)

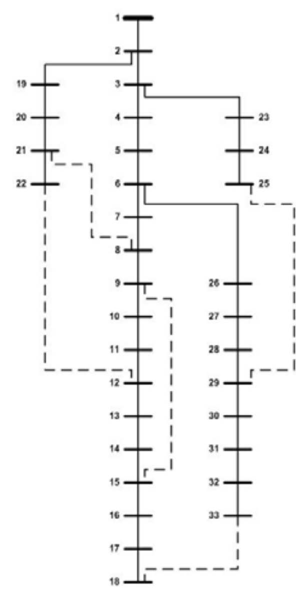

Figure 4. 33 bus distribution system [30].

Inherently, the formulation of this method insures radial structure and prevents any possible islanding in the process of optimization and evaluation of solutions. Therefore, there are no more obligations to check radial and islanding possibility. This causes significant reduction in calculation and execution time in each iteration [20].

In this work due to benefits of fixed loop method, it is proposed as coding method for frog definition. In fixed loop method all switches are supposed to be close. t loops are created which t indicates the number of tie switches, in a radial distribution network the number of possible.

TABLE 3.
RESULTS OF RECONFIGURATION FOR 69 BUS SYSTEM OF FIGURE 5

	Original Network	Optimum State	
		Das [31]	Proposed Method
Open Switches	69-70-71-72-73-74-75-76-77-78-79	14-71-79-39-70-51-28-73-76-46-67	76-45-47-39-51-08-78-79-66-30-77
Total loss (kW)	227.53	205.32	203.62
Minimum Voltage (p.u.)	0.9053	0.9268	0.9311

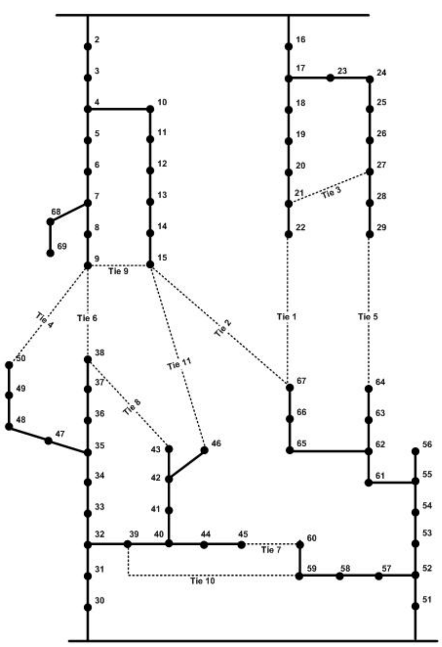

Figure 5. 69 bus distribution system [31].

existing loops is equal to t. in order to eliminate checking radial distribution and islanding in each frog evaluation, a look up table which contains all possible loops with changing the state of switches is considered. Figure 1 represents possible loops in a network with two tie switch. To create this look up table, all the branches which participate in each loop considered as a string. Also, each branch is eligible to appear in one string, for instance, branch 3 and 4 in Figure 1 are common between two loops, therefore, for string representation, they considered in only one string. Table 1 shows the proposed look up table for Figure 1(a).

Each frog is a vector which dimension is equal to the possible loops or number of string in the look up table. For instance in the network of Figure 1 each frog dimension is equal to two. Also, the variables in the frog indicate the number of the branch in each string which must be eliminated to keep the radial structure. For illustration, {5 and 4} is a frog and shows in the first string in Table 1 the fifth branch, branch 10, must be open and in the second string the forth element, branch 5, must be opened. Therefore, in each evaluation, with altering in variables of each frog considering look up table ensures radial structure and avoids islanding, as mentioned.

TABLE 4.
RESULTS OF RECONFIGURATION FOR 83 BUS SYSTEM OF FIGURE 6

	Original Network	Optimum State	
		Chiou [32]	Proposed Method
Open Switches	84-85-86-87-88-89-90-91-92-93-94-95-96	55-07-86-72-13-89-90-83-92-39-34-42-62	55-07-86-73-13-89-90-83-92-39-34-42-62
Total loss (kW)	531.99	469.88	469.88
Minimum Voltage (p.u.)	0.9285	0.9532	0.9532

4.2. Evaluation of Solutions (Frogs)

First initial population of frogs is generated randomly. In the next step the fitness value for each frog is calculated by employing Equation (6). The proposed SFLA process for reconfiguration can be defined as the below steps:

1. Generating initial population randomly
2. Adjusting each frog's variable according to lookup table
3. Translating the frog's information (values) into correspond network structure
4. Execution of load flow for determining total distribution loss for each individual frog
5. Calculation of fitness value for each frog
6. Partitioning the frog into m number of memeplex
7. Local search within each memeplex
8. Exchanging the information among the memeplexes

The above steps continuous until the termination criterion satisfied. This termination criterion, in this work, must satisfied one of the following conditions: maximum number of iteration or no improvement in the result for number of evolutions (Figure 2 shows the Flowchart of used SFLA for reconfiguration. Figure 3 shows Frog variables for network in Figure 1(b).

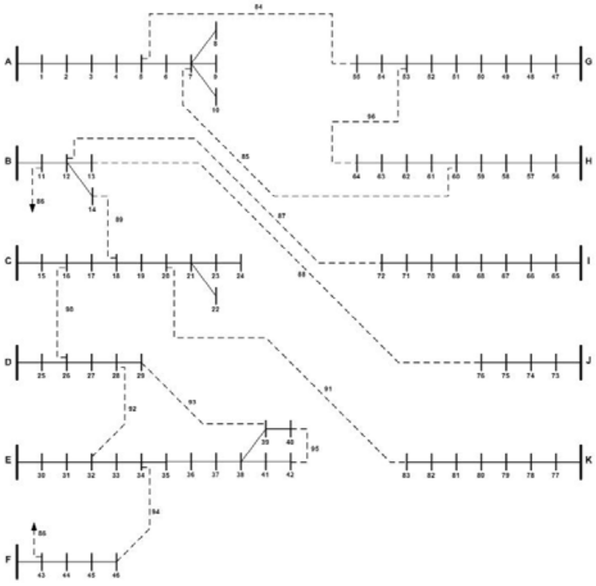

Figure 6. 83 bus distribution system [32].

5. SIMULATION AND RESULTS

In this section the proposed SFLA reconfiguration is simulated and tested on different test systems. In order to provide fair comparison among different algorithm, different case study is considered in this section.

1) Case1: A single line diagram of a 12.66kV radial distribution system having 33 nodes, 37 branches and 5 tie switches is shown in Figure 4. In this case the proposed SFLA reconfiguration is implemented on 33 bus test system. Detail information for this system is available in [30]. Table 2 represents the state of switches along with the result of [30] in reconfiguration of the test system.
2) Case2: the proposed algorithm is employed to obtain the optimum state of the switches of 69 bus distribution system [32]. It is shown in Figure 5. This system is a 11kV distribution system consist of two feeder, 69 nodes and 11 tie switches. Table 3 shows the results of the proposed algorithm along side of the result by approaches which has been introduced in [31].
3) Case3: Also in this case the SFLA reconfiguration method is compared with that one of [32]. The system has 11 feeders, 83 sectionalizing switches, 13 tie switches and 83 nodes as shown in Fig. 6. In [33], 83 bus radial distribution system considered as test system. Table 4 indicates the results of this comparison.
4) Case4: Finally, in this case the results of the proposed approaches in this paper is evaluate with [33] (distribution system shown in figure 7) results. Table 5 shows the results.

TABLE 5. RESULTS OF RECONFIGURATION FOR 69 BUS SYSTEM FIGURE 7

	ORIGINAL NETWORK	Optimum State	
		Venkatesh [33]	Proposed Method
Open Switches	69-70-71-72-73	72-26-70-65-60	15-72-10-60-70
Total loss (kW)	226.92	136.23	124.8
Minimum Voltage (p.u.)	0.9092	0.9375	0.9453

6. CONCLUSION

Reconfiguration as an alternative for loss reduction and improving network loadability and reliability became a practical solution in distribution networks. In this paper reconfiguration is defines as an optimization problem. Different evolutionary approaches for optimization exist. However, this paper considered SFLA. This is due to SFLA algorithm has some benefits over other methods. Implementation of reconfiguration with SFLA provides numerous advantages, according to the results of section V. the SFLA reconfiguration causes more loss reduction and improves the voltage profile in comparison to the other existing methods.

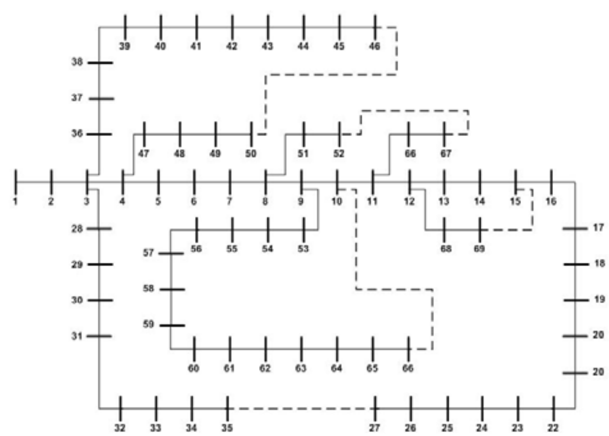

Figure 7. 69 bus distribution system [33].

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