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Reconfiguration of Distribution Power Systems for Optimal Operation

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***Abstract*— This paper aims to study the problem of minimizing the electrical losses in distribution systems through a feeder reconfiguration. Population based meta-heuristic technique has been employed to solve reconfiguration problem. The algorithm was tested on 33-bus, 69-bus, 84-bus and 118-bus radial distribution systems. The results demonstrate the efficiency of reducing active power loss and enhancement of voltage profiles. A comparison study was also made, were the applied method produce better results than other methods published in recent literature.**

***Keywords*— distribution systems; reconfiguration; power loss; differential evolution algorithm.**

I. Introduction

In the modern world, electricity demand is increasing day by day, therefor it is important not only to extract electrical energy from all available resources but also to reduce power loss to the minimum. Power system is generally divided into three sections generation, transmission and distribution, this last represent the final link between electrical companies and customers and it is responsible for the dissipation of 10–13% of the total power generated in developing countries [1]. The distribution network system has some distinguish features over the transmission system, such as operating at lower voltages, radial configuration and high r/x ratio, consequently larger resistive losses compared to the transmission. Power distribution systems typically have two types of switches designed for both protection and configuration purposes: normally open switches (or tie-switches) and normally close switches (or sectionalizing switches) whose status determine the topological configuration of the system. Network reconfiguration refers to the action of opening and closing tie and sectionalizing switches in power distribution systems in order to alter the network topology, and therefore the power flowing from the substation to the customers.

In normal operation, reconfiguration of a distribution network is used for two main reasons, load balancing and active power loss reduction. Load balancing refers to transferring loads from heavy loaded feeder to light loaded feeder by changing the topological structure of the distribution system through a reconfiguration process. While reconfiguration for active power loss reduction is basically modify the network structure of distribution feeders in order to find optimal radial network that minimizes the active loss which is the subject of this work.

The concept of changing the topology of distribution systems for loss minimization was first introduced in [2], branch and bound method was proposed, to search for a minimum loss operating spanning tree configuration for urban power distribution system, and modified after that in [3] using heuristic approach. In [4], branch-exchange method with a simple formula based on heuristics, that considered the switching operating (open/close) of only one pair at time. In [5], the reconfiguration for both loss reduction and load balancing was addressed, guided by two different power flow approximation methods with varying degrees of accuracy, this technique proved to be very time consuming in large systems. Due to the failure of previous techniques to guaranty the quality of the obtain solution. Many researchers drove toward stochastic-based algorithms with variety of methods employed in the past to solve the distribution network reconfiguration. In [6, 7, 8], genetic algorithm, particle swarm optimization with continuous encoding, and later on with binary particle swarm encoding, and many other optimization methods have been used to solve the reconfiguration problem. Attempts using fuzzy logic, neural network are presented in [9, 10]. However, when using ANN some problem emerged, such as getting trapped in local minima and increasing computational complexity. From literature survey, it is found that most existing reconfiguration algorithms fall into two categories. In the first, branch exchange, the system operates in a feasible radial configuration and the algorithm opens and closes candidate switches in pairs. In the second, loop cutting, the system is completely meshed and the algorithm opens candidate switches to reach a feasible radial configuration [11]. In this work, the problem of reducing active losses by feeder reconfiguration is done using Differential Evolution (DE) algorithm.

This paper is organized as follows: section I provides a literature survey on reconfiguration for loss reduction, problem formulation along with the used algorithm are given in section II and III, simulation results and discussion are presented in section IV. Finally, section V conclude this work.

II. Problem Formulation

In this work, the total active loss is defined as the fitness function evaluated using a load flow algorithm. The result of

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the load flow calculations have been used to check the voltage drop constraints. For example, a radial distribution system with n nodes, the problem states of finding an optimal configuration among all possible configurations that minimizes the total active loss with all constraint verified.

The objective function to be minimized can be expressed as:

$$\min \quad F(x, t_i) \tag{1}$$

Where x is the vector of switches status, and t_i represent the current configuration.

$$F = \sum_{k=1}^{N_b} P_{loss}(i) \tag{2}$$

Where $P_{loss}(i)$ is the active power loss of branch i given by:

$$P_{loss}(i) = |I(i)|^2 R(i) \quad \text{for} \quad i = 1,2,3,\ldots,N_b \tag{3}$$

R(i) and I(i) are resistance and actual current of the i^{th} branch, respectively. N_b is the number of branches.

The objective function (1) should conserve:

- Radial configuration

The system has to remain radially operated after reconfiguration. Thus, no loop is allowed in the new configuration.

- Bus isolation

No bus is allowed to be isolated. Therefore, all buses must be served after the reconfiguration. In other words, only one switch is opened in each loop.

A. Constraints

The objective function in (1) is subjected to the following constraints:

1) Equality Constraints

- Power Flow constraints

The equality constraints are active and reactive power flow equations given as:

$$\begin{cases} P_{G_i} - P_{D_i} - \sum_{i=1}^{N_b} V_i V_j Y_{ij} \cos(\theta_{ij} - \delta_i + \delta_j) = 0 \\ Q_{G_i} - Q_{D_i} - \sum_{i=1}^{N_b} V_i V_j Y_{ij} \sin(\theta_{ij} - \delta_i + \delta_j) = 0 \end{cases} \tag{4}$$

$$i = 1,2,3,\ldots, N_b$$

Where P_{Gi}, Q_{Gi}, P_{Di} and Q_{Di} are the active and reactive power generated (resp. demand) at the i^{th} bus, V_i and δ_i are respectively the amplitude and angle of the voltage at the i^{th} bus. Y_{ij} and θ_{ij} are respectively the amplitude and angle of the branch admittance between the i^{th} and j^{th} bus.

2) Inequality Constraints

- Voltage constraints

Voltage magnitude at each bus must lie with their permissible ranges to maintain power quality as:

$$V_i^{\min} \le V_i \le V_i^{\max} \qquad \text{for} \quad i = 1,2,3,\ldots, N_b \tag{5}$$

Where V_i^{min} and V_i^{max} are respectively the minimum and maximum voltages of the bus.

The problem is to determine the open switches allowing the system to minimize the active power loss while satisfying the network constraints. It is an optimization problem where power flow must be carried out at each iteration, to evaluate possible configurations. These problems are suitable for global optimization methods. Therefore, a meta-heuristic algorithm described in the next section will be used in this work.

III. Optimization Methods

A. Differential evolution algorithm

Differential Evolution (DE) is a stochastic optimization method introduced in 1995 by Storn and Price [12]. Similar to Genetic Algorithm (GA), can handle nonlinear, noisy, or problem that has many local minima [12, 13]. Differential evolution is a population based optimization method. The next generation is created through selection, mutation and crossover from the current population.

1) The Mutation: An initial mutant parameter vector, called donor vector $V_{i,G+1}$ is created by choosing randomly three members of the population. The donor vector $V_{i,G+1}$ written in (6) is created by adding the weighted difference of two of the vectors to the third one.

$$V_{i,G+1} = X_{r1,G} + F(X_{r2,G} - X_{r3,G}) \tag{6}$$

Where $X_{r1,G}$ represents an individual of g^{th} generation, F is a mutation constant selected between (0, 2) [12].

2) *The Crossover:* To improve the diversity, crossover process is introduced, in which a trail vector $U_{i,G+1}$ is created as a perturbation of the target vector $X_{i,G}$, and the donor vector $V_{i,G+1}$.

$$U_{j,i,G+1} = \begin{cases} V_{j,i,G+1} & \text{if} \quad r_j \le CR \quad or\ j = j_{rand} \\ X_{j,i,G} & \text{if} \quad r_j > CR \end{cases} \tag{7}$$

In (7) r_j is a uniformly distributed random variable ($0 < r_j < 1$) and j_{rand} is random index ($1 \le j_{rand} \le n$). CR is constant parameter called crossover constant.

3) *The Selection:* The selection of the better individual that minimizes of the objective function involves a simple replacement of the original individual with the obtained new individual if it has a better fitness. This process is given by (8).

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$$X_{j,G+1} = \begin{cases} U_{i,G+1} & \text{if} \quad f(U_{i,G}) \leq f(X_{i,G}) \\ X_{i,G} & \text{if} \quad f(U_{i,G}) > f(X_{i,G}) \end{cases} \qquad (8)$$

With $i \in [1, N_p]$.

DE is simple algorithm, operates under few controlled parameters, strong optimizing capability, and ease of use. Considering these advantages, DE is widely applied in practical engineering optimization problems [12]. For those reasons it was chosen in this work to solve distribution network reconfiguration.

IV. SIMULATION RESULTS

To validate the developed program, several applications were made on different sizes networks models (i.e., 33-bus, 69-bus, 84 bus, and 118 bus). Metaheuristic method explained in section III was employed as optimization tool to solve the non-linear combinatorial problem. The results were discussed and compared when possible with those found in literature. Fig. 1 shows the one line diagram of 118 bus system, It contains 117 sectionalizing switches and 15 tie-switches with total P_{load} = 22.70 MW and total Q_{load} = 17.04 MVAR.

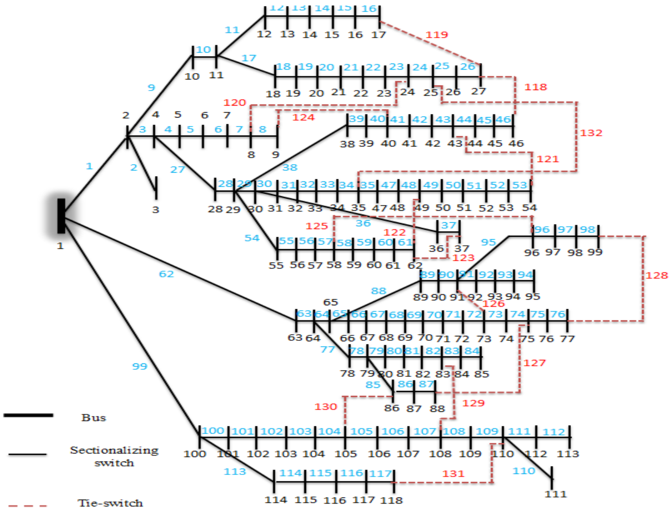

Fig. 1 118 bus in the initial configuration.

Table 1 summarizes the reconfiguration results. Compared to the initial configuration the new configuration obtained by DE reduced the active power loss. For example, the optimal configuration for 118 bus system is achieve by opening switches {23, 26, 34, 39, 42, 51, 58, 71, 74, 95, 97, 109, 122, 129 and 130}, the total power loss in this case is 869.71 kW, with 33% of loss reduction. Moreover, Table 2 shows the results reported in Table 1 compared to other optimization methods found in recent literature such as Artificial Immune Systems and Ant Colony Optimization (AIS-ACO), Honey-Bees Mating Optimization (HBMO), Harmony Search Algorithm (HSA) and Tabu Search method (TS). Clearly DE proved it superiority over these methods in solving the reconfiguration problem (reduction the total active loss). The results are found to be very satisfying, for instance in the case of 69 bus the total loss was reduced to the half, with the accurate percentage of 56.17 % of loss reduction.

TABLE II. COMPARISONS OF RECONFIGURATION RESULTS WITH OTHERS

Test System	Method	Optimal Configuration	Real Power Loss (kW)	Minimum Bus Voltage (p.u.)
33 bus	FWA [1]	7-14-9-32-28	140.3	-
	Merlin and back [2]	7-10-14-37-32	139.98	0.9413
	DE	7-14-9-32-37	139.52	0.9378
69 bus	HSA [16]	69-18-13-56-61	99.35	0.9428
	FWA [1]	69-70-14-56-61	98.59	0.9495
	DE	69-70-14-58-61	98.58	0.9495
84 bus	HBMO [14]	7-14-34-39-42-55-62-72- 83-86-88-90-92	482.14	0.9529
	AIS-ACO [15]	7-13-34-39-42-55-62-72- 86-89-90-91-92	469.88	0.9479
	DE	55-7-86-72-13-89-90-83-92-39-34-42-62	469.80	0.9532
118 bus	HSA [16]	43-27-23-53-123-62-125-126-75-72-129-130-131-132-33	935.01	0.9323
	TS [17]	43-27-23-52-49-62-40-126-74-72-77-83-131-110-33	884.16	0.9321
	DE	42-26-23-51-122-58-39-95-71-74-97-129-130-109-34	869.71	0.9323

TABLE I. RECONFIGURATION RESULTS WITH DE ALGORITHM.

Before Reconfiguration			After Reconfiguration			
Test System	***Real Power Loss (KW)***	***Minimum Node Voltage (p.u.)***	***Branches Switched Out***	***Real Power Loss (KW)***	***Minimum Node Voltage (p.u.)***	***Loss Reduction (%)***
33 bus	531.81	0.9286 at bus N° : 10	7-14-9-32-37	139.52	0.9378 at bus N° : 32	31.10%
69 bus	1298.06	0.8688 at bus N° : 77	69-70-14-58-61	98.58	0.9495 at bus N° : 61	56.17%
84 bus	531.81	0.9286 at bus N° : 10	55-7-86-72-13-89-90-83-92-39-34-42-62	469.80	0.9532 at bus N° : 72	11.65%
118 bus	1298.06	0.8688 at bus N° : 77	42-26-23-51-122-58-39-95-71-74-97-129-130-109-34	869.71	0.9323 at bus N° : 111	33%

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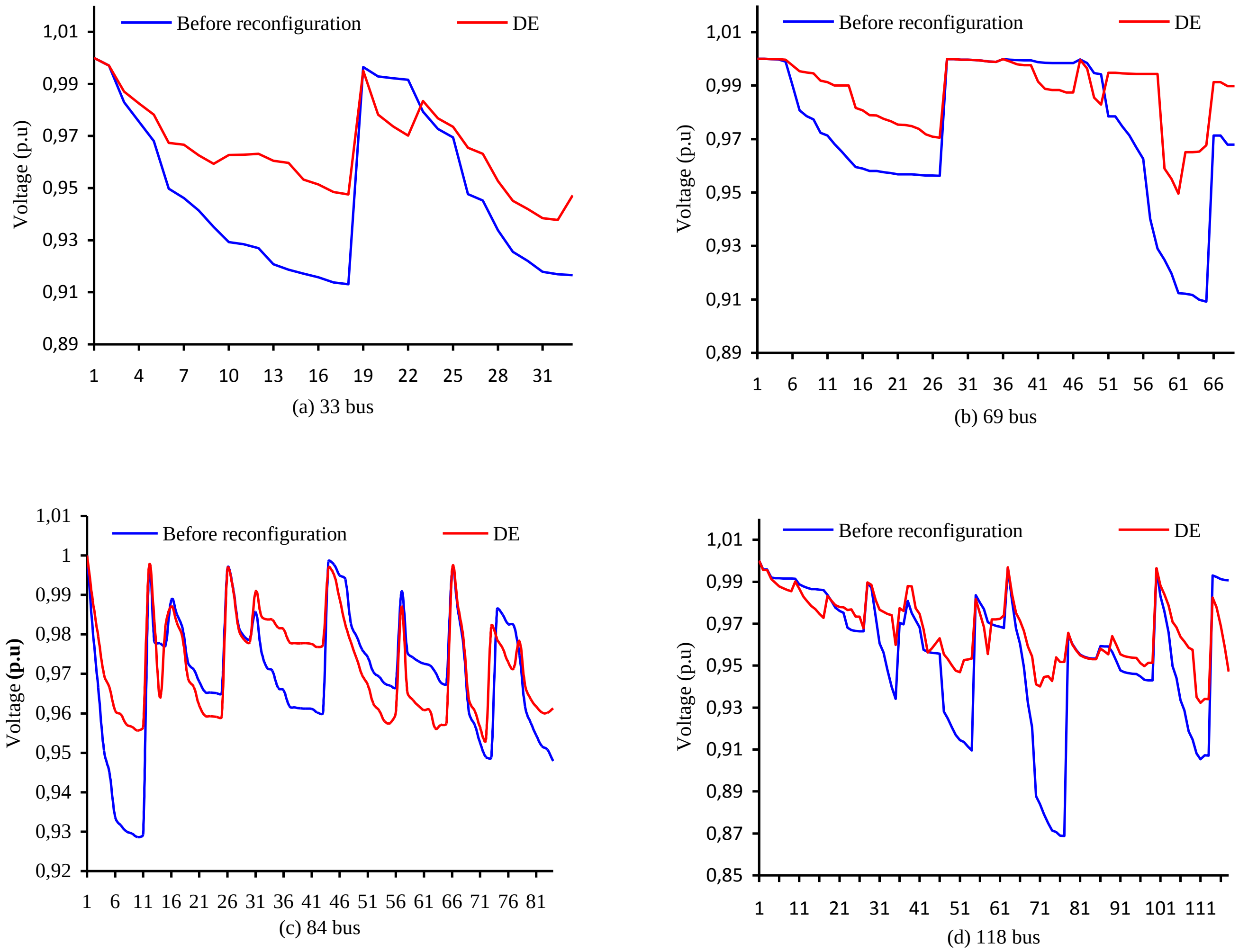

Fig. 2 Voltage profile before and after reconfiguration.

It was noted that the reconfiguration has not only an impact on the active loss but also on the voltage profiles since the active power represent a voltage drop, minimizing the active loss should improve the voltage profiles. Fig. 2 represents the voltages before and after the reconfiguration for all systems. It can be seen that the voltage profile of the distribution systems improved and placed in acceptable margin after the reconfiguration.

V. Conclusion

This paper presented the study of distribution system reconfiguration for optimal loss reduction, using loop counting technique. Small and large size networks were tested, by applying differential evolution algorithm, the results demonstrated that new configuration obtained by DE algorithm reduced the active power loss in all cases. Furthermore, improvement overall in the voltage profile for all tested distribution networks. A comparison study was also made, were the used method produce better results than other methods published in recent literature.

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