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# Reliable Distribution Feeder Reconfiguration Containing Distributed Generation Using Evolutionary Algorithm

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***Authors' contributions***

*This work was carried out in collaboration between both authors. Author MB performed the simulation analysis and wrote the first draft of the manuscript. Author MOS designed the study, managed the analyses of the study and managed the literature searches. Both authors read and approved the final manuscript.*

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## ABSTRACT

**Aims:** One of very important method for saving electrical energy and loss reduction in distribution systems is distributed feeder reconfiguration (DFR). This process is carried out by changing distribution system topology by opening and/or closing of circuit breakers.
**Place and Duration of Study:** Department of Electrical and Electronic Eng, University of Sistan and Baluchestan, Zahedan, Iran, 2015-2016.
**Methodology:** Status of the circuit breakers is optimally determined to have an improved system operation and reduced power losses.
**Results:** This paper proposes a multi-objective evolutionary method for distribution feeder reconfiguration. The multi-objectives optimization minimizes power losses and improves reliability of the system. For this purpose, a particle swarm optimization algorithm is used for solving the problem.
**Conclusion:** Simulation results show the efficiency of the proposed method for DFR.

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*Keywords: Feeder reconfiguration; distributed generation; hybrid evolutionary algorithm; loss reduction.*

## 1. INTRODUCTION

In the distribution system with radial structure, the configuration can be changed to achieve a new radial structure to reduce power loss, to improve system reliability and to enhance power quality. Radial distribution networks have some advantages in compare with ring networks. For example, they have a lower rate of short circuit currents and the number of protective and switching equipment is smaller.

In recent years, considerable researches have been conducted for loss minimization in the distribution network by DFR method. In 1975, [1] have introduced the DFR for minimizing active power losses using DC load flow solution. Reference [2] presented the use of the radial distribution power flow method to determine radial configuration with minimum active power losses. In 1988, [3] has introduced a method based on heuristic algorithm to determine the radial configuration of distribution networks, which finally has minimal active power losses. Furthermore, and in other researches, DFR is solved by evolutionary algorithms such as: simulated annealing [4], evolutionary programming (EP) [5-7], and fuzzy logic [8].

In [9], the authors presented an objective function for distribution expansion planning which is combination of cost of energy not supplied (ENS), cost of active power losses and maintenance cost. [10] has discussed the ENS for distribution networks. In [11], a fuzzy logic has been used for minimizing the ENS. Recently, in addition to ENS, optimal location for sectionalizing switches is evaluated for minimizing ENS [12,13].

Billinton and et al. in [14], have presented a nonlinear method for determining the location and size of the switches to increase the reliability of the radial system with respect to investment and repair costs.

In Ref. [15] and [16], differential search and genetic algorithms are used to optimally position the remote control switches. Using these switches increases the reliability of the system.

In reference [17], the network reconfiguration is carried out to improve the operation indices using Cuckoo algorithm.

Today, the use of distributed generations (DGs) in distribution networks has risen steadily. Using DGs in addition to economic savings has other benefits such as increased power quality, reliability and peak shaving [18]. The authors in [19] have outlined the advantages and disadvantages of DGs in distribution networks.

DGs can reduce the times, as well as the number of outages during faults and network restoration times, and generally increase network reliability. Regarding the presence of DG resources in the distribution network, network reconfiguration in the presence of these resources has been of interest to researchers in recent years in order to improve performance indicators such as reducing losses and improving voltage profiles [20,21]. Considering the significant impact of DG resources on network utilization, in recent years, many activities have been done to determine the optimal location of the site and the size of these resources.

This paper addresses the problem of network reconfiguration in the presence of DG resources to improve network utilization indicators. In this paper, DFR problem is solved by PSO algorithm, the objective function in this problem is consist of active power losses and reliability index (ENS). In addition, Bus-Branch incidence matrix [22] is used for checking the radial structure of distribution systems.

The remainder of this paper is conducted as follows: Section II presents the mathematical formulation of the DFR problem including objective functions of the problem. In this formulation, radial structure of distribution network is checked and constraints of the DFR problem are examined to be verified. Next section is devoted to present the numerical results. A distribution system with 33 buses is used as a test system to verify the applicability and validity of the proposed approach. Finally, conclusion of the paper is drawn in Section IV.

## 2. PROBLEM FORMULATION

In the DRF problem, there are many different objectives. In this paper, loss minimization and improving the reliability have been considered as the objectives and the remaining ones mentioned above are considered as the constraints. The DFR problem is explained as:

## 2.1 Objective Functions

The first objective is to minimize the total active power losses, which can be modeled as:

### 2.1.1 Minimizing active power losses

The active power losses in distribution networks can be calculated as follow:

$$P_{Loss}(X) = \sum_{k=1}^{N_{brch}} \left( R_k \times \left| I_k \right|^2 \right) \tag{1}$$

In which the $R_k$ and $I_k$ are the resistance and the current of Kth line respectively and $N_{brch}$ the number of lines. The first objective function ($F_1$) is total active power losses:

$$F_1 = P_{Loss}$$

Here, the decision variable is:

$$X = [SW_1 \quad SW_2 \quad ... \quad SW_n \quad P_1 \quad P_2 \quad ... \quad P_k] \tag{2}$$

$X$ is the vector of control variables. $SW_L$ is the Lth switch which should be opened to have a radial structure. Finally, $P_k$ is the output active power of kth DG unit.

### 2.1.2 Minimizing energy not supplied

Most power outages are caused by faults in the transmission and distribution systems. Accordingly, the distribution feeder reconfiguration problem should be carried out to optimize a reliability index such as minimization of ENS as follows [23]:

$$\begin{aligned} ENS(X) &= \sum_{j=1}^{N_{bus}} ENS^j \\ &= \sum_{j=1}^{N_{bus}} \left( P_j \times \sum_{i \in V \; i \neq j} \left( U_{j,i} + U'_{j,i} \right) \right) \end{aligned} \tag{3}$$

$U_{j,i}$ and $U'_{j,i}$ are calculated as follow:

$$\begin{aligned} U_{j,i} &= \beta_{j,i} \times t_{j,i} \\ U'_{j,i} &= \beta_{j,i} \times t'_{j,i} \end{aligned} \tag{4}$$

where, $N_{bus}$ and $P_j$ are number of buses and active power demand of bus #j. $V$ is a set of branches which are Related to bus #j (upstream and downstream branches). $U_{j,i}$ and $U'_{j,i}$ are reparation and restoration times (h/year) of $i$th branch which is a member of the set $V$. $\beta_{j,i}$ , $t_{j,i}$ and $t'_{j,i}$ are rate of faults in ith branch, average reparation and restoration time (h), respectively. In this paper, ENS index is evaluated by spanning of tree in graph theory method. This index can be used for the calculation of ENS with and without presence of DG (which is modeled by negative load) in distribution systems [24,25]. For instant, a simple distribution network is shown in Fig. 1 which is used as an example. The ENS3 is determined by all failure situations that lead to prevent Bus 3 to receive energy. For example, if there is a fault in branch 1-2 or branch2-3, after the average reparation time t1-2 or t2-3 the energy supply will be returned to the Bus 3; or if there is a fault in branch3-4 after the average restoration time t'3-4, the energy will be returned to the Bus 3. So, the energy-not-supplied can be evaluated as follows:

$$ENS_3 = P_3 \times (U_{1,2} + U_{2,3} + U'_{3,4}) \tag{5}$$

### 2.1.3 Constraint and limits

The DFR problem is subject to the following constraints.

### 2.1.4 Voltage limits of buses

$$v_j^{\min} \le v_j \le v_j^{\max} \tag{6}$$

Where, $v_j$, $v_j^{min}$ and $v_j^{max}$ are the magnitude, minimum and maximum value of voltage at bus $j$.

### 2.1.5 Active power flowing through feeders and branches

$$PF_k \le PF_k^{\max} \tag{7}$$

Where, $PF_k$ and $PF_k^{max}$, are the flowing active power of branch $k$ and its maximum allowable value.

### 2.1.6 Power output of distributed generation

$$P_{dg} \le P_{dg}^{\max} \tag{8}$$

Where, $P_{dg}$ *and* $P_{dg}^{max}$, are the power output of $d$th distribution generation and its maximum capacity.

## 2.2 Radial Structure of the Distribution Network

The structure of distribution system should be radial due to the simpler protection schemes of distribution networks. For this purpose, branch-bus incidence matrix is used for checking radial structure of networks. The branch-bus incidence matrix of A is a Nbranch × Nbus matrix wherein the kth row of the matrix corresponds to the kth branch in the network and the jth column of the matrix corresponds to the jth bus in the system which has a branch leaving the bus. Incidence matrices are mostly used in graph theory [26]. The method for calculation of the branch-bus incidence matrix is as follows:

If the kth branch (corresponding to kth row) leaves from jth bus (corresponding to jth column) then the matrix element ($a_{kj}$) is equal to 1.

If the kth branch (corresponding to kth row) enters toward jth bus (corresponding to jth column) then the matrix element ($a_{kj}$) will be -1.

All remaining entries will be identically zero.

While the number of buses is one more than the number of branches in the radial distribution networks, the first column of branch-bus incidence matrix A should be deleted to have a square matrix A'.

If the determinant of branch-bus incidence matrix A' is 1 or -1, the network's graph will be radial.

For example, the Bus-branch incidence matrix for the simple distribution network which is shown in Fig.1 can be evaluated as follows:

$$\begin{array}{c} [bus2 \quad bus3 \quad bus4 \quad bus5] \\ A = \begin{bmatrix} -1 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 \\ 0 & 1 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{bmatrix} \begin{bmatrix} l_{1-2} \\ l_{2-3} \\ l_{3-4} \\ l_{1-5} \end{bmatrix} \end{array} \quad (9)$$

$$|\det(A)| = 1 \quad (10)$$

A determinant of A is equal 1, so the simple radial network is radial (it is clear that form Fig. 1).

## 2.3 PSO Algorithm

This paper uses PSO for optimizing objective functions. PSO is inspired by social behavioral pattern of organisms such as a school of fish or a flock of birds in their food hunting. This algorithm is population-based and is initialized with a random population of solutions, referred to as particles, that iteratively evolve throughout the search space to eventually attain the optimum or a near-optimal solution. As one of the meta-heuristic algorithms, Particle Swarm Optimization (PSO) has shown its advantages in many applications. The PSO algorithm has a flexible and well balanced mechanism to enhance the global and local exploration abilities. In addition, it suffices to specify the objective function and to place infinite bounds on the optimized parameters. This algorithm has also been found to be robust in solving problems featuring non-linearity, non-differentiability and high dimensionality. Velocity and updated position of each particle in PSO algorithm are represented by the following equations [27-29]:

$$V_i^{iter+1} = \omega \cdot V_i^{iter} + c_1 \cdot rand_1(\cdot)\left(P_{Best_i} - X_i^{iter}\right) + c_2 \cdot rand_2(.)\left(G_{Best} - X_i^{iter}\right) \quad (11)$$

$$X_i^{iter+1} = X_i^{iter} + V_i^{iter+1} \quad (12)$$

Where, $X_i^{iter}$ and $V_i^{iter}$ are position and velocity of ith particle in iterth iteration, respectively. $P_{Besti}$ is the best previous recorded experience of the ith particle, $G_{Best}$ is the best particle among the entire population. *Rand₁(.)* and *Rand₂(.)* are random number between 0 and 1. Also, $c_1$ and $c_2$ are the positive constants, named cognitive and social parameters, respectively and $\omega$ is the inertia weight. Based on the experience in this paper, $C_1$ and $C_2$ are equal to 2 and $\omega$ is considered to be 1. Also, the number of particles and maximum iteration are chosen 50 and 100 respectively.

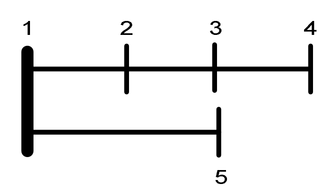


**Fig. 1. Simple radial distribution network**

# 3. SIMULATION RESULTS

Results from a test case based on the 33-bus distribution test system [30] are presented in this section. This system consists of 33 buses, 32 lines, 2 feeders and 12.66kV substation with capacity of 2600kW. The more detail data about this network can be obtained from [30]. The schematic of this network is shown in Fig. 2. DG units has been considered as negative load with the capacity of 300kW (2 micro turbines installed in bus#8 and bus#25) with variable power factor. The distribution load flow formulation for radial distribution systems [31] has been used in the proposed approach.

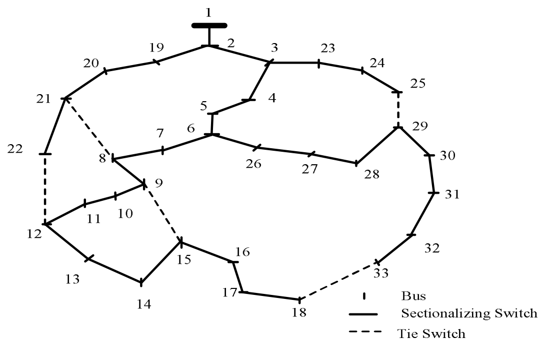


**Fig. 2. Single line diagram of 33-bus test distribution network**

Network reconfiguration is done in two modes without DG resources and in the presence of DG resources considering power loss and ENS as separate objective functions, respectively. Consequently, for each mode, two groups of answers will be obtained. The results obtained in the first case are related to the time when the objective function is the power loss of the network and the results obtained in the second case relate to the time when the objective function is the ENS. The power loss and ENS in each stage are calculated using power flow and equation (1) and (3) respectively. The results for all cases are tabulated in Table 1.

These results have been obtained using PSO algorithm. The results for the case of reconfiguration without DG resources and considering power losses as objective function shows that the optimum value of power loss is 139.5 Kw. The same results are given in ref [32] for different optimization algorithms that shows the validity of obtained results in this paper.

It is clear that considering the DG in DFR provides better performance of distribution networks by improving power loss and ENS values.

Furthermore, this paper uses the optimal Pareto fronts for obtained set of non-dominated solution. In this method the power loss and ENS have been minimized, simultaneously and that a Decision maker has several selections for selecting a compromised scheme. Table 2 and Fig. 3 shows the set of non-dominated solution which are obtained using PSO algorithm.

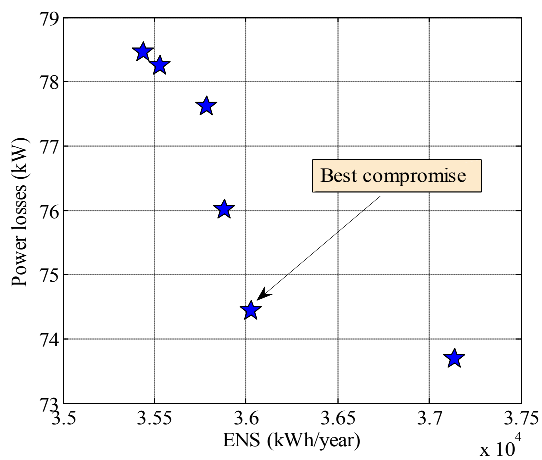


**Fig. 3. Pareto fronts for power loss & ENS**

**Table 1. Objective function values and the decision variables in all cases**

| | Power losses | ENS | Open switches | DG power | DG PF |
|---|---|---|---|---|---|
| Before reconfig. | 202.7 | 42538 | 33-34-35-36-37 | _ | _ |
| After reconfig. | **139.5** | 46984 | 7-14-9-32-37 | _ | _ |
| | 144.6 | **42477** | 7-9-13-28-36 | _ | _ |
| After reconfig. & DG units | **69.6** | 38132 | 7-14-9-32-28 | U8=300<br>U25=300 | PF8=0.55<br>PF25=0.22 |
| | 160.9 | **35439** | 6-13-9-36-25 | U8=300<br>U25=300 | PF8=-0.78<br>PF25=-0.44 |

**Table 2. Set of non-dominated obtained using PSO algorithm**

| Open switch | | | | | DG output (kW) | | Power factor | | ENS (kWh/year) | Power losses (kW) |
|---|---|---|---|---|---|---|---|---|---|---|
| 7 | 13 | 9 | 36 | 28 | 290.0314 | 255.8683 | 0.504553 | 0.212824 | 36031.0266 | 74.44269407 |
| 7 | 13 | 9 | 36 | 28 | 294.0019 | 298.6971 | 0.407995 | 0.352994 | 35530.26867 | 78.25373258 |
| 7 | 13 | 9 | 36 | 28 | 295.5553 | 262.9399 | 0.9 | 0.174536 | 35885.1979 | 76.00007201 |
| 7 | 13 | 9 | 36 | 28 | 289.8308 | 279.3866 | 0.680779 | 0.311389 | 35786.93048 | 77.60836192 |
| 7 | 13 | 9 | 36 | 28 | 300 | 300 | 0.9 | 0.337265 | 35438.8015 | 78.44922336 |
| 7 | 14 | 9 | 36 | 28 | 274.0919 | 262.0819 | 0.589534 | 0.206778 | 37136.78228 | 73.68161 |

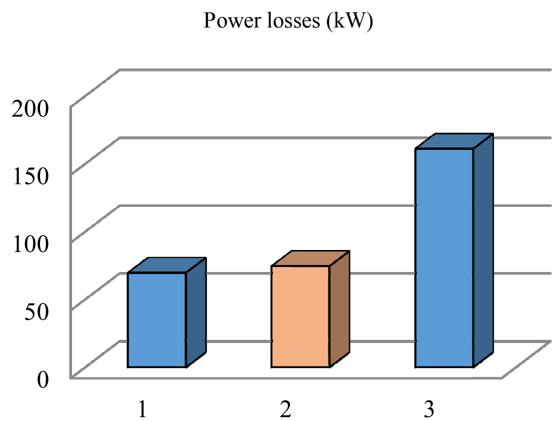


**Fig. 4. Comparing power loss value of best compromised solution with the power loss value of optimum solutions for power loss and ENS objectives**

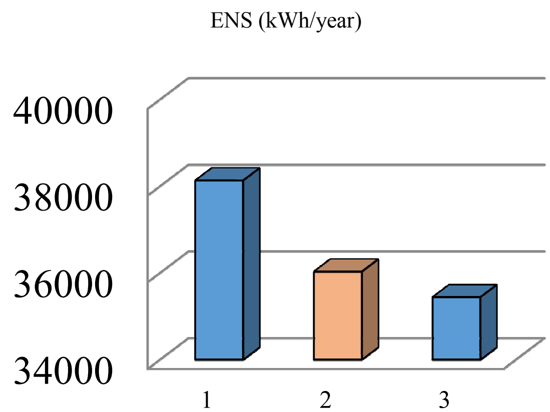


**Fig. 5. Comparing ENS value of best compromised solution with the ENS value of optimum solutions for power loss and ENS objectives**

The best compromised solution in the case assuming the same importance for the objective functions. This statement can be assessed in the results of the Figs. 4 and 5 that show the total losses and ENS in the network respectively. From these figures it can be seen that the power loss for the best compromised solution is 74.44 kW (is shown as No 2 in Fig. 4) which is between 69.5875 kW and 160.9694 kW (which are shown as No 1 and No 3 in Fig. 4 respectively) related to single objective DFR optimization problem in the case of considering power loss and ENS as separate objective functions, respectively. Similarly, the total ENS for the best compromised solution is 36031.0266 kWh/yr that is shown as No 2 in Fig. 5. It is between 35439 kWh/yr and 38132 kWh/yr which relate to single objective DFR optimization problem in the case of considering power loss and ENS as separate objective functions and are shown as No 1 and No 3 in Fig. 5 respectively.

## 4. CONCLUSION

Distribution network reconfiguration is an effective method to optimize the operating conditions of a distribution network. Reducing losses in power distribution networks is important. At the same time exploitation of high-reliability distribution networks is one of the important goals of distribution system operators. To enhance reliability performance of the distribution networks in the DFR operating phase, the distribution operators are inevitable to include reliability indices (here, ENS) in the DFR problem. Optimizing the above indicators with a tool such as network reconfiguration leads to a multi-objective optimization problem. The power loss and ENS have been minimized, simultaneously. The PSO algorithm yields optimal Pareto solutions taking into account different objectives functions (including power loss function and ENS) in the form of Pareto set which represents the tradeoff between the objectives. Results for the test distribution network show that the power loss for the best compromised solution is 74.44 kW. Also the total ENS for the best compromised solution is 36031.0266 kWh/yr. In addition, according to the results, we realized the importance of DG in distribution networks is high, consideration of DG in DFR problem, leads to decrease in ENS, and power loss.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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