

Ageing Analysis and Reconductoring of Overhead Conductors for Radial Distribution Systems Using Genetic Algorithm

Mahdi Mozaffari Legha[†] and Mohammad Mohammadi*

Abstract – In medium voltage electrical distribution networks, reforming the loss reduction is important, and in line with this, the issue of system engineering and use of proper equipment Expansion of distribution systems results in higher system losses and poor voltage regulation. Therefore, an efficient and effective distribution system has become more important. So, proper selection of conductors in the distribution system is crucial as it determines the current density and the resistance of the line. Evaluation of aging conductors for losses and costs imposed in addition to the careful planning of technical and economic networks can be identified in the network design. In this paper the use of imperialist competitive algorithm; genetic algorithm; is proposed to optimal branch conductor selection and reconstruction in radial distribution systems planning. The objective is to minimize the overall cost of annual energy losses and depreciation on the cost of conductors to improve productivity given the maximum current carrying capacity and acceptable voltage levels. Simulations are carried out on 69-bus radial distribution network using genetic algorithm approaches to show the accuracy as well as the efficiency of the proposed solution technique.

Keywords: Aging conductors, Backward-forward sweep, Genetic algorithm, Loss reduction, Radial distribution systems.

1. Introduction

The main objective of an electrical distribution system (EDS) is to provide a reliable and cost-effective service to consumers by considering power quality within standard ranges. Thus, it is necessary to properly plan the EDS and evaluate several aspects such as new equipment installation cost, equipment utilization rate, quality of service, reliability of the distribution system and loss minimization, taking into consideration an increase of system loads and newly installed loads for the planning horizon [1]. There are several parameters to be taken into account to model the conductor size selection (CSS) problems such as: conductor's economic life, discount rate, cable and installation costs and type of circuit (overhead or underground) [2]. Dynamic programming approach was utilized to solve the CSS problem in [3]. They present models to represent feeder cost, energy loss and voltage regulation as a function of a conductor cross-section. In [4], the conductor size selection was performed with regards to financial and engineering criteria in the feeder. In [5] and [6] the CSS problem is solved using heuristic methods. Reference [5] uses a selection phase by means of economic criteria, followed by a technical selection using a sensitivity index that seeks to ensure a feasible operation of the EDS, whereas [6] presents a heuristic method using a

novel sensitivity index for the reactive power injections. The heuristic methods are robust and easily applied; however, they normally converge to a local optimum solution. In some studies, a linear approximation in the calculation of power losses or voltage regulation is considered [7], while approximates the load as a constant current model [3]. In [7], a mixed integer linear model for the problem of conductor selection size in radial distribution systems is presented. In this model, the behavior of the power type load is assumed to be constant. Several studies have used evaluative techniques to solve the CSS problem [8-10]. In [11] the optimal CSS placement is solved using a genetic algorithm. In further studies, aging studies, aging effects of conductor's lines which are due to weather conditions are not considered.

In this paper, optimal type of conductor selection is proposed for planning radial distribution systems using genetic algorithm (GA). The objective is to minimize the overall cost of annual energy losses and depreciation on the cost of conductors in order to improve productivity given the maximum current carrying capacity and acceptable voltage levels. Moreover, the Backward-Forward sweep method is used which is simple, flexible, reliable, does not require Jacobean matrix and its inverse, and has high convergence speed.

2. Optimal Conductor Size Selection

The conductor size selection problem involves determining the optimal conductor configuration for a radial

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distribution system using a set of types of conductors. Each type of conductor has the following characteristics: 1) resistance per length, 2) reactance per length, 3) maximum current capacity, 4) cross-sectional area and 5) building cost per length.

3. Power Flow Analysis Method

The methods proposed for solving distribution power flow analysis can be classified into two categories: Newton-Raphson (NR) method and Backward-Forward sweep method. The method proposed for solving distribution power flow analysis is Backward-Forward Sweep method which is an iterative means to solving the load flow equations of radial distribution systems which has two steps.

3.1 Newton-Raphson (NR) method

There are several different methods of solving the resulting nonlinear system of equations. The most popular is known as the Newton-Raphson method. This method begins with initial guesses of all unknown variables (voltage magnitude and angles at Load Buses and voltage angles at Generator Buses). Next, a Taylor Series is written, with the higher order terms ignored for each of the power balance equations included in the system of equations. The result is a linear system of equations that can be expressed as:

$$\begin{bmatrix} \Delta\theta \\ \Delta|V| \end{bmatrix} = -J^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \quad (1)$$

Where ΔP and ΔQ are called the mismatch equations:

$$\Delta P_i = -p_i + \sum_{k=1}^N |V_i||V_k|(G_{ik} \cos \theta_{ik} + B_{ik} \sin \theta_{ik}) \quad (2)$$

$$\Delta Q_i = -Q_i + \sum_{k=1}^N |V_i||V_k|(G_{ik} \sin \theta_{ik} - B_{ik} \cos \theta_{ik}) \quad (3)$$

And J is a matrix of partial derivatives known as a Jacobian:

$$J = \begin{bmatrix} \frac{\partial \Delta P}{\partial \theta} & \frac{\partial \Delta P}{\partial |V|} \\ \frac{\partial \Delta Q}{\partial \theta} & \frac{\partial \Delta Q}{\partial |V|} \end{bmatrix} \quad (4)$$

The linearized system of equations is solved to determine the next guess ($m + 1$) of voltage magnitude and angles based on:

$$\theta^{m+1} = \theta^m + \Delta\theta \quad (5)$$

$$|V|^{m+1} = |V|^m + \Delta|V| \quad (6)$$

The process continues until a stopping condition is met. A common stopping condition is to terminate if the norm of the mismatch equations is below a specified tolerance.

A rough outline of solution of the power-flow problem is:

1. Make an initial guess of all unknown voltage magnitudes and angles. It is common to use a “flat start” in which all voltage angles are set to zero and all voltage magnitudes are set to 1.0 p.u.
2. Solve the power balance equations using the most recent voltage angle and magnitude values.
3. Linearize the system around the most recent voltage angle and magnitude values
4. Solve for the change in voltage angle and magnitude
5. Update the voltage magnitude and angles
6. Check the stopping conditions, if met then terminate, else go to step 2.

3.2 Backward-forward sweep method

The Backward sweep updates currents using Kirchhoff's Current Law (KCL), and the Forward sweep updates voltage using voltage drop calculations [12]. The Backward Sweep calculates the current injected into each branch as a function of the end node voltages. It performs a current summation while updating voltages. Bus voltages at the end nodes are initialized for the first iteration. Starting at the end buses, each branch is traversed toward the source bus updating the voltage and calculating the current injected into each bus. These calculated currents are stored and used in the subsequent Forward Sweep calculations. The

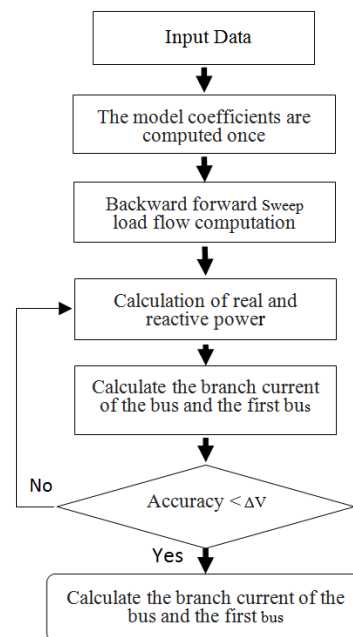


Fig. 1. Flowchart of the Backward-Forward sweep method

calculated source voltage is used for mismatch calculation as the termination criteria by comparing it to the specified source voltage. The Forward Sweep calculates node voltages as a function of the currents injected into each bus. The Forward Sweep is a voltage drop calculation with the constraint that the source voltage used is the specified nominal voltage at the beginning of each forward sweep. The voltage is calculated at each bus, beginning at the source bus and traversing out to the end buses using the currents calculated in the previous Backward-Forward sweep Flowchart of the method depicted in Fig. 1 [1, 17, 20].

4. Aging Conductors Analysis

Conductors from the construction phase to the operational phase of destruction are affected by a variety factors such as wearing damage and it's finally decided to enter the power network or utility side. Evaluation conductors of electrical distribution networks have a very important role in asset management systems. In this paper conductors case study are used in Kosar feeder, Zafar substation networks, with 18.74 Km of the Kerman area Inclusive conductors such as Hayna (A=126 mm²), Doug (A=120 mm²) and Mink (A=70 mm²). Also, information of aging conductors was collected 2 meters. According to the information network each section was determined by the electricity distribution network. After collecting the conductors cable of Kerman area, resistance and corrosion rate were measured. Conductor resistance test results for each of the years are indicated in Table 1.

Table 1. Analysis conductors properties

Year	R [Ω /km]	A [mm ²]
new	0.4545	70
1	0.4580	70
38	0.4760	70
new	0.2712	120
42	0.3320	120
new	0.1576	126
24	0.2130	126
26	0.2430	126

1 km = 1000meter

5. Objective Function

The objective is selection of conductor's size from the available size in each branch of the system which minimizes the sum of depreciation on capital investment, cost of energy losses and improvement reliability while maintaining the voltages at different buses within the limits. In this case, the objective function with conductor c in branch i is written as

$$\text{Min } f(i, c) = w1 * CE(i, c) + w2 * DCI(i, c) + w3 * C_{ENS} \quad (7)$$

Subject to

$$V_{min} \leq |V_i| \leq V_{max} \quad i = 1, 2, 3, \dots, n \quad (8)$$

$$|I_j| \leq I_{max} \quad j = 1, 2, 3, \dots, n - 1 \quad (9)$$

Where $CE(i, c)$ is the Cost of Energy Losses and C_{ENS} is the Cost of reliability and $DCI(i, c)$ is Depreciation on Capital Investment of c conductor type of i -th branch, n is buss number, i is the branch number and w is the weighting factor [13]. The annual cost of loss in branch i with conductor type k is,

$$CE(i, c) = P L(i, c) * \{K_p + K_E * \delta * T\} \quad (10)$$

Where K_p is annual demand cost due to Power Loss (\$/kW), K_E is annual cost due to Energy Loss (\$/kWh), δ is Loss factor, ($PL(i, c)$) is real Power Loss of branch i under peak load conditions with conductor type c and T is the time period in hours (8760 hours). Depreciation on capital investment is given as

$$DCI(i, c) = \gamma * A(c) * \{C_c + L_i\} \quad (11)$$

Where γ is Interest and depreciation factor, C_c is cost of type conductor (\$/km), (A_c) is cross-sectional area of c type conductor and L_i is length of branch i (km).

$$C_{ENS} = \frac{h}{8760} \times \sum_i U_i \times PL_i \times Cost_Shed \quad (12)$$

Where C_{ENS} the cost of energy not supplied (\$); U_i : i mean outage times a year (hour/year); $Cost_Shed_i$: Cost of outage time (\$/Kwh). PL_i Average time to confirm any of the loads of the network is obtained from the following equation

$$U_i = \sum_j \lambda_{ij} \times r_j \quad (13)$$

λ_{ij} : Number of failures per year for equipment failures that result in lost time, i is the j .

r_j : The average time required to fix your equipment after each fault j (hour).

6. Genetic Algorithm

GA's are generalized search algorithms based on the mechanics of natural genetics [14]. GA maintains a population of individuals that represent the candidate solutions to the given problem. Each individual in the population is evaluated to give some measure to its fitness to the problem from the objective function. GA's combine solution evaluation with stochastic operators namely, selection, crossover and mutation to obtain optimality.

6.1 Concept of genetic algorithm

The genetic algorithm is a method for solving optimization problems that is based on natural selection, the process that drives biological evolution. The genetic algorithm repeatedly modifies a population of individual solutions. At each step, the genetic algorithm selects individuals at random from the current population to be parents and uses them to produce the children for the next generation. Over successive generations, the population “evolves” toward an optimal solution. You can apply genetic algorithm to solve a variety of optimization problems that are not well suited for standard optimization algorithms, including problems in which the objective function is discontinuous, non-differentiable, stochastic, or highly nonlinear [17].

6.2 Genetic operators

- 1) Selection: Select two parent chromosomes from a population according to their fitness. Chance for the better fitness individual to be selected is higher to produce the next generation with the higher fitness value.

1	1	0	1	0	1	0	...	n
0	0	1	1	0	1	1	...	n

Fig. 2. Single point crossover

- 2) Crossover: The crossover operator involves the exchange of genetic material between chromosomes (parents), in order to create new chromosomes (offspring). Various forms of this operator have been developed. The simplest form, single point crossover, is shown in Fig. 3. This operator selects two parents, chooses random position in the genetic coding, and exchanges genetic information to the right of this point, thus creating two new offspring.

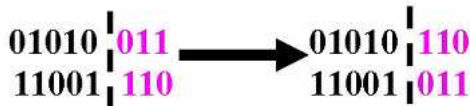


Fig. 3. Single point crossover

- 3) Mutation: The mutation operator, in its simplest form, makes small, random, changes to a chromosome. For a binary encoding, this involves swapping gene 1 for gene 0 with small probability for each bit in the chromosome, as illustrated in Fig. 4.



Fig. 4. Binary mutation operators

The flow chart of proposed GA is depicted in Fig. 1.

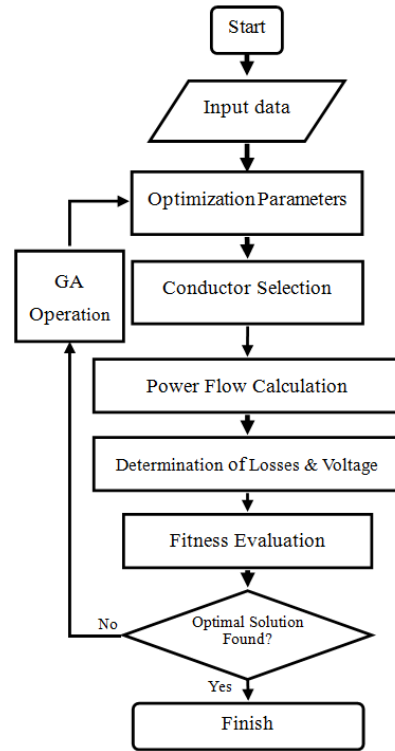


Fig. 5. Flowchart of the proposed GA algorithm

7. Tests and Results

Simulations are carried out on 69-bus radial distribution network using GA approach in order to show the accuracy as well as the efficiency of the proposed solution technique. The single line diagram for proposed radial distribution systems is shown in Fig. 2. Length of all branches is considered to be equal to 60m. The properties of the new conductors used in the analysis of this system are given in Table 2. The initial data for load flow solution based on the Backward-Forward sweep are selected as: $V_{base} = 20kV$ and $S_{base} = 1000kVA$. The other parameters used in computation process are: $KP = 1.04$ (\$/kW); $KE = 0.012$ (\$/kWh).

The parameters used in GA algorithm are: Number of iterations is 33; Population size is 100; Cross over probability is 0.8; and Mutation probability is 0.01, V_{min} for any bus= 0.95 and V_{max} for any bus= 1.05. Also, loss factor is 0.2, which represents adequately the energy losses for the load level in terms of the maximum power losses.

Table 2. Conductor properties

Type	R [Ω/km]	X [Ω/km]	Cmax [A]	A [mm ²]	Cost [Toman/m]
Hyena	0.1576	0.2277	550	126	2075
Dog	0.2712	0.2464	440	120	3500
Mink	0.4545	0.2664	315	70	2075

1 km = 1000meter

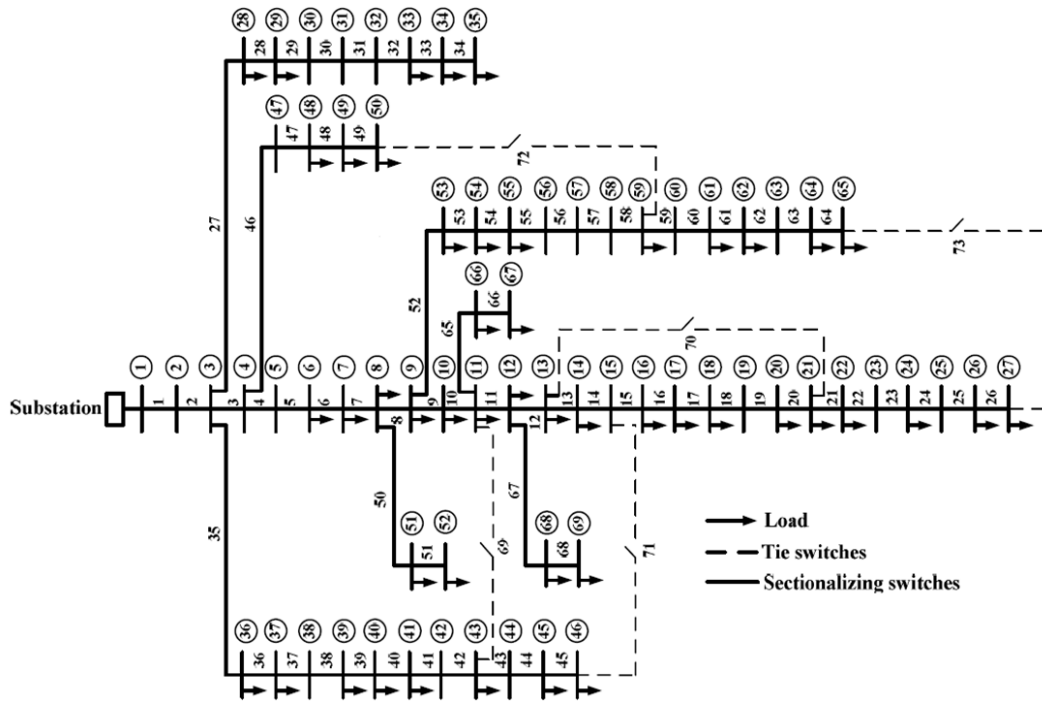


Fig. 6. Single line diagram for a 69-bus radial distribution system

Table 3. Conductor selection results

Conductor design method	Type	Branch number
Conventional	Hyena	From 1 to 26
	Dog	Rest of 68 branches
	Mink	---
GA based new conductors	Hyena	20,21,28,38,43
	Dog	
	Mink	Rest of 68 branches
GA based new & Aging conductors	Hyena	From 1 to 13
	Dog	33,34,41,42,43,44,45 61,62,63,64
	Mink	Rest of 68 branches

Table 4. Obtained loss results.

Method	Total Loss [W]	Total cost [Toman]
Conventional	32453.24452	21136896
GA with consideration of new conductors	15392.43506	48629196
GA with consideration of new & aging conductors	14158.38579	52864416

1 \$ = 3200 Toman

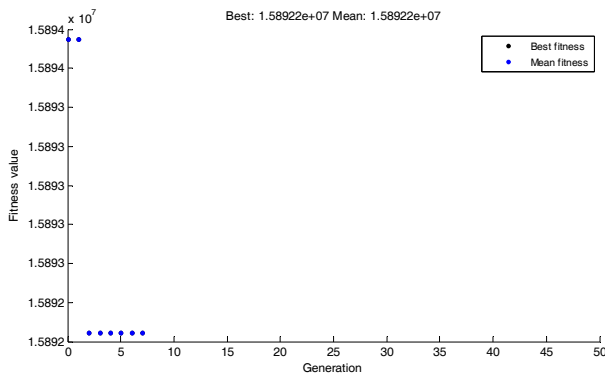


Fig. 7. Convergence values for GA fitness functions

The results of conductor selection are shown in Table 3. Convergence values for GA fitness functions are illustrated in Fig. 7.

The voltage profile of nodes and power loss profile of branches in the system after GA implementation are

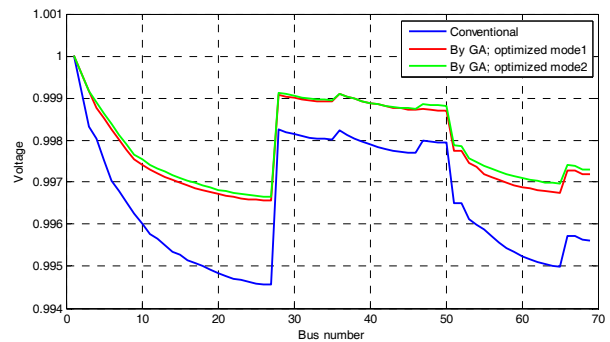


Fig. 8. Voltage profiles of 69-bus system. Mode 1: optimization using GA with consideration of aging conductors; Mode 2: optimization using GA with consideration of new conductors

compared with Conventional conductor design and depicted in Figs. 8 and Fig. 9. It can be seen that the voltage profile achieved by GA optimization algorithms are almost the same although they show better improvement in comparison with Conventional method. Moreover, a decrease in peak power loss based on peak power loss profiles is illustrated. The total power loss is shown in

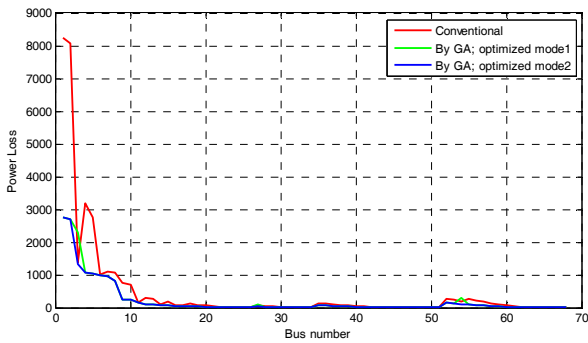


Fig. 9. Peak power loss profiles in each branch. Mode 1: optimization using GA with consideration of aging conductors; Mode 2: optimization using GA with consideration of new conductors

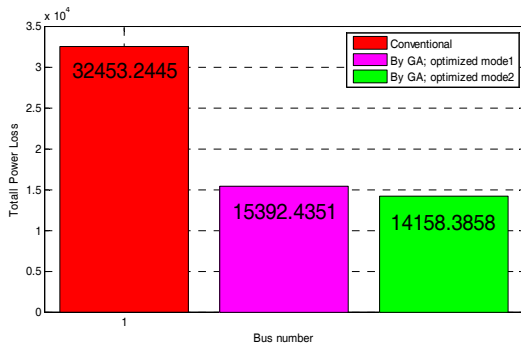


Fig. 10. Total power loss for different conductor selection method. Mode1: optimization using GA with consideration of aging conductors; Mode2: optimization using GA with consideration of new conductors

Fig. 10 and the costs based on conductor selection are compared in Table 4. The real power loss reductions are 579.4903 kW, which is approximately 5.4% in comparison with the Conventional design for GA respectively. Proceeding in a similar manner, the total cost reduction (sum of annual cost of power loss and depreciation on capital investment cost) are obtained 27% for GA respectively.

8. Conclusion

Optimal selection of conductor type for planning radial distribution systems using evolutionary approaches is presented with the objective to minimize the overall cost of annual energy losses and depreciation on the cost of conductors in order to improve productivity. The power losses, voltage magnitude, and current flow magnitudes are calculated using the Backward-Forward sweep method.

The performance of the proposed evolutionary approaches

(GA) in comparison with a conventional method is investigated using a 69-bus radial distribution network. The power loss reduction and voltage profile improvement has been successfully achieved which demonstrates the effectiveness of the proposed approaches. The results offer the potential of using GA for improving plant productivity and economy.

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