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Optimization conductor's selection in radial distribution systems using GA

Mahdi Mozaffari Legha[1], Mehdi Khobiyari[2]
[1]*Department of Power Engineering, Institute of Higher Education Javid, Jiroft, Iran.*
Email: mozaffarilegha.m@gmail.com
[2]*Department of Power Engineering, Institute of Higher Education Javid, Jiroft, Iran.*
Email: mehdi66khobiyari@gmail.com

Abstract: *The availability of an adequate amount of electricity and its utilization is essential for the growth and development of the country. Development of distribution systems result in higher system losses and poor voltage regulation. Consequently, an efficient and effective distribution system has become more urgent and important. Hence proper selection of conductors in the distribution system is important as it determines the current density and the resistance of the line. This paper presents optimal branch conductor selection of radial distribution systems using intelligent method of Genetic Algorithm (GA) 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 back/forward sweep method is applied for load flow solution of proposed radial distribution system. Simulations are carried out on 69-bus radial distribution networks based on GA optimization method. Results obtained with the proposed approaches are compared. The power loss reduction and voltage profile improvement has been successfully achieved which demonstrate the effectiveness of the proposed methods.*
Keywords: *Optimal Conductor Selection, Genetic Algorithm, radial distribution systems, back/forward sweep, Voltage profile, Loss Reduction.*

INTRODUCTION

Distribution system is one from which the power is distributed to various users through feeders, distributors and service mains. Feeders are conductors of large current carrying capacity, carrying the current in bulk to the feeding points. Conductor is often the biggest contributor to distribution system losses. Economic conductor sizing is therefore of major importance. If a conductor is loaded up to or near its thermal rating, the losses will be increased. Therefore, line conductors are loaded below their thermal limit. The power loss is significantly high in distribution systems because of lower voltages and higher currents, when compared to that in high voltage transmission systems. Studies have indicated that as much as 13% of total power generated is consumed as $R.I^2$losses in distribution level. Reactive currents account for a portion of these losses. Reduction of total loss in distribution systems is very essential to improve the overall efficiency of power delivery. The pressure of improving the overall efficiency of power delivery has forced the power utilities to reduce the loss, especially at distribution level. Selection of conductors for design and upgrading of distribution systems is an important part of the planning process. After taking all the factors into consideration, utilities select four or five conductors to meet their requirement [1,8]. This selection is done mainly based on engineering judgment. Historical factors also play role in the selection process, i.e., if a company has been using a particular size of conductor, they would like to continue to use that size unless there are compelling reasons not to do so. The available literature consists of work of only a few researchers on finding the best set of conductors in designing a distribution system. Funkhouser and Huber[2]. Worked on a method for determining economical aluminum conductor steel reinforced (ACSR) conductor sizes for distribution systems. They showed that three conductors could be standardized and used in combination for the most economical circuit design for the loads to be carried bya 20 kV distribution system. They also studied the effect of voltage regulation on the conductor selection process. Wall et al [3]. have considered a few small systems to determine the best conductors for different feeder segments of these systems. The study done by Ponnavaikko and Rao [4] suggested a model to represent feeder cost, energy loss cost and voltage regulation as a function of conductor cross-section. The researchers proposed an objective function for optimizing the conductor cross section. Tram and Wall [5] worked on similar grounds where again the authors took different examples of feeder systems and calculated the best conductor for each feeder segment based on specific requirements of voltage and losses. Anders et al.[1] analyzed the parameters that affect the economic selection of cable sizes. The authors also did a sensitivity analysis of the different parameters as to how they affect the overall economics of the system. Lappet and Allen [1,6] suggested that conductor selection is not only based on simple engineering considerations such as current capacity and voltage drop but also on various other considerations such as load growth and wholesale power cost increase. In this paper, GA algorithm is proposed for selecting the optimal type of conductor for radial distribution systems. The conductor, which is determined by this method, will satisfy the maximum current carrying capacity and maintain acceptable voltage levels of the radial distribution systems. In addition, it gives the maximum saving in capital cost of conducting material and cost of energy loss. The demand for electrical energy is ever increasing. Today over 25% of the total electrical energy generated in Iran is lost in transmission (8-10%) and distribution (17-23.45%) [1]. The electrical power deficit in the country is currently about 18%. Clearly, reduction in distribution losses can reduce this deficit significantly. The main reason for having high losses in developing countries like Iran is stretching of distribution lines beyond the limits of load centers, increase of load abnormally without considering the current carrying capacity of the conductors and imbalance of generation and load causing reactive power generation, etc.

Hence proper selection of conductors in the distribution system is important as it determines the current density and the resistance of the line. A lower conductor size can cause high $R.I^2$ losses and high voltage drop which causes a loss of revenue as consumer's consumption lowered and hence revenue is reduced. Increasing the size of conductors will require additional investment, which may not pay back for the reduction in losses.

The recommended practice is to find out whether the conductor is able to deliver the peak demand of the consumers at the correct voltages, that is, the voltage drop must remain within the allowable limits as specified in the [2,3]. The preferred solution for problems like high losses and voltage drops is network reconductoring. This scheme arises where the existing conductor is no more optimal due to rapid load growth. This is particularly relevant for the developing countries, where the annual growth rates are high and the conductor sizes are chosen to minimize the initial capital investment. Studies of several distribution feeders indicate that the losses in the first few main sections (say, 4 to 5) from the source constitute a major part of the losses in the feeder. Reinforcing these sections with conductors of optimal size can prevent these losses. Thus, we can minimize the total cost, that is, the cost of investment and the cost of energy losses over a period of 5 to 10 years. The sizing of conductor must depend upon the load it is expected to serve and other factors, such as capacity required in future.

2. Load flow method

In order to evaluate the power distribution network and examine the effectiveness of possible changes on system in network programming state, it is necessary to perform power flow analysis on the network which is probably the most important of all network calculations.

2.1 Backward Forward Sweep method

The methods proposed for solving distribution power flow analysis are essentially classified into three categories: direct methods, backward/forward sweep methods and Newton-Raphson (NR) methods. In this paper we utilize the back/forward sweep method which is simple, flexible, reliable, and didn't need Jacobian matrix and its inverse and have high convergence speed. Study of power flow system is usually performed to achieve the following goals:

a) Sufficient Active and reactive power flow in network branches.
b) To avoid overloading in different sections.
c) Effect of adding new parts to the system under study.
d) To analysis the loss in different section at the critical situation.

e) The optimal power flow analysis and assignment.
f) Optimization of system losses.

The Back/Forward Sweep algorithm is as below:
First, the initial voltage of all buses is consider to be 1<0. With the known primary load of each line, the current of last bus is calculated as below:

$$s_n = V_n I_n^* \rightarrow I_n^* = \frac{s_n^*}{v_n^*} = \frac{p_n^* - JQ_n^*}{V_n^*}$$
$$Vmax < |Vn| < Vmin \quad n = 1,2,3,\ldots$$

In each iteration, new voltage and load flow is calculated.New voltage of each bus is calculated using kvl law and by starting from first bus.
Having new voltages, new current of each line is obtained utilizing the last bus.This process will continue until the maximum total voltage difference of all buses is greater than the pre-specified value [4,7,8,10]. The flowchart of proposed Back/Forward Sweep method is shown in Fig (1).

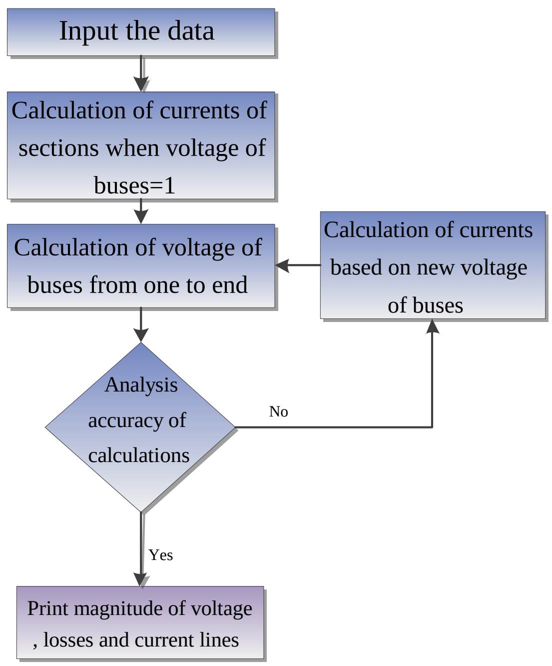

Fig 1 : Flowchart Back/Forward Sweep method

3. Problem Formulation

Objective function

The objective of optimal conductor selection is select conductor size from the available in each branch of thesystem which minimizes the sum of depreciation on capital investment and cost of energy losses whilemaintaining the voltages at different buses within the limits. In this case the objective function with conductor c in branch i is written as

$$Minimize\ f(i,c) = CE(i,c) * DCI\ (i,c)$$

subject to

$$Vmax < |Vn| < Vmin \quad n = 1,2,3,\ldots$$

$$|I\,b| \leq Imax \quad b = 1,2,3,\ldots$$

where f is sum of depreciation on capital investment and cost of energy losses of CE is the cost of Energy Losses; DCI is depreciation on capital investment; i is branch in system; c is the type of conductor used in the branch; k is total number of buses in the network; b is total number of branches.
The annual cost of loss in branch i with conductor type k is,

$$CE(i,c) = Peak\ Loss(i,c) * \{KP + KE.\,LSF.\,T\}$$

where Kp is Annual demand cost due to power loss (Toman/kW); Ke is Annual cost due to energy loss(Toman/kWh); LSF is Loss factor; Peak loss(i,c) is Real power loss of branch; i under peak load conditions with conductor type c; T is the time period in hours (8760 hours). Depreciation on capital investment (DCI) is given as

$$DCI(i,c) = IDFC * A(c) * \{Cost(c).\,len(i)\}$$

where IDFC is Interest and depreciation factor; Cost (c) is Cost of c type conductor (Rs /km; Len (i) is Length of branch i (km)
A(c) Cross-Sectional area of c type conductor in mm^2.
Loss factor is defined as ratio of energy loss in the system during a given time period to the energy loss that could result if the system peak loss had persisted throughout that period. In British experience, loss factor is expressed in terms of the load factor (Lf) as

$$LSF = 0.84\,Lf\,2\ 0.16Lf \quad (7)$$

Evaluation of fitness function

The evaluation of fitness function is a procedure to determine the fitness of each string in the population. Since the proceed in the direction of evolving best-fit strings and the fitness value is the only information available to the GA, the performance of the algorithm is highly sensitive to the fitness values. The fitness function F, which has been chosen in this problem, is

$$F = \frac{1}{1 + f(i,c)}$$

4. Algorithms for optimal type of conductor selection

In this section, optimal branch conductor selection of radial distribution systems using intelligent methods of Genetic Algorithm (GA) with the objective to minimize the overall cost of annual energy losses and depreciation on the cost of conductors is proposed.

4.1. Implementation of GA for optimal conductor selection

In artificial intelligence, an Evolutionary Algorithm (EA) is a subset of Evolutionary Computation that involves combinatorial optimization problems. GA's are generalized search algorithms based on the mechanics of natural genetics [13]. 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. Genetic Algorithms combine solution evaluation with stochastic operators namely, selection, crossover and mutation to obtain optimality. The flow chart of proposed GA is depicted in Fig (2)

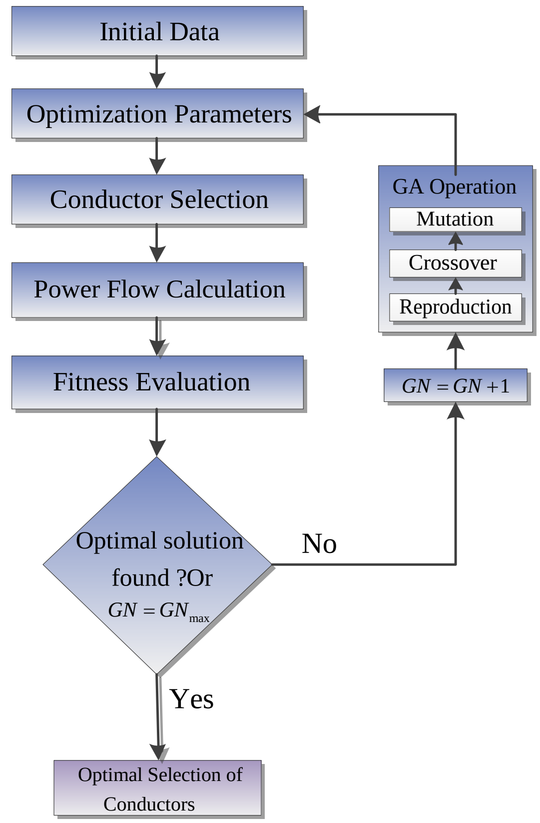

Fig 2 : Flowchart of the proposed GA algorithm

5. Results and analysis

The optimal branch conductor selection of a radial distribution system considered. Simulations are carried out on 69-bus radial distribution networks based on GA optimization method. In order to show effectiveness of the proposed algorithm, the results were compared with conventional conductor design. The single line diagram for proposed 69-node radial distribution systems is shown in Fig (4). Length of all branches is considered to be equal to 60m. The properties of the conductors used in the analysis of this system are given in Table (1).

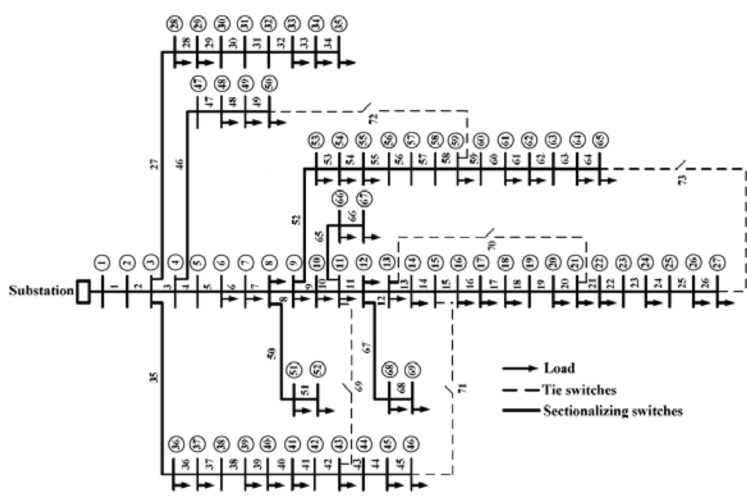

Table 1: Conductor properties.

Type	R [Ω/km]	X [Ω/k m]	Cm ax [A]	A [mm 2]	Cost [Toma n/m]
Hyena	0.1576	0.22 77	550	126	2075
Dog	0.2712	0.24 64	440	120	3500
Mink	0.4545	0.26 64	315	70	2075

The initial data for load flow solution based on the back/forward sweep are selected as: V=20000; $P = 10^4$; $\varepsilon = 0.0001$ 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.

The other parameters used in computation process are: KP = 2500 Toman/kW ; KE = 0.5 Toman/kWh; LSF=0.2. The results of Conductor selection are shown in table (2). The Voltage profile and Power loss in the system after GA implementation is compared with Conventional conductor design and depicted in fig (5) and fig (6).

Table 2 : Conductor selection results.

Conductor Design Method	Type	Branch Number
Conventional	Hyena	From 1 to 26
	Dog	Rest of 68 branches
GA Based	Hyena	20,21,28,38,43
	Mink	Rest of 68 branches

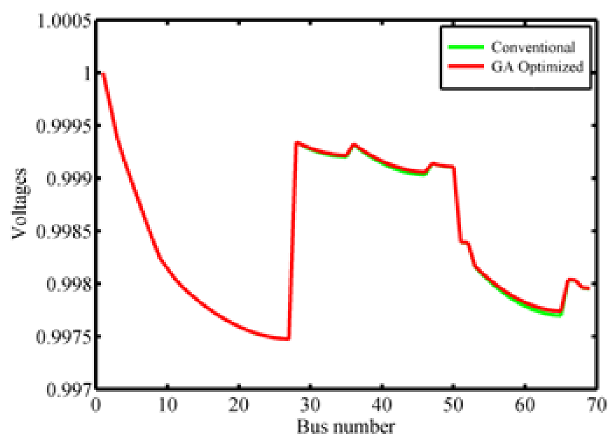

Fig 5. Voltage profiles of 69-bus system

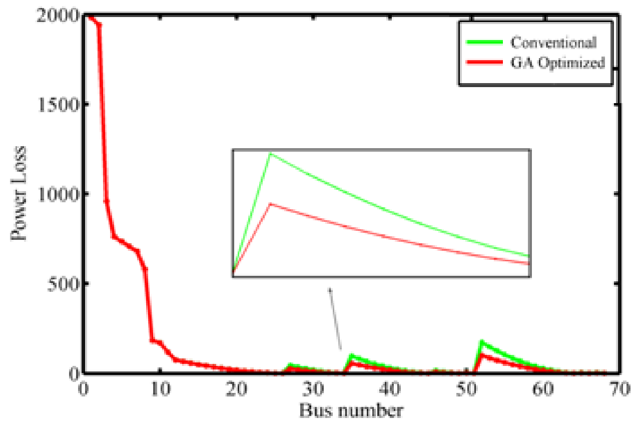

Fig 6. Peak power loss profiles in each branch

It is obvious that voltage profile achieved by GA optimization methods are almost the same while having a little improvement in compare with conventional method. Also, we have a decrease in peak power loss based on peak power loss profiles. The total power loss is shown the costs based on conductor selection are compared in table (3). The real power loss reductions are 579.4903 kW and 606.7364 kW, which is approximately 5.4% and 5.6% in compare with the Conventional design for GA respectively. Proceedings in a similar manner, The total cost reduction (sum of annual cost of power loss and depreciation on capital investment cost) are obtained 27% and 30% for GA respectively.

Table 3 : Obtained Loss results.

	TotalLoss [W]	Total Cost [Toman]	Cost Reduction
Conventional	10695.6498	72,351,576	-
GA Based	10116.1594	52,864,416	27%

6. Conclusion

Optimal set selection of conductors for designing a distribution system is a challenging problem. In this paper, an optimal conductor selection in radial distribution systems is proposed with goal of productivity improvement using GA approache.

In these approaches, optimal selection of branch conductor is done by minimizing the sum of cost of energy losses and depreciation cost of feeder conductor. The proposed algorithms were tested on 69-bus system and results obtained are encouraging. The results offer potential of using GA for improving plant productivity and economy.

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