Optimal Conductor Selection Using Genetic Algorithm

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Abstract- **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. 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. This paper presents the methodology for the selection of optimal conductors, in radial distribution systems. The main objective is to minimize the real and reactive power losses in the system and also to maximize the total saving in cost of conducting material while maintaining the acceptable voltage levels. The optimal selections of conductor sizes are obtained by conventional method and genetic algorithm method Reduction of total loss in distribution systems is very essential to improve the overall efficiency of power delivery. In this paper an attempt has been made for selecting optimal size of branch conductor of radial distribution feeders. The number of computations is more in conventional method that is why genetic algorithms are employed for the optimal selections of conductor sizes.**

Keyword: conductors, feeders, genetic algorithm, conventional method, real power loss, reactive power loss, distributed load flow, cost and savings.

I. 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 I2R 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 [14]. 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 [1] 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 by a 13 kV distribution system. They also studied the effect of voltage regulation on the conductor selection process. Z.Wang [2] presents a new approach to the optimization problem of conductor size selection in planning radial distribution systems which is formulated as an integer programming problem. However, it is difficult to solve such a large scale problem accurately and provides an approximate optimal solution.

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.

Sujit Mandal [5] presented a systematic approach for selection of an optimal conductor set. Several financial and engineering factors are considered in his method. His main intention was to arrive at a solution, which will be the most economical when both capital and operating costs are considered. W.C. Kiran & R.B. Adler [6] in 1982 suggested a dynamic model for the development of primary and secondary circuits supplying a residential area. Main features of his model is, that it can support optimal conductor sizing associated with capital requirement and energy losses, as area load evolves. These revenue requirements are responsive to change in area load (positive or negative) arising with change in the number of residences and change in load as per residence, year by year. Leppert and Allen [7] 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, e.g. load growth and wholesale power cost escalations. M. Sreedhar *et al.* [8] presents a novel method based on fuzzy logic approach for design of radial distribution systems, which selects the optimal size of branch conductor. A fuzzy based satisfaction parameter is proposed which handles voltage deviation index, power quality index and cost function. Ranjan R *et al.* [9] developed voltage deviation index (VDI) as power quality index and then propose a simple computer algorithm for the optimal branch selection based on evolutionary programming. The proposed method incorporates the voltage constraints, maximum current carrying capacity of each feeder and minimization of proposed VDI simultaneously.

In this paper Genetic Algorithms are proposed for selecting the optimal size of conductor for radial distribution networks. 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. and it gives the maximum saving in capital cost of conducting material and cost of energy loss when compared with conventional method. The proposed methods were tested on the feeders of 28 bus IEEE system.

Size of Feeder's Conductor

The conductor size of a feeder is governed by the current carrying capacity, voltage drop, and overall economy. The current carrying capacity of a conductor depends on the conductor losses and surroundings. For determining the voltage drop, it is necessary to calculate the inductive reactance of the feeder. After calculating the inductive reactance, the voltage drop of conductor can be calculated. If the voltage drop comes out to be higher than it is necessary to select another conductor size to reduce the voltage drop.

The value of conductor size obtained above should be checked for overall economy. By the application of Kelvin's law, the most economical conductor size can be calculated. According to Kelvin's law the most economical cross-section is that which makes the annual value of interest and depreciation of the conductor equal to the annual cost of the energy wasted in the conductor. The maximum current on the feeder is not remains always but it occurs certain times. At all the other time the value of current is less than the maximum value. And it is necessary to have a factor for this calculation. This factor is known as loss factor which is defined as:

Loss Factor=average power loss/loss at peak load

If the load is constant through out the time than loss factor is one. In actual practice load varies time to time. If the actual load pattern is known then loss factor can be easily calculated. An approximate value of loss factor can be found from the following equation:

Loss Factor = (0.2 × Load Factor) + 0.8 (Load Factor)2

where , Load Factor = average load / peak load

II. PROBLEM FORMULATION

The objective is to select optimal size of the conductor in each branch of the system, which minimizes the sum of depreciation on capital investment and cost of energy losses. In detail, the objective function for optimal selection of conductor for branch j with k type conductor is

$$\text{Min } F(j,k)=CL(j,k)+CC(j,k) \quad ....(1)$$

(i) Cost of energy losses (CL):
The annual cost for the loss in branch j with k type conductor is,

$$CL(j, k) = \text{Peak loss}(j, k)[cpl + cel\times Lsf \times 8760]$$

where
cpl = Annual demand cost due to power loss(Rs./kW)=1000(Rs/kw)
cel = Annual cost due to energy loss(Rs./kWh)=.5(Rs/kw)
Lsf = Loss factor=.2
Peak loss(j, k) = Real power loss of branch j under peak load conditions with k type conductor

(ii) Depreciation on capital investment (CC):

The annual capital cost for branch j with k type conductor is,

$$CC(j, k) = fid\times [cost(k) \times len(j)]$$

where
fid = Interest and depreciation factor=.1
Cost(k) = Cost of k type conductor(Rs./km)
Len(j) = Length of branch j(km)

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:

$$Lsf = 0.2Lf + 0.8Lf^2$$

III. LOAD FLOW

The flow of active, reactive power is known as load flow. Power flow analysis is used to determine the steady state operating condition of the system. The goal of the distribution system power flow function is to study the distribution networks under various loading conditions and configurations. Provided with bus voltage magnitudes and phase angles output from the power flow function, one can derive more information for the distribution network, including real and reactive power flow in each line, line section power loss, and the total real and reactive power at each bus. Radial Distribution Systems (RDS) require special load flow methods to solve power flow equations owing to their high R/X ratio. Hence methods like Newton Raphson cannot be applied. A method name Backward/Forward sweep based on Kirchhoff's current law (KCL) and Kirchhoff's voltage law (KVL) for evaluating the node currents and voltages iteratively is applied for figure 1. In this approach, computation of branch current depends only on the current injected at the neighbouring node and the current in the adjacent branch. This approach starts from the end nodes and moves towards the root node during branch current computation. The node voltage evaluation begins from the root node and moves towards the nodes located at the far end of the main lines that is to the end nodes. This method is also known as ladder iterative method. It can be classified as:

3.1. Backward Sweep Method
3.2. Forward Sweep Method

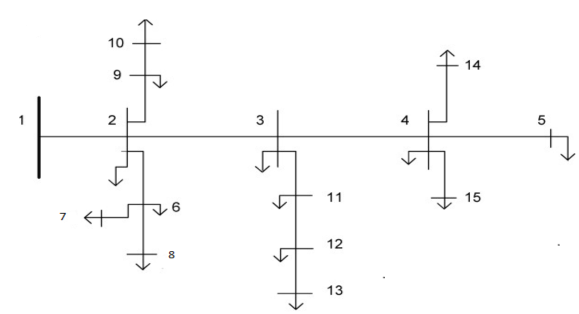

Figure 1. Radial distribution networks for 15 nodes

The calculation is done as follows:

3.1 BACKWARD SWEEP:

Assume rated voltage Vrated at the end node voltages (V_5, V_7, V_8, V_{10}, V_{13}, V_{14}, V_{15}) in figure 3.1
Start with the node 14 and compute the node current

$$I_5 = (S_5/V_5)^*$$

Apply the Kirchhoff's current law to determine the current flowing from node 4 toward node 5:

$$I_{4-5} = I_5$$

Compute with this current the voltage

$$V_4 = V_5 + Z_{4-5} * I_{4-5}$$

Node 4 is a junction node.
Select node 13 and compute the node current

$$I_{13} = (S_{13}/V_{13})^*$$

Apply the Kirchhoff's current law to determine the current flowing from node 12 toward node 13

$$I_{12-13} = I_{13}$$

Compute with this current the voltage

$$V_{12} = V_{13} + Z_{12-13} * I_{12-13}$$

And in this way the forward sweep is applied and reached till the root node.
Using the current I_{1-2} compute the voltage V_1. At the end of the forward sweep the magnitude of the compute voltage V_1 is compared to the magnitude of the rated voltage V_{rated}.

$$\text{Error} = (V_{rated} - V_1)$$

If the error is less than a specified tolerance, the solution has been achieved. A typical tolerance is 0.001 per unit. If the error is greater than this tolerance, the backward sweep begins. The backward sweep begins at the node 1 with the rated voltage and the current from the forward sweep method.

3.2 FORWARD SWEEP:

Start with node 1 and $V_1 = V_{rated}$.
Compute the voltage

$$V_2 = V_1 - Z_{1-2} * I_{1-2}.$$

Compute the voltage

$$V_3 = V_2 - Z_{2-3} * I_{2-3}$$

In this way the backward sweep continues till the end node.
Compute the voltage

$$V_5 = V_4 - Z_{4-5} * I_{4-5}.$$

After the backward sweep the first iteration is completed. At this point the forward sweep will be repeated, only this time starting with the new voltage at end nodes. These steps will be repeated until the error is less than the specified tolerance.
This load flow is thus applied on the test case considered. Henceforth this method is superior in number of iteration, computationally efficient, accuracy is high.

IV. PROPOSED ALGORITHM

4. Evolutionary Algorithms

4.1 Genetic Algorithm (GA)

A genetic algorithm (GA) which is a search algorithm based on the mechanism of natural selection and natural genetics. To solve the optimization problem formulated in equation (1) a genetic algorithm (GA) is proposed, the most popular form of Evolutionary Algorithms, inspired by the principle of evolution and, in essence, consists on a population of strings transformed by three genetic operators: selection, crossover and mutation. Each string (chromosome) represents a possible solution to the problem being optimized and each part of the string (sub string) represents a value for some variable of the problem (gene). These solutions are classified by an evaluation function, giving better values, or fitness, to better solutions. Each solution must be evaluated by the fitness function (having the role of environment) to produce a value. The pair (chromosome, fitness) represents an individual. The GA algorithm proposed in this paper has the following characteristics,

Coding
Each possible radial distribution system with some of a problem in a GA starts from the parameter encoding (i.e., the representation of the problem). The encoding must be designed to utilize the GA's ability to efficiently transfer information between chromosome strings and objective function of problem. The proposed approach uses the string length that represents the conductor size in each branch of the system. Two bits are reserved for each branch.

Initialization
A random initial population is considered. Parameters of GA must be initialized such as generation size, population size, crossover probability and mutation probability for feeder reconfiguration.

Fitness Evaluation
All individual are evaluated with the same fitness function. The fitness function incorporates the objective function.

Fit[i]=1.0/(+0.005*obj[i]);

Reproduction operation
In this operation, the matting pool needs to be formed by the population in proportion to their elitism. Elite ones will copy more to the matting pool. If the probability is high, then the convergence rate increases. But it will not be too high to get the good result. The implementation of elitism is done by choosing the best population from the previous generation. The population is chosen as 10 so initially the performance index for all the population is calculated and then the chromosomes are arranged in the descending order according to their fitness value. Then the first 20% of the population is copied to the next generation.The roulette wheel selection was used to guarantee the occupancy of an area equal to the individual's share of the total fitness.

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Crossover

Given a crossover is performed considering one or more crossover point. This parent selection is to be repeated two times to get the two parents for crossover. After selecting the parents, a random number is generated between 0 and 1, and then this random number is compared with the crossover probability (Pc). If it is less than Pc, crossover is performed. If it is greater than Pc, Par1 and Par2 are directly selected as Chld1 and Chld2. The crossover probability is taken as 0.70.

Mutation

Given a crossover probability, random alteration of genes in an individual may occur. A mutation represents a simple bit change. The mutation probability is taken as 0.01.

V. RESULTS AND DISCUSSION

The proposed method is tested on 28 bus feeder distribution system. A Binary coded Genetic Algorithm (GA) and proposed conventional methods are applied to solve the problem. The best result is tabulated. The program is written in MATLAB software. And the conventional method seems to be sensitive to the some parameters, according to the experiences of many experiments, the following conventional method and GA parameters can be used.

Table 1. Genetic parameters setting.

Genetic Parameter	Setting
Initial population size	10
Elitism probability	0.2
Switches mutation rate [%]	0.7
Crossover rate [%]	0.01

Table 2. Comparison of real and reactive power loss between conventional method (CM) and genetic algorithm (GA)

	With selected Conductors (CM)	With selected Conductors (GA)
Real power loss(p.u)	0.44	0.4115
Reactive power loss(p.u)	0.277	0.211
Net savings in total cost(Rs)	17766.23	20155

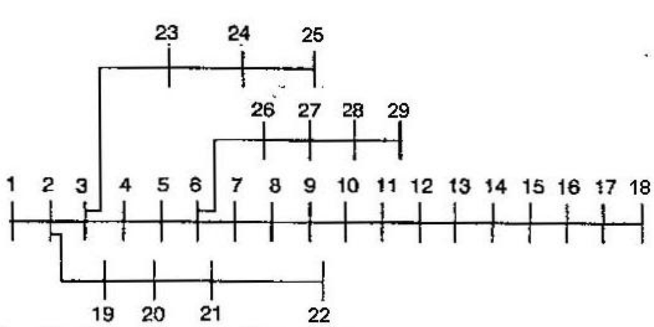

Fig 2.Single line diagram of 28 Bus System

VI. CONCLUSION

A study of distribution network using GA is presented in the paper. The DNRC model, in which the main objective is to minimize the real and reactive power losses in the system and also to maximize the total saving in cost of conducting material while maintaining the acceptable voltage levels In the application of GA to the DNRC, some improvements of algorithms are made on chromosome coding, fitness function and mutation pattern. The genetic string used in the paper is shortened to minimize the required memories and to ensure search efficiency. The proposed process of adaptive mutation not only prevents premature convergence, but also leads to a smooth convergence. From several case studies and comparison with other methods, it can be concluded that the global optima have been found by the proposed algorithm.. The solution algorithms have been tested for test system with 28 bus system. The GA approach has demonstrated an ability to provide accurate and feasible solutions within reasonable computation time.

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Table 3: electrical characteristics of 11kv conductors

S. no	Conductor name	R (Ω/km)	X (Ω/km)	Cost (RS/km)	Imax (A)
1	Squirrel	1.371	0.39	11695	107
2	Weasel	0.911	0.38	11695	139
3	Rabbit	0.514	0.37	17752	193
4	Ferret	0.73	0.36	11700	130

TABLE-4. DATA OF IEEE 28 BUS SYSTEM

	Bus From-To	Resistance (p.u)	Reactance (p.u)	Line length (km)	P (MW) (End BUS)	Q (MVAR) (End BUS)	End Bus Voltage (p.u)
1	1-2	1.8	0.7	0.5	140	90	0.991
2	2-3	2.2	0.9	0.07	80	50	0.990
3	3-4	1.3	0.5	0.074	80	60	0.988
4	4-5	0.9	0.3	0.2	100	60	0.987
5	5-6	3.6	1.5	1.7	80	50	0.980
6	6-7	2.7	1.1	0.3	90	50	0.978
7	7-8	1.4	0.6	0.8	90	40	0.977
8	8-9	2.7	1.1	1.04	80	40	0.974
9	9-10	3.6	1.5	0.07	90	50	0.970
10	10-11	2.7	0.7	0.9	80	50	0.969
11	11-12	1.3	0.3	0.07	80	50	0.965
12	12-13	4.1	1.1	0.54	90	40	0.964
13	13-14	4.1	0.8	1.4	70	50	0.961
14	14-15	3.0	0.7	0.03	70	40	0.960
15	15-16	2.7	1.1	0.07	70	40	0.955
16	16-17	4.1	0.7	0.04	60	40	0.951
17	17-18	2.7	0.7	0.13	60	30	0.945
18	2-19	3.4	0.9	0.7	70	30	0.941
19	19-20	1.3	0.3	0.17	50	40	0.996
20	20-21	2.7	0.7	0.11	50	30	0.993
21	21-22	4.9	1.4	0.73	40	30	0.988
22	3-23	3.5	1.0	1.7	50	30	0.976
23	23-24	3.0	0.8	0.3	50	20	0.997
24	24-25	5.5	1.5	0.08	60	30	0.989
25	25-26	2.7	0.7	1.01	40	20	0.983
26	26-27	1.3	0.3	0.07	40	20	0.975
27	27-28	1.3	0.3	0.9	40	20	0.974