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Optimal conductor selection in radial power distribution system planning using genetic algorithm

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ABSTRACT

This paper presents optimal cross section selection of MV feeders in radial power distribution system planning to reduce power loss and improve voltage profile using genetic algorithm. To analysis the steady state of network in each step of optimization, a direct approach load flow which is both robust and efficient and has high convergence speed is used. In this paper, feeder cross section selection will be performed considering the economic, power loss, and energy loss factors so that, constraints like maximum current capacity of feeders and allowed voltage drop of nodes are satisfied. The obtained result of feeder cross section selection problem will be close to absolute optimum point because of using genetic algorithm as an optimization tool. The proposed method is implemented on MATLAB software environment and through numerical example the validity of proposed method is verified.

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Introduction

The optimum planning of power distribution networks is one of the most important research fields for electrical engineers. That is because of the close proximity of these networks to the ultimate consumers and of their great length, which has as a consequence increased capital investment and increased operational costs because of their losses. Distribution system planner must ensure that there is adequate substation capacity and feeder capacity to meet the load growth within the planning horizon year. The ultimate aim of this research is to plan distribution networks which satisfy the growing demand for electricity, fulfill specific technical operational constraints and which are also characterized by the minimum overall cost (investment and operational cost).

Power losses in the lines account for the bulk of the distribution system losses. The capital investment in laying distribution network lines accounts for a considerable fraction of total capital investment. Therefore, considerable attentions have been given on optimal distribution systems planning over last few years.

In recent researches, many approaches have been proposed to solve power distribution system planning problem. In Ref. [6, 12], feeder cross section selection problem has fulfilled with using analytic methods considering allowable voltage drop so that, economic costs arising from investment cost, power and energy loss cost has minimized. In Ref. [7, 11, and 13] conductor selection problem has solved with heuristic optimization methods and in these papers the aim is minimizing economic cost with satisfying constrains of power distribution system planning. Ref. [8] minimizes investment cost plus power and energy loss costs and also improves voltage profile with replacing existing conductors using evolutionary programming. Ref [10] has performed feeder cross section selection with considering technical and economic factors.

In general, in most of the existing distribution systems, the conductors are not selected in a systematic way. Therefore, the capital cost of conducting material and power loss in the feeders is more and also the maximum current carrying capacity and voltage limits are not generally satisfied.

This paper presents a method based on genetic algorithm for conductor selection in power radial distribution system planning. The selected conductors with proposed method cosiders maximum current carrying capacity of conductors as well as limit of allowable voltage drop for nodes. Additionally causes a compromise between investment cost (arising from feeder to be built, cost of maitanace and operation), power and energy loss cost, then make maximum saving.

Load flow analysis

Load flow is an important tool for the analysis of any power system and it is used in the operational as well as planning stages. The load flow solution provides the steady state condition of a power system. The conventional load flow analysis methods, which were essentially developed to solve problems posed at the transmission network level, can encounter convergence problems when applied to distribution networks. The reason is that the R/X ratio is usually high for radial distribution systems. In the optimization process of power distribution system, load flow subroutine-program must be run successively. Therefore a selected method must have high convergence speed and robustness.

Node and Section Numbering

The procedure of node numbering adopted for the proposed approach is explained considering Fig. 1 as test system. [11]

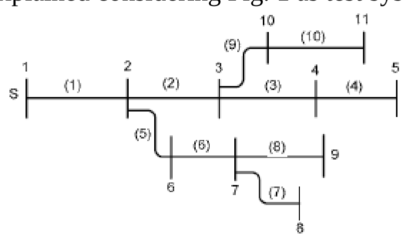

Fig. 1 A simple radial distribution feeder

Steps for node numbering are displayed bellow:

Step 1: The nodes in the main feeder (feeder starting from

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substation node (1) are numbered, as it is shown in Fig.1. These nodes are numbered 1, 2, 3, 4, 5 and (1), (2), (3), (4) are section numbers. The node numbering and section numbering are started from substation that is assigned node number 1.

Step 2: The nodes on the main feeder other than substation are explored for the laterals. In Fig.1, node 2 has a lateral. Then node numbers and section numbers are assigned starting from the sending node (node 2) of the lateral 6, 7 and 8. These are node numbers of the first lateral from the substation and (5), (6) and (7) are the section numbers.

Step 3: Lateral under consideration is explored for the sub laterals, it is seen that node 7 is having sub lateral. Number is assigned for the sub lateral node starting from node 7 as 9 and section number as (8).

Step 4: Repeat steps 2 and 3 and the nodes and sections numbered accordingly.

Direct approach load flow

Because of the spread range of R and X, and radiality of the power distribution system, the load flow problem of the radial distribution network is included as an ill-condition problem. One of the major reasons, which make the load flow program diverge, is the ill-condition problem of the Jacobian matrix or Y admittance matrix. In order to prevent this problem, the proposed method of Ref. [3] is used. Test results in Ref. [3] show that the proposed method is robust, efficient, and suitable for large-scale distribution systems. In the direct approach load flow, two matrices, which are developed from the topological characteristics of distribution systems, are used to solve load flow problem. The BIBC matrix represents the relationship between bus current injections and branch currents, and the BCBV matrix represents the relationship between branch currents and bus voltages. These two matrices are combined to form a direct approach for solving load flow problems.

Technique of problem solution

Great attention should be rendered to the problem of cross section selection of feeders of large MV networks. If a special type of feeder is built at the inappropriate section, it can result in an increase in system losses, degrade voltage profile, implying in an increase in costs and, therefore, having an effect opposite to the desired. For that reason, the development of an optimization methodology capable of indicating the conductor cross section selection problem that improves the system operation characteristics can be very useful for the system planning engineer. In this paper Genetic Algorithm has been used as an optimization tool.

Genetic Algorithm

GA is one of the stochastic search algorithms based on the mechanics of natural genetics. A solution variable for the problem is first represented using artificial chromosomes (strings). In other words, the problem is encoded to strings that GA can handle. It requires the solutions to be presented or coded as a finite-length string. A string represents one search point in the solution space. GA is a parallel search method because it uses a set (population) of strings (i.e. multiple search points). Unlike various constructive optimization procedures which use sophisticated methods to obtain a good single solution, it deals with a set of solutions and tends to manipulate each one in the simplest way. It modifies strings (searching points) using natural selection and genetic operators such as cross-over, mutation, and perturbation. After convergence, strings are decoded to the original solution variables and the final solutions are obtained. The GA is a search technique originally inspired by biological genetics.

Coding and decoding

In the coding process of the optimal conductor cross section selection problem, decimal numbers are used for encoding of chromosomes instead of binary numbers. In the coding procedure each gene stands for a network section (the line that is built between node i, j) therefore, the length of each chromosome is equal to number of the network sections. Each gene could be selected between [0-N_B] that, N_B is the total number of conductors with standard cross sections (mm^2) which are considered in system planning period. Fig. 2 shows an example to explain typical chromosome (with N_B=4).

B1	B2	B3	B4	B5	B6			Bm
2	1	4	2	3	1	...	1	4

Fig. 2 Typical chromosome coding (NB=4, Bm section)

For example; on the first section, second type of conductor will be built, on second section, the first conductor type and on third section, the fourth conductor type, … and on mth section, the fourth conductor type will be built.

Selection

This process determines which individuals of the present population will be selected to give rise to the next population. Two different methods, namely the roulette wheel and the tournament, have been employed for the selection of parents, the second one being restricted to situations where negative values of the merit function arise. The tournament selection consists of choosing the fittest individual among a set a randomly chosen parents. The roulette wheel, restricted to positive fitness values, under this selection technique, the probability for any individual to be selected is directly proportional to its fitness.

Cross over

Crossover produces a new solution (child) from a randomly selected pair of parent solutions providing inheritance of some basic properties of the parents in the offspring.

Crossover is technique, which is used to rearrange the information between the two different individuals and produce new one. The crossover operator is the main search tool. It mates chromosomes in the mating pool by pairs and generates candidate offspring by crossing over the mated pairs with probability Pc. Many variations of crossover have been developed, e.g. one-point, two-point and N-point, and random multipoint crossover. In this paper a one-point crossover is employed and the probability (Pc) of the crossover is 0.75.

Parent1	2	1	4	2	3	1
Parent2	1	1	4	3	2	2
Child1	2	1	4	2	2	2
Child2	1	1	4	3	3	1

Fig. 3 Cross over example

Mutation

Mutation is used to random alteration of bits of string position. The bit will be changed from a decimal number to another number.

With this operator, some of the genes in the candidate parents are inverted with probability Pm to add the next population. The mutation operator is included to prevent premature convergence by ensuring the population diversity.

The third “set” in new population is therefore generated. In this paper, the probability of mutation (Pm) is assumed to be between 0.01 and 0.1.

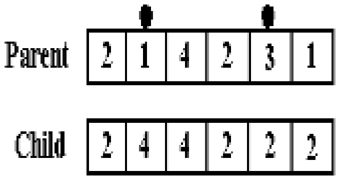

Fig. 4 Mutation example

Perturbation

Perturbation is the process of random modification of the decimal value of one gene in the chromosome to another decimal number. It is not a primary operator but it ensures that the probability of searching any region in the problem space is never zero and prevents complete loss of genetic material through reproduction, crossover, and mutation. It may help us in feeder tapering and when the near optimally solution can not be improved, this operator will guide the problem to the absolute optimum with a very small variation in near optimally solution.

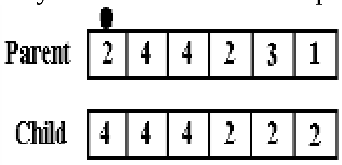

Fig. 5 Perturbation example

The combination of produced children from various operators of genetic algorithm (called “set”) to make a new population is shown in Fig.6. The number of each “set” to be combined to make new population is proportional to the total number of chromosome in that population.

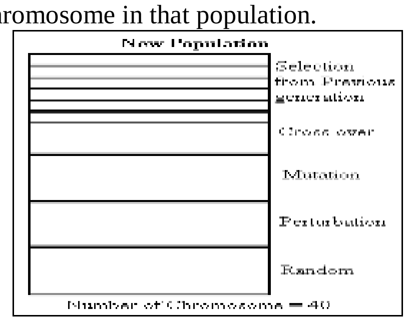

Fig. 6 Form of new population

Termination criterion

After the fitness has been calculated, it has to be determined if the termination criterion has been met. This can be done in several ways.

The algorithm used here stops when a finite generation number has been reached and the best fit among the population is declared the winner and solution to the problem.

Cost function

The problem may be stated as an optimization problem as follows:

Minimize an objective function representing the fixed costs correspondent to the investment in lines and the variable costs associated to the operation of the system, subject to voltage and current constraints, expressed by the following equation:

$$J = \min(\mathrm{F1} + \mathrm{F2}) \quad (1)$$

$$\mathrm{F1} = \sum_{\substack{(i,j)\in m \\ i\neq j}} [(Len_{ij}) \times (FC_{ij})]$$

$$\mathrm{F2} = \sum_{i=1}^{N} P_{\mathrm{loss,i}} \times (C_P + C_E \times 8760 \times \mathrm{LSF_i}) \times \mathrm{PW^i}$$

$$\mathrm{PW} = \left(\frac{1+\inf r}{1+\mathrm{intr}}\right)$$

J = the cost function to be minimized and consists of: fixed cost (F1) which caused by installation and maintenance cost of feeders and variable cost (F2) associated with power and energy loss cost;

Len_{ij} = the length of feeder in Km that will be built between buses i, j;

FC_{ij} = the purchase and installation cost of feeder with defined size;

m = the total number of network sections,

N = the planning period;

$P_{loss,i}$ = the power loss of i[th] year of system; C_E = the energy loss cost;

C_P = the power loss cost;

PW^i = the present worth factor for i[th] year; LSF_i = the loss factor for i[th] year;

intr and infr are interest rate and inflation rate, respectively.

The power losses in the grid are calculated using the load-flow results for the maximum load condition. Then, the energy losses for the period of one year are calculated multiplying the power losses for the maximum load condition by the loss factor and by the number of hours in one year (8760). The associated cost of the energy losses is calculated according to the costs of the energy in ($/kW/year). The present value of these yearly costs is calculated according to the discount rate and to the time period under study.

The present worth factor is applied on variable cost of various plans in the planning period to compare economic worth of them.

Problem constraints

The optimization problem of conductor size selection in planning radial distribution systems is to select the conductor sizes with the minimal total cost under the constraints of:

Voltage:

The voltage amplitude at every node in the feeder must be higher than minimum acceptable value of voltage (V_{min}), means:

$$|V_i| > V_{\min} \qquad \text{for } i = 2,3,...n \qquad (2)$$

Current:

Current flowing through section j with a given type of conductor (K) should be less than the maximum allowable current carrying capacity of K conductor ($I_{max\,(k)}$), i.e.

$$|I_{(jj,k)}| < I_{\max\,(k)} \qquad \text{for } jj = 1,2,...,m \qquad (3)$$

For the sake of simplicity, the following conditions apply in this paper: 1- only a peak load for a planning period of one year is considered. And 2- the feeder configuration is known.

In each generation fitness value of J according to (1) will be calculated that must be minimized in the optimization process.

To succeed this aim the constraints like maximum allowable voltage drop and maximum allowable current carrying capacity must be satisfied. The conductor selection problem in under study radial distribution system will be solved with GA operator’s implementation and considering termination criterion of problem.

Test results

To illustrate the effectiveness of the proposed method, two test cases are studied. These two examples are typical 16-bus [8] and 27-bus [11] radial distribution systems whose single line diagrams are shown in Fig. 7 and Fig.8. The technical and economic information associated with these systems is presented in table I.

Test result 1

A study case of 16-bus, 11kv system that is shown in Fig.7, is considered from Ref. [8].

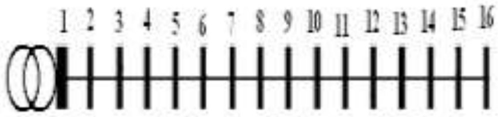

Fig. 7- 16 bus power distribution system of Ref [8]

Load demand and lines information of system exist in above mentioned reference. The used standard conductors in the planning of this system are given in table II.

In Ref. [8], voltage profile improvement and loss reduction has attained with conductor replacement using evolutionary programming. The calculated types of conductors for Ref. [8] and proposed methods are demonstrated in table III and the comparison between them, are given in table IV. According to these tables it is found that proposed method with considering problem's constraints has been caused a reduction in the cost function of final plan compare with both "before conductor replacement condition" (initial state) and "after conductor replacement condition" (using Ref. [8] method).

Test result 2

A study case of 27-bus, 20kv system that is shown in Fig.8, is considered from Ref. [11].

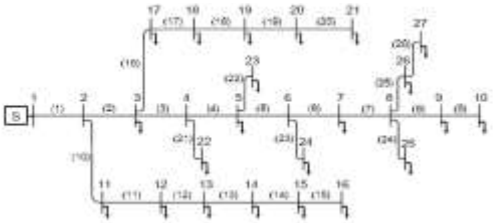

Fig. 8- 27 bus power distribution system of Ref [11]

Load demand and lines information of system exist in above mentioned reference. The used standard conductors in the planning of this system are given in table V.

The calculated types of conductors from both Ref. [11] and proposed methods are available in table VI and the comparison between them, are shown in table VII. According to these tables it is found that proposed method has been caused a reduction in the cost function of final plan compare with Ref. [8] method.

Therefore, the proposed method has obtained better solution than both Ref. [8] and Ref. [11] results.

Conclusion

This study has presented a robust and comprehensive approach to solve the optimal conductor selection problem in a radial distribution network. The proposed algorithm can be used in conductor selection for planning and optimization of radial distribution networks. The objectives considered attempt to minimize of capital investment and power and energy loss, subject to voltage drop and current carrying capacity constraints. Also, because of using GA as an optimization tool, the selected conductors for various segments does not need to standardize after finishing calculation process, like analytic methods.

As two case studies, proposed algorithm is applied to typical medium voltage radial distribution networks with satisfactory and comparable results to other references. In practice, there are numerous HV/MV substations in each network area that may have more than ten MV feeders (proportional to its capacity). Therefore, if the conductor selection problem of MV feeders has done with more attention, too much money saving will be accrued.

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Table I Technical and economic information used for planning

Min-Voltage (PU)	0.9	N (year)	10
Intr	15%	Load growth	5%
Infr	15%	C_E (R/kwh)	65
Lsf	0.6	C_P (R/kw)	800000

Table II Standard conductor information for studying 16 bus system

Conductor Type *	Cross Section (mm^2)	R (Ω/km)	X (Ω/km)	Price (R/km)	Max Current (Amp.)
1	12.9	1.376	0.3896	7651620	115
2	19.35	0.9108	0.3797	9645310	150
3	32.26	0.5441	0.3673	11951384	208
4	48.39	0.3657	0.3579	14221846	270

* 1: Squirrel, 2: Weasel, 3: Rabbit, 4: Raccon

TableIII Selected cross section type with proposed and ref [8] methods (16 bus system)

Node i	Node j	Initial State	Ref. [8]	Proposed Method
1	2	4	4	4
2	3	4	4	4
3	4	4	4	4
4	5	4	4	4
5	6	3	4	4
6	7	3	4	4
7	8	3	4	4
8	9	3	4	4
9	10	2	4	4
10	11	2	4	4
11	12	2	3	3
12	13	1	3	3
13	14	1	3	1
14	15	1	3	1
15	16	1	2	1

Table IV Comparison of proposed and ref [8] methods (16 bus system)

	Initial State	Ref [8]	Proposed Method
Min Voltage (PU)	0.8867	0.91537	0.91125
Power Loss (KW)	53.442	37.33	38.489
Cost Function ($R)	8.0982e+008	7.7922e+008	7.6045e+008

TableV Standard Conductor Information For Studying 27 Bus System

Conductor Type *	Cross Section (mm^2)	R (Ω/km)	X (Ω/km)	Price (R/km)	Max Current (Amp.)
1	42.77	0.7822	0.2835	10555101	150
2	73.77	0.4545	0.2664	13074130	212
3	118.5	0.2733	0.2506	15940637	288
4	126.2	0.2712	0.2464	16340637	308
5	226.2	0.1576	0.2277	19340637	400

* 1: Fox, 2: Mink, 3: Dog, 4: Hyna, 5: Lynx

Table VI Selected cross section type with proposed and ref [11] methods (27 bus system)

Node i	Node j	Ref. [11]	Proposed Method	Node i	Node j	Ref. [11]	Proposed Method
1	2	5	5	14	15	2	1
2	3	5	5	15	16	1	1
3	4	5	5	3	17	5	5
4	5	5	5	17	18	3	5
5	6	5	5	18	19	5	3
6	7	3	5	19	20	2	2
7	8	3	5	20	21	1	1
8	9	1	1	4	22	1	1
9	10	1	1	5	23	1	1
2	11	5	5	6	24	1	1
11	12	5	5	8	25	1	1
12	13	3	5	8	26	1	1
13	14	3	3	26	27	1	1

Table VII Comparison of proposed and ref [11] methods (27 bus system)

	Initial State	Ref [11]	Proposed Method
Min Voltage (PU)	0.8867	0.98607	0.98676
Power Loss (KW)	53.442	40.831	39.538
Cost Function ($R)	8.0982e+008	6.3832e+008	6.3271e+008