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Optimal substation placement and feeder routing in distribution system planning using genetic algorithm

Belal Mohammadi Kalesar and Ali Reza Seifi
School of Electrical & Computer Engineering, Shiraz University, Shiraz, Iran.

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ABSTRACT

In this paper, an attempt has been made to develop a new algorithm for distribution system planning. The proposed algorithm does not require prior knowledge of candidate substation location and can obtain the “number, location and service area” of HV/MV substations, the optimal feeder configuration and the optimal sizes of branch conductors while satisfying constraints such as current capacity, voltage drop and heuristic rules. Several algorithms are proposed for distribution systems planning. A comprehensive algorithm is developed for obtaining the optimal “number, location and service area” of substation using GA and a generalized algorithm is modified to optimal feeder path on minimum loss criterion. Direct approach load flow is used for solving radial distribution networks and branch conductor optimization algorithm. The load flow algorithm and branch conductor optimization techniques are used as subroutine in the generalized distribution systems planning algorithm. Through numerical example the validity of proposed method is verified.

Introduction

The problem of distribution system planning is to find the optimum location of the substation and the optimum feeder configuration to connect the loads to the substation. 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). In the substation planning problem, the number, locations, and service area of the substations are determined using genetic algorithm. Then, the feeder network is determined based on the requirements of minimum investment cost and maximum available configurations in future system operation.

In recent researches, many approaches have been proposed to solve power distribution system planning problem but they assume that new equipment installation candidates are known before hand. However, the assumption of the known candidate locations of feeder or substation may simplify the problem but can not give the optimum solution. Heuristic rules are incorporated in [3] for obtaining the optimal feeder path (based on shortest-path algorithm) and the optimal location of substation on minimum loss criterion. Ref. [4] assumes that number and capacity of substation in the area are known and to minimize the loss, load points are assigned to the nearest available substation, thus service area of substations are obtained. Ref. [5] uses Heuristic procedure to determine number, capacity, and service area of substations. Ref. [6] finds the combination of substations capacity to satisfy total area loads that have lower cost without feeders’ cost, then multi-source locating algorithm is used in the locating process. In Ref. [8], simulated annealing method is used for feeder routing of power distribution system that minimize the quantity that arising from load/distance product, which means that transporting large amounts of power over long distances should be avoided. Ref. [12] proposes a new algorithm for the optimal feeder routing problem using the dynamic programming technique and geographical information systems (GIS) facilities. Most of the above mentioned references assume that the number and location of substations and new feeder installation candidates are known before hand.

In this paper, a comprehensive algorithm is developed for obtaining the optimal “number, location and service area” of substations using GA and a generalized algorithm [3] is modified using GA to optimal feeder path on minimum total cost (fixed and variable) criterion.

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. [2] is used in this paper. Test results in that reference 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.

HV/MV substations

The distribution system is fed through HV/MV substations. A substation’s service area is defined by the area covered by its feeders. A service area is the territory served by a substation with certain load points. To minimize the loss, load points should be assigned to the nearest available substation. In order to

Tele:
E-mail addresses: seifi@shirazu.ac.ir, belal.mohamadi@gmail.com

help planners to choose good initial sites for substation location we propose another computational tool. It is based on a mathematical model that attempts to find the load centers of the distribution network. Technique of problem solution is based on Genetic Algorithm as an optimizing tool.

Technique of problem solution

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). 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). These strings in the initial population are generated randomly. It modifies strings (searching points) using natural selection and genetic operators such as cross-over and mutation. After convergence, strings are decoded to the original solution variables and the final solutions are obtained.

I- Encoding and decoding

In the coding process of the problem, decimal numbers are used for encoding of chromosomes instead of binary numbers. In the coding procedure each gene stands for a load point therefore, the length of each chromosome is equal to number of the network nodes. All of the load points in the network are numbered (from 1 to n) and will be put into groups. Each group stands for a substation service area and will be fed from a substation.

Each of genes in chromosome could be selected between [1-N_S] that, N_S is the initially max number of feasible substation installations in the supply area (max number of groups) with considering the standard capacities of substations in the inventory.

Then N_S can be obtained as follows; (See an example in the appendix (A) for more detail)

$$N_S = \frac{\sum_{i=1}^{n}(P_i * \cos\varphi_i)}{S_{\min} * UF(S_{\min})} + \text{IT} \quad (1)$$

P_i = Active power of i[th] load point in the network area;

n = Number of load points in the network area;

$\cos\varphi_i$ = power factor of i[th] load point in the network area;

IT = a positive integer constant;

$$S_{\min} = \min\{S_i \mid S_i \in Q\};$$

UF(S_{min})= the loading coefficient of smallest substation in the inventory.

Where, Q is the inventory of available standard substation capacities to be built in the planning period.

Fig. 1 shows an example to explain typical chromosome (with N_S=3 and n load points); the first load point will be assigned to the second group, the second load point to the first group, the third load point to the first group … and in the same manner the n[th] load point will be assigned to the third group (see Fig.1). Fig.2 shows an area with 3 groups and 30 load points that members of each group are marked with different symbol (*, +, o). This process is done automatically by coding and decoding programs that described above.

Lp1	Lp2	Lp3	Lp4	Lp5	Lp6		n
2	1	1	2	3	1	...	1	3

Fig. 1- A chromosome in a population (N_S=3, Lpn load points)

After putting the load points into groups, a substation will be assigned to each group and will be located in the center of each group. The optimal location of substation {X(s), Y(s)} for S[th] HV/MV substation can be computed through Eq.1 in the center of S[th] group to minimize total power loss of feeders (see Fig.3).

$$X_S = \frac{\sum_{i=1}^{n} L_i^2 X_i}{\sum_{i=1}^{n} L_i^2}, \quad Y_S = \frac{\sum_{i=1}^{n} L_i^2 Y_i}{\sum_{i=1}^{n} L_i^2} \quad (2)$$

(X_S, Y_S) = coordinates of load centre, (X_i, Y_i) = coordinates of load points i,

n = number of load points in the study area,

L_i = horizon year demand of load point i.

The capacity of substations that will be installed in center of each group is calculated as follows:

$$S_i = \{S_k \mid S_k \in Q\} \quad i = 1,2,...,N_s$$
$$s.t. \quad S_k \geq XL_k / \cos\varphi \quad (3)$$

XL_k is the sum of the active power of loads of horizon year plus total power loss of system (approximately 10 percent of total loads) in each future substation's service area.

In this way, initial service area of each substation will be determined.

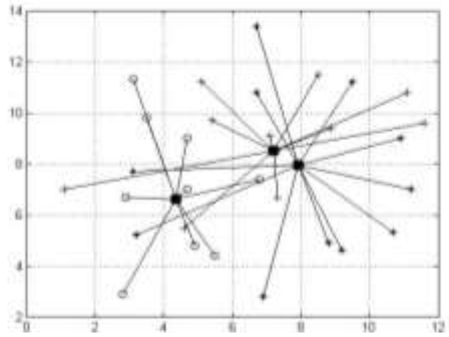


Fig. 2- Groups of load points (N_S=3) in a typical chromosome

Note that in the beginning of the program, the number of substations is equal to N_s but it is possible that the number of substations be reduced. For example in Fig.1, If any load points are not assigned to the second group by the chance, or the second group is removed from a chromosome by the GA operators, the number of substations will be reduced to two in that chromosome.

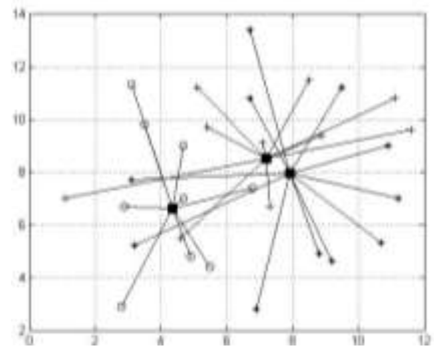


Fig. 3- Locating a substation in center of each groups using Eq.1 (N_S=3)

Fig.3 shows the location of substations that are calculated with Eq.1 and are located in the center of load points of each group. Therefore, the location and number of substations for this step are determined temporarily and will be modified on the next iteration. Also this figure shows the service area of each substation and load points that will be fed from it. This service area is determined for this step and will be edited on the next iterations of the program. It seems that these service areas of the substations are mixed together and there are not acceptable in practice but they will be improved with progress of optimization process. The presented algorithm doesn’t need to divide service area to blocks because of its simplicity.

Selection

This process determines which individuals of the present population will be selected to add 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. This operator is used to rearrange the information between the two different individuals and produce new one to add to the next population. 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.

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. 4- Cross over example

Mutation

Mutation is used to random alteration of gene in string position. The gene will be varied from an existing decimal number to another number.

With this operator, some of the genes in the candidate parents are varied from existing decimal number to another number 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.

Parent	2	1	4	2	3	1
Child	2	4	4	2	2	2

Fig. 5- 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 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.

Parent	2	4	4	2	3	1
Child	4	4	4	2	2	2

Fig. 6- Perturbation example

The components of new population called “set”, which are created from GA operators, are described below:

Set 1: The chromosomes selected with “Selection” stage
Set 2: The chromosomes generated with “Cross Over” operator implementation on set 1.
Set 3: The chromosomes generated with “Mutation” operator implementation on set 1.
Set 4: The chromosomes generated with “Perturbation” operator implementation on set 1.
Set 5: Randomly generated chromosomes.

The number of chromosomes in each “set” to be combined to make new population is proportional to the total number of chromosome in that problem.

Termination criterion

After the fitness function of chromosomes 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. After convergence, strings are decoded to the original solution variables and the final solutions are obtained.

Cost function

This model considers two kinds of costs: fixed and variable cost. The fixed cost comprises of building and equipment costs and variable cost includes the cost of energy losses. The objective function seeks to minimize the variable cost plus the fixed cost. This can be formulated as follows:

$$\begin{aligned} &\mathrm{Min\,COST} = \mathrm{C1} + \mathrm{C2} \\ &s.t. \sum_{k \in J1} (W_k * \cos\varphi_k) \le S_i * \mathrm{UF}(S_i) \\ &\mathrm{i} = 1,2,...,\mathrm{N} \end{aligned} \tag{4}$$

C1= the cost of energy losses on the feeders; C2= the investment cost and operational cost of future substations;

S_i= the capacity of substation i

UF(S_i)= the loading coefficient of transformers in substation i.

The capacity of HV/MV transformers must be sufficient to transport the electrical energy [6, 10]. It should be noticed that the ratio between the fixed and variable costs for a substation is much higher than the corresponding ratio for a feeder [2]. However, in substation placement problem the exactly planning of MV network is not the main purpose but for power loss and voltage drop modeling of downstream system, the MV network model must be taken into account. Appropriate or inappropriate location determination of HV/MV substations can affect planning of other part of distribution network such as, MV/LV substations location and medium voltage feeders planning. In other hand, medium voltage feeders and other part of distribution system planning will be confronted with technical and economical problems, if substation placement has done carelessly. Therefore, the index (that is known LP^2) is added to cost function for modeling the role of MV network in total power loss [6 and 7]. This model was one of the first models proposed for distribution planning, and is relatively unsophisticated. The quantity that is being minimized is the square of load/distance product, which means that transporting large amounts of power over long distances should be avoided.

$$C1 = \gamma \sum_{i=1}^{N} \sum_{j \in Ji} W_j^2 d_{ij}$$
$$C2 = \sum_{k \in N} [(cf_k)_Q + (cv_k)_Q (x_k)_Q^2] \quad (5)$$

W_j = load magnitude of load point j;

$d_{ij} = \sqrt{[(X_i - X_j)^2 + (Y_i - Y_j)^2]}$ is the distance between substation i and load point j;

Generally, a straight line was used for calculating the distance between a load point and a substation [6, 7], which is a straight forward but non-practical way for most planning techniques.

γ = cost coefficient;

N = total number of future substations;

Ji = set of load points which is served by substation i;

$(cf_k)_Q$ = investment cost of a substation of size Q, at the node k;

$(cv_k)_Q$ = cost coefficient of a substation of size Q, at the node k;

$(x_k)_Q$ = power flow, in KVA, supplied from a substation of size Q, at the node k;

The first part of C2 function is investment cost of substation and the second part stands for cost of power loss of transformers in substation (proportional with square of injected power from substation).

Feeder routing algorithm

The Feeder routing algorithm consists on two phases. Forming the initial feasible solution and modify the obtained topology of network using GA. These phases will be described in the next sections.

Phase 1: Forming the initial feasible solution

A feasible solution has to satisfy the consumers' demand, Kirchhoff's current law, the power capacity limits, and the voltage drop and radiality constraints. To start feeder routing procedure a best initial feasible solution is needed for improving the computational characteristic and convergence time of GA. Once a service area and its load points are decided, the shortest path algorithm [3] is used to determine the load allocation to feeders. All steps of this algorithm have described in Ref. [3]. It is worth mentioning here that substation is chosen as node 1 and other load points will be numbered again (from 2 to n+1). The current feasible obtained radial network will be substantially improved by genetic algorithm in the next phase.

Phase 2: Applying GA

The produced network with shortest path algorithm is sensitive to load points geographic location in case study and causing near optimally network that can be improved with applying genetic algorithm's operators. The produced network with shortest path algorithm will be named "initial solution" (see Fig. 7). Genetic algorithm will change the network's configuration to reduce total power loss and cost function. The crossover and mutation operations are implemented as follows with the different manner in comparison to the other papers (see Fig. 8):

The crossover and mutation operators will change configuration of networks that have better cost function in the population to create new offspring to add and complete next population. With these operators, lines are randomly and successively selected to disconnect. Because of disconnecting a line, a part of network will be un-energized (some load points of network that is connected to power supply is named "Part1" and other load points is named "Part2").

To energize "Part2" of network, two nodes must be selected (one node from "Part1" and other from "Part2") to connect together. Some of the load points in "Part1" those are closer than others to load points in "Part2" are selected and named "setA1". When a node is selected randomly from "setA1" (that is named "node1"), nodes in the "Part2" will be sorted according to shortest distance to "node1" and some of them with shortest distance selected and named "setA2". Then, one node will be selected randomly from "setA2" and named "node2" to connect to "node1".

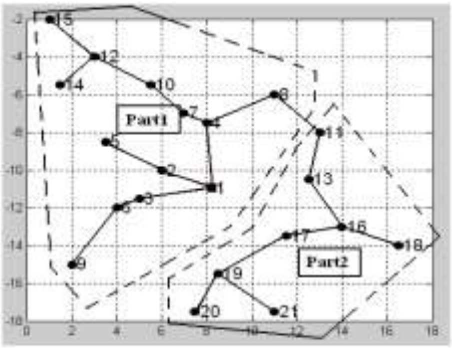


Fig. 7- Obtained by shortest path algorithm implementation

In this example:

Part1= {1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14, 15}

Part2= {11, 13, 16, 17, 18, 19, 20, 21}

setA1= {1, 2, 3, 4, 6, 8}

setA2= {11, 13, 17, 19}

node1= 1, node2= 17

By the way, all the time the number of outgoing feeders from substation should be remained constant.

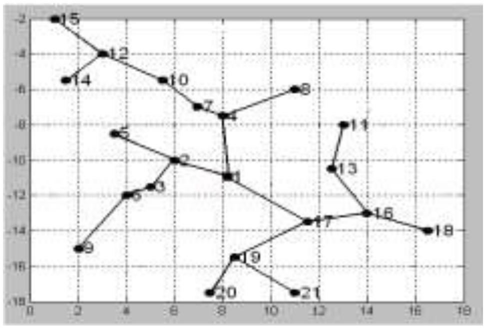


Fig. 8- After applying GA's operators

The aim of this method is to add a line that does not make a loop in network besides to prevent creation infeasible network (a network with very long feeders). The difference between operators (cross over, mutation …) is in the number of lines to be selected to open simultaneously. That is, the number of lines to be selected to open with cross over is more than mutation because, the cross over operator will make a large change in parent to create a child, but mutation operator will make a few change on parents to get a better solution and prevent premature convergence. The GA was observed to be able to identify promising areas of the solution space quicker than the random search method.

Cost function

It is assumed that, there are no existing substations or lines in the network and the network area is like the new town on power planning phase. The problem may be stated as an optimization problem as follows:

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

$$C(y,x) = \sum_{(i,j)\in N_{FF}} \sum_{\Omega\in N_{\Omega}} [(L_{ij})_{\Omega} \times (cf_{ij})_{\Omega}] + \sum_{i=1}^{N} \mathrm{P}_{\mathrm{loss},i} \times C_{\mathrm{E}} \times \mathrm{PW}^{\mathrm{i}} \times 8760 \times \mathrm{LSF}_{\mathrm{i}} \qquad (6)$$

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

N_{FF}= set of proposed feeder routes (between nodes) to be built;

N_{Ω} = set of proposed feeder sizes to be built;

$(L_{ij})_{\Omega}$ = length of feeder of size Ω to be built on the route between nodes i, j;

$(cf_{ij})_{\Omega}$ = fixed cost of a feeder of size Ω to be built on the route between nodes i, j;

Note: the size of each feeder is determined through optimal cross section selection procedure described in section 5.

N= period of planning (years);

$\mathrm{P}_{\mathrm{loss},i}$ = peak power loss of network in ith year;

C_{E} = energy loss cost;

PW^{i} = present worth coefficient for ith year;

$\mathrm{LSF}_{\mathrm{i}}$ = loss factor in ith year;

infr, intr are inflation rate and interest 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 (8760hr). The associated cost of the energy losses is calculated according to the costs of the energy in (Rs/kW/year).

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

In each generation fitness value of J according to (6) 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.

Problem constraints

The optimization problem of feeder routing in planning radial distribution systems is to build feeders to supply load points with the minimal total cost under the constraints of:

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

$$|V_i| > V_{\min} \qquad \text{for } i = 2,3,...n \qquad (7)$$

II- Current: Current flowing through section jj 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.

$$|I_{(jj,k)}| < I_{\max(k)} \qquad \text{for } jj = 1,2,...,m \qquad (8)$$

Optimal feeder cross section selection

Selection of optimal branch conductor size is extremely important in distribution system planning.

The aim of optimal conductor size selection is to design a feeder so as to minimize an objective function, which is sum of capital investment and energy loss costs for the feeders. In the optimal planning of power distribution systems, selection of branch size subroutine program must be run in each chromosome of feeder routing program. Therefore, it is needed to use an approach that has low run-time and robust result. This paper uses heuristic method presented on Ref. [11] to optimal branch conductor selection.

Test results

The proposed approach is tested on two distinct problems in the following sections: HV/MV substation placement and Feeder routing.

HV/MV substation placement

A study system of 50 load points is considered for HV/MV substation "number, location, and service area" determination problem. The information of 50-load point system for horizon year is given with table 4 in Appendix. The maximum utility factor of substations for this planning problem is considered equal to 80 percent. The set of available standard substation capacities and related fixed costs is shown in table 1. Fig. 9 shows the load points in the network with geographical location.

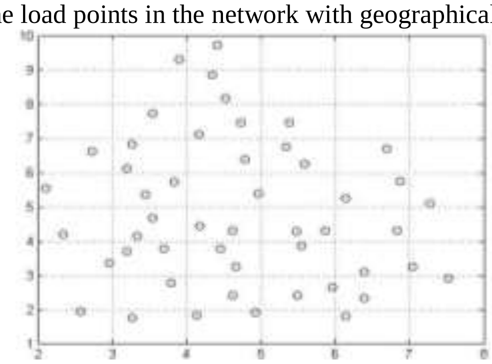


Fig. 9- Geographic location of 50 load points in the area

Fig. 10 shows that two substations are obtained to built and supply the area. The capacity of each substation is 10MVA, with 0.7787 and 0.7905 as utility factors. It is obvious that the coordinates of the substations are (4.3, 6.5) and (4.8, 3) approximately.

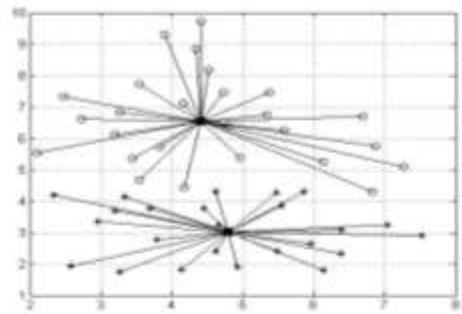


Fig. 10- Location and service area of two HV/MV substations

Feeder routing

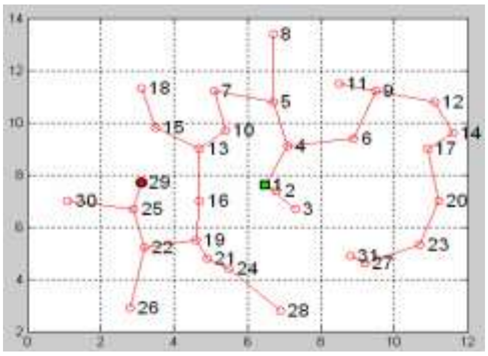
In this paper, the proposed method is tested on two test systems. One of these test systems is 31-load point (heavy loads) as shown in Fig. 11 and other is 54-load point (light loads) as shown in Fig. 12. It is assumed that only three feeders for 31-load point and four feeders for 54-load point can be emerged from the substation. The information of 31-load point system has given in the Appendix (table 5) and information of 54-load point system, exist in Ref. [3].

For this study case, four different types of conductor are considered: Squirrel, Weasel, Rabbit and Raccoon. Table 3 shows the technical and economical data of these conductors. And other data are:

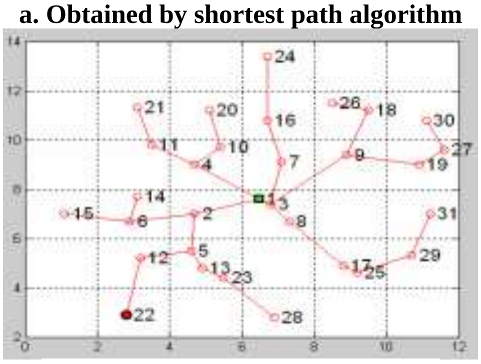
N = 10 years, CE = 30Rs, Lsf = 0.45,
Minimum voltage= 0.95PU, Intr = 20%,
Infr = 5%, Nominal voltage = 11KV,
Power factor = 0.75, and Load growth = 2%

Table 2 shows that, an improvement in total cost function for 31 and 54-load point systems in planning period was obtained comparing shortest path algorithm application.

With comparing the results of Fig. 11 (a) and (b) it is clear that, the obtained network with shortest path algorithm is not a good solution and need to be modified. The total cost function was improved about 50 percent after applying GA. In the case of Fig. 12 (a) and (b) improvement in cost function is about 12 percent.

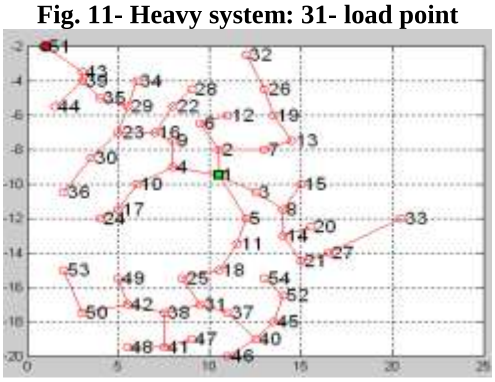


a. Obtained by shortest path algorithm

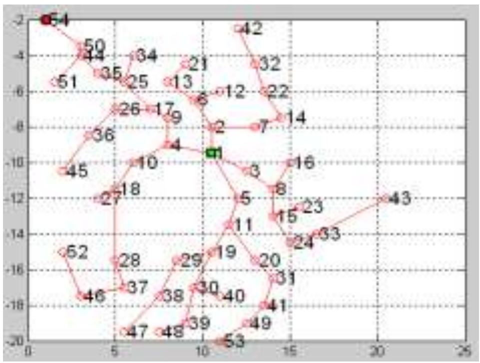


b. Obtained by improving with GA

Fig. 11- Heavy system: 31- load point



a. Obtained by shortest path algorithm



b. Obtained by improving with GA

Fig. 12- Light system: 54- load point

Conclusion

In this paper, distribution system planning problem is divided into two sub-problems: the substation planning problem and the feeder planning problem. A new model is presented here to select automatically the optimal size, location, and service area of substations in the power distribution system, which does not require the candidate substation locations. The solution method is based on the genetic algorithm. This method is a comprehensive approach and has no limitation and is able to apply to MV/LV substation planning problem. The produced network with shortest path algorithm is sensitive to load points geographic location in case study and causing near optimally network that can be improved with applying genetic algorithm's operators. Because of working with geographic location instead of predefined paths for feeders, the encoding and decoding procedure and GA's operator implementation are different.

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9- Appendix

9. A. An example for "number, location and service area" determination of HV/MV substations

This algorithm is implemented on very light and small network to simplicity. Let's assume there are 5 load point in the simple network area (like low voltage system) with 0.8 power factor and the available standard substation capacities in the inventory are: 500, 1000, 1500 KVA. Utility factor for planning purpose is considered equal 0.8.

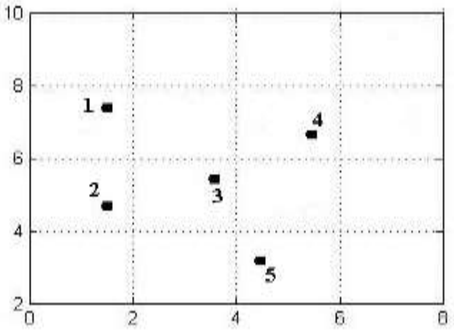

Fig.A.1- location of five load point system

For first step, we must find N_s, that is initially number of substations to be built to feed the load points. From Eq.2 it is calculated N_s=4. Now, the first population of GA that is generated randomly should be formed.

Table A.1- coordinates of load point in Ex.

Load No.	X	Y	KVA
1	1.5	7.5	250
2	1.5	4.5	250
3	3.5	5.5	250
4	5.5	6.5	250
5	4.5	3	250

The generated GA population in first generation is shown below:

1	2	3	2	4	3
2	3	1	1	1	3
3	4	4	3	2	1
4	1	2	2	3	4
		⋮			
20	2	3	1	1	3

Corresponding to chromosomes of above population we putting loads into groups. For example, in the first chromosome: 1st load will put into third group, 2nd load to first group, 3rd load to fourth group, 4th load to third group and 5th load to second group.

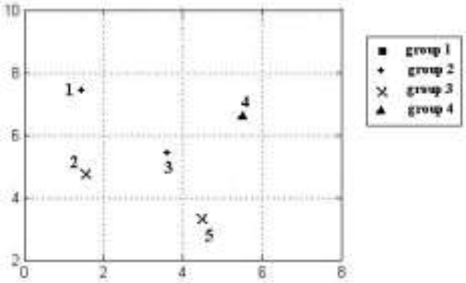

Fig.A.2- groups that each load point put into it for first chromosome

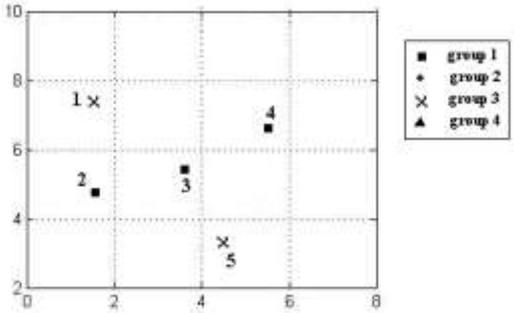

Fig.A.3- groups that each load point put into it for second chromosome

In this step, we must define a substation for each group to feed them; therefore we use Eq.1 to determine the coordinates of substations and Eq.3 to calculate the capacity of substations that will be installed in center of each group.

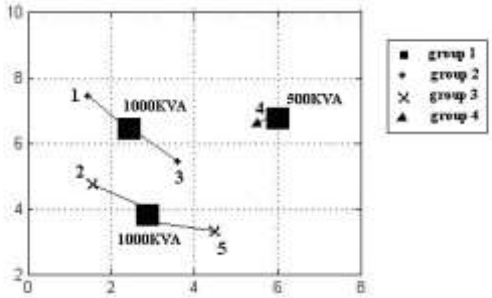

Fig.A.4- capacities and locations of substations for first chromosome

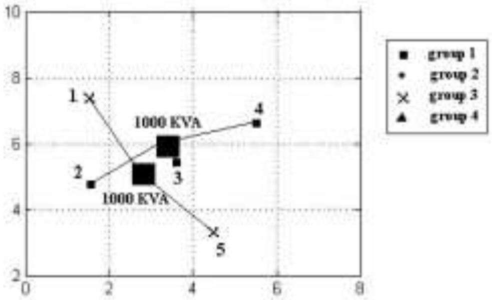

Fig.A.5- capacities and locations of substations for second chromosome

And therefore, the number, location and service area of substations for each chromosome will be determined. Then calculate cost function from Eq.4, 5 for each chromosome to compare them and using GA operators to produce a new population. Of course, Genetic Algorithm will improve the solutions obtained here until the near optimally solution result. This example seems to be fictitious but the presented algorithm is so robust that can be used to real power distribution system planning using powerful computers that can handle these programs quickly.

Table 1- Inventory of available standard substation capacities and related fixed costs

Capacity (MVA)	Cost (Rs/unit)
2.5	1,000,000,000
5	1,800,000,000
7.5	2,600,000,000
10	3,400,000,000

Table 2- cost function, total power loss, and minimum voltage of network

Figure	Cost Function (Rs)	Total power loss (KW)	Min Voltage (PU)
11(a)	1.27E+09	641.3	0.8112
11 (b)	6.29E+08	659.3	0.956
12 (a)	1.31E+09	91.23	0.95
12 (b)	1.15E+09	100.3	0.9501

Table 3- Technical information of conductors

Conductor Type	Cross Section (mm^2)	Resistance (Ω/km)	Reactance (Ω/km)	Price (Rs/km)	Max Current (Amp.)
Squirrel	12.9	1.376	0.3896	1E+07	80
Weasel	19.35	0.9108	0.3797	1.2E+07	100
Rabbit	32.26	0.5441	0.3673	1.5E+07	120
Raccon	48.39	0.3657	0.3579	1.7E+07	150

Table 4- Coordinates and amount of load points for 50 load point system

Load point	X	Y	loads (KVA)	Load point	X	Y	loads (KVA)
1	5.86	4.31	250	26	2.47	7.32	315
2	5.47	4.28	250	27	2.73	6.62	315
3	5.54	3.84	250	28	3.26	6.82	315
4	4.66	3.26	250	29	3.19	6.12	315
5	4.45	3.78	250	30	3.83	5.71	315
6	3.69	3.78	250	31	3.44	5.36	315
7	3.79	2.76	250	32	3.53	4.66	315
8	4.61	2.41	250	33	4.96	5.39	315
9	5.49	2.41	400	34	4.78	6.38	315
10	5.95	2.64	400	35	5.33	6.73	250
11	6.39	3.08	400	36	5.58	6.24	250
12	6.39	2.32	400	37	6.14	5.24	250
13	6.14	1.79	400	38	4.18	4.42	400
14	4.61	4.31	400	39	2.10	5.54	250
15	3.32	4.13	400	40	6.69	6.71	250
16	3.19	3.69	400	41	6.83	4.31	250
17	2.96	3.34	400	42	5.38	7.47	250
18	2.33	4.19	250	43	4.73	7.47	250
19	7.03	3.26	250	44	4.15	7.11	250
20	4.91	1.91	315	45	3.53	7.73	250
21	4.13	1.82	315	46	7.26	5.10	250
22	3.26	1.73	315	47	6.87	5.74	315
23	2.56	1.94	315	48	4.52	8.17	315
24	7.52	2.90	315	49	4.34	8.84	315
25	4.41	9.72	315	50	3.90	9.31	315

Table 5- Coordinates and amount of load points for 31 load point system

Load point	X	Y	loads (KVA)	Load point	X	Y	loads (KVA)
1	-	-	0	17	3.19	3.70	400
2	5.86	4.31	250	18	2.96	3.35	400
3	5.47	4.28	250	19	2.34	4.20	250
4	5.54	3.85	250	20	7.04	3.26	250
5	4.67	3.26	250	21	4.92	1.92	315
6	4.46	3.79	250	22	4.14	1.83	315
7	3.70	3.79	250	23	3.26	1.74	315
8	3.79	2.76	250	24	2.57	1.94	315
9	4.62	2.41	250	25	7.52	2.91	315
10	5.50	2.41	400	26	4.41	9.72	315
11	5.96	2.65	400	27	2.48	7.32	315
12	6.39	3.08	400	28	2.73	6.62	315
13	6.39	2.32	400	29	3.26	6.83	315
14	6.14	1.80	400	30	3.19	6.13	315
15	4.62	4.31	400	31	3.84	5.72	315
16	3.33	4.14	400				