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A Novel Method for Optimal Location and Expansion of Subtransmission Substations Considering Existing Medium-Voltage Distribution Feeders

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Abstract: This research presents an accurate comprehensive cost function for the problem of optimal location of subtransmission substations. Technical constraints and economical parameters are investigated in the modeling. Genetic algorithm is used to optimize the cost function. Coding of decision variables is done in a way that finding the correct solutions is achieved faster. For the first time in this study, free capacity of medium voltage distribution feeders is used for optimal location of subtransmission substations. Also cost of coupling to upward grid in candidate substations with considering different levels of subtransmission voltage is presented. Efficiency of the proposed algorithm is evaluated via several case studies.

Key words: Optimization, genetic algorithm, power system planning, medium voltage feeder

INTRODUCTION

The main target of power system planning and developing in each part of generation, transmission and distribution is response to consumption growth through confident method with maximum reliability and economical efficiency. In distribution part various evolutionary plans are presented that aims of all are optimizing the distribution grid. Each one of these plans considers a different method for modeling the distribution grid. The constraints and solution procedures of these methods are different. It is possible to classify the presented plans through different viewpoints[1-16]:

- Classifying the methods based on the modeling of the distribution system
- Classifying the methods based on planning interval
- Classifying upon the optimization methods
- Classifying based on assumed constraints

Due to complex structure of distribution system, it is impossible to optimize the structure of the grid in a global manner. Thus, the system planning is divided into two subsets[1]: The first subset involves determination of location and sizing of substations (subtransmission and distribution)[2,3]. The second subset considers optimal routing of distribution feeders[4,5]. Some researchers try to solve these subsets simultaneously but due to complexity of the problem they could not present any precise and complete model[6-8]. In some other researchs, these two subsets have been solved continuously for a location[9].

All the optimization methods of planning and expansion of distribution systems are classified in two below groups:

- Mathematical programming methods
- Innovative methods including intelligent systems and evolutionary algorithms

It is interesting that all the initial researches have been based on the mathematical programming whereas most of recent works are concentrated on innovative and intelligent methods[6,11].

Due to instinct discreteness of planning and expansion problem of distribution systems, most of the studies in this field use discrete methods. Though, there are few papers which use continuous methods[5,11,12]. Also, some researchers innovate some methods using complex procedures, in which the run-time of the continuous algorithms is decreased[4].

Voltage drop on feeders and radiality of feeders are two important constraints of distribution grid planning, which are ignored in some papers. For example, in mathematic model of[13], radiality of feeders is ignored. Also some other models ignore the constraint of lowest permitted voltage drop[4,13]. The problem of optimal location of subtransmission substations is investigated in[10], in which cost of coupling the candidate subtransmission substations to upward grid is not considered.

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In[16], a method for substation expansion planning is presented, where the problem solution is performed in two stages. First, using a mathematical classifying technique, an initial list of the acceptable responses based on the constraints on capacity of substations and feeders and also voltage drop is presented, then genetic algorithm as an optimization program, determines the location and capacity of new substation and also the expansion capacity of existing substations.

In the present research, reviewing the performed researches on the optimal planning of distribution grids, an accurate comprehensive cost function for the problem of optimal location of subtransmission substations is presented. Technical constraints and economical parameters are evaluated accurately and the influence of economical indexes such as annual interest rate and annual inflation rate on modeling is considered. The cost of Energy losses in subtransmission transformers and the cost of coupling to upward grid in candidate locations considering the different subtransmission voltage levels with precise details are contemplated. Genetic algorithm is employed to optimize the cost function. The efficiency of represented method is shown with variation of different parameters in long time planning scheme of a distribution grid.

PROBLEM DESCRIPTION AND OPTIMIZATION ALGORITHM

For optimal planning of distribution grid, it is necessary to determine the location and capacity of subtransmission substations in such a way that all load points be energized with minimum possible cost. Choice of location and capacity of subtransmission substations is dependent to some important indexes such as load density of load points, geographical constraints and so on. In large scale systems since having too many several choices, obtaining a system with minimum cost which efforts load demand, is a difficult task. The main target of this research is determination of optimal location, capacity and service area of subtransmission substations considering existing medium-voltage distribution feeders in a long term scheduling period.

The area under study is divided into smaller regions (load center) for load prediction. Each region accompanied with its corresponding consuming load in its gravity center is defined as a load point. For long term scheduling, firstly, whole planning period (from base year until horizon year) is divided into some sequential time intervals. The reason is the practical constraints to construct and equip the subtransmission substations. This period is often 2 to 3 years. Then, it is supposed that the prediction and determination of gravity centers for each region through different time intervals from base year until horizon year is performed with proper methods.

After prediction of the loads of regions, it is necessary to determine the candidate locations to construct substations in under study area. Some of these candidate locations will be selected to substation construction after program running. In selection of candidate locations there are some indexes considered such as: land price, location of existing substations, distance from load centers, distance to the upward grid and so on. Optimization is performed in each time period to find optimal location, capacity and service area of subtransmission substations through candidate construction candidates (considering the whole constraints).

The following variables are determined through scheduling:

- Optimal location to construct the new substation from candidate locations
- Transformer capacity which must be considered in each new substation and also construction timing of new substation
- Number and capacity of transformers which must be added to existing substations and also timing of substation capacity increment
- Optimal service area of each substation in each stage of long term period of planning
- Use of free capacity of medium voltage distribution feeders if available

Cost function: Considering the distribution grid with all details (involving feeders, distribution transformers and conductors) accompanied with subtransmission substations in an almost large area (cities) is a difficult and large problem, so for optimal location of subtransmission substations, downward grid (distribution) is assumed as areas with their demand amount concentrated in their gravity centers. Demand amount in mentioned areas is obtained by load prediction.

Cost function of the problem is expressed such below:

$$F_{total} = F_1 + F_2 + F_3 + F_4 + F_5 + F_6 \quad (1)$$

Where:

F_1 = Cost of land, purchase and insulation cost of substations and coupling cost of subtransmission substations to upward grid

F_2 = Cost of power transition which is proportional to voltage drop index
F_3 = Cost of energy losses in medium-voltage feeders
F_4 = Cost of transformer's copper losses in subtransmission substations
F_5 = Cost of transformer's no-load losses in subtransmission substations
F_6 = Cost of losses in upward grids

Except for investments related to purchase and construction spent at the first of construction period, to calculate other above mentioned costs, real costs which are affected by two indexes of inflation rate and annual interest rate must be used. In this research to model the time and economical indexes, evaluation is performed with the method of present cost value.

$$F_1 = A_1\sum_{i=1}^{n}(C_{f,i})\delta_i \quad (2)$$

$$F_2 = A_2\sum_{i=1}^{n}\sum_{j=1}^{l}(d_{ij}S_{ij})\alpha_{ij}\delta_i \quad (3)$$

$$F_3 = A_3\sum_{h=1}^{M}\beta^h \times \sum_{i=1}^{n}\sum_{j=1}^{l}(d_{ij}S_{ij}^2)\alpha_{ij}\delta_i \quad (4)$$

$$F_4 = A_4\sum_{h=1}^{M}\beta^h \times \sum_{i=1}^{n}(P_{L,i}\times\frac{P_{p,i}}{P_{r,i}})\delta_i \quad (5)$$

$$F_5 = A_5\sum_{h=1}^{M}\beta^h \times \sum_{i=1}^{n}(P_{C,i})\delta_i \quad (6)$$

$$F_6 = A_6\sum_{h=1}^{M}\beta^h \times \sum_{i=1}^{n}(D_iP_{p,i}^2\lambda_i) \quad (7)$$

Subject to:

$$\begin{cases}\sum_{j=1}^{l}S_{ij} = H_{i_{max}} \\ K_{min}\times S_{i_{max}} \le H_{i_{max}} \le K_{max}\times S_{i_{max}}\end{cases} \quad \text{for } i=1,....n \quad (8)$$

$$M = P_T - T_T + 1 \quad (9)$$

$$\beta = \frac{1+f}{1+e} \quad (10)$$

n = No. of existing and candidate substations
l = No. of load points that connected to i th substation
d_{ij} = Distance of load point j from substation i (km)
S_{ij} = Load of j th load center connected to i th substation (MVA)
$P_{L,i}$ = Copper losses of transformer in substation i in rated load (MW)
$P_{P,i}$ = Peak of supplied load by transformer of i th substation
$P_{r,i}$ = Rated power of transformer of i th substation (MW)
$P_{c,i}$ = No-load losses of transformer of i th substation (MW)
D_i = Distance of substation i th from the nearest upward line (km)
δ_i = Zero or one (deciding variable which indicates the presence or non-presence of substation)
α_{ij} = Zero or one (deciding variable which indicates the presence or non-presence of feeder)
λ_i = Coefficient of upward grid voltage level conversion for substation i

$$\lambda_i = (\frac{V_b}{V_{r,i}})^2(\frac{R_{r,i}}{R_b}) \quad (11)$$

V_b = Base voltage of upward grid
$V_{r,i}$ = Other existing voltages of upward grid
R_b = Base resistance of upward grid conductor per one kilometer
$R_{r,i}$ = Conductor resistance, dependent on voltage level choice of upward grid for substation I, per one kilometer
K_{max} = Weighing coefficient for maximum loading of substations
K_{min} = Weighing coefficient of minimum loading of substations
$S_{i_{max}}$ = Max. capacity which can be installed in candidate substations; and maximum installed or expandable capacity for existing substations
P_T = Planning period length at time intervals
T_T = Mean time interval
β = Economical coefficient for conversion of current costs of i th year to base year
f = Annual inflation rate
e = Annual interest rate
$C_{f,i}$ = Sum costs of required land, purchase and installation of substation equipments and coupling subtransmission substations to upward grid in candidate locations
A_1 = Weighting coefficient related to costs of required land, purchase and installation of substation equipments and coupling subtransmission substations to upward grid (in candidate locations and expansion of existing substations)

A_2 = Weighting coefficient related to cost of power transition (proportional to voltage drop index)

$$A_2 = R_v \quad (12)$$

For conductor type (currency unit/km.MVA)

A_3 = Weighting coefficient of losses cost in medium-voltage feeders

$$A_3 = LSF \times \frac{8760 \times R}{V^2} \times R_I \quad (13)$$

R_I = Energy cost per one MW.hour
R = Resistance of initial grid conductor (medium voltage) per one kilometer
V = Voltage of initial grid, medium voltage, (KV)
LSF = Coefficient of losses for initial grid, medium voltage
A_4 = Weighting coefficient of copper losses of transformers in subtransmission substations

$$A_4 = 8760 \times LSF \times R_I \quad (14)$$

A_5 = Weighting coefficient of no-load losses of transformers in subtransmission substations

$$A_5 = 8760 \times R_I \quad (15)$$

A_6 = Weighting coefficient of losses cost in upward grid lines

$$A_6 = HSF \times \frac{8760 \times R_H}{V_H^2} \times R_I \quad (16)$$

R_H = Resistance of upward grid conductor per one kilometer
V_H = voltage of upward grid (KV)
HSF = Loss coefficient of upward grid

Costs related to coupling of subtransmission substations to upward grid and cost of energy losses of the connecting lines between subtransmission substations and upward grid are the cases not considered in most of previous methods. Sixth expression and part of first expression in cost function devote to these cases. Possibility of importing different values of subtransmission voltages in this cost function is of cases not considered in previous researches. Equation (11) presents the procedure of calculating the coefficient of upward grid voltage levels conversion. Having this coefficient, without any need to add other parts to cost function, we can complete the optimization. If all the possible voltages of upward grid are equal, then λ_i for all substations will equal to value 1.

Other index of proposed cost function of this research which is less considered in similar studies, is the cost related to losses of transformers in subtransmission substations. No-load and copper losses are mentioned in forth and fifth expressions of proposed cost function of this research. In times which are not peak losses of transformers are the considerable part of distribution grid losses.

Index of product between distance and amount of load power, is the result of the fact that loads must be supplied by the nearest substation. Also, since the power of load point is proportional to current (assuming constant voltage) and the distance of load point from substation is proportional to resistance, so it is possible to assume the index of product between amount of load point power and its distance proportional to voltage drop and the index of product between square of the load point power and its distance to substation proportional to losses amount. Last mentioned cases are the costs related to power transition and energy losses in medium voltage feeders which are considered in the second and third terms of cost function.

Cost related to coupling of subtransmission substations to upward grid, is considered as an independent cost in first expression of cost function and the cost of required land and purchase and installation of substation equipments is added to it. Note that the investment related to land purchase, purchase of required equipments and construction of communication lines is spent in base year and thus there is no economical coefficient to convert the current costs of i th year to base year in expressions of cost function which involve the above mentioned costs. The expressions of cost function related to energy losses are variable costs that their amounts are dependent on load amount in time and interest rate and inflation rate. So, for these expressions, using economical coefficient to convert the current costs of i th year to base year, all the costs are calculated for unique time and then the cost function is calculated.

Having K_{max} in relation (8) results in guaranteed continues energy delivery in the case of emergency events. In other words, always a part of subtransmission substations transformers capacity is exploitable as a reserve capacity. Having K_{min} in relation (8) means that minimum loading of subtransmission substations transformers must not be less than a specified value.

Since concentration point of load is a virtual and supposed point, so finding distance with radial and

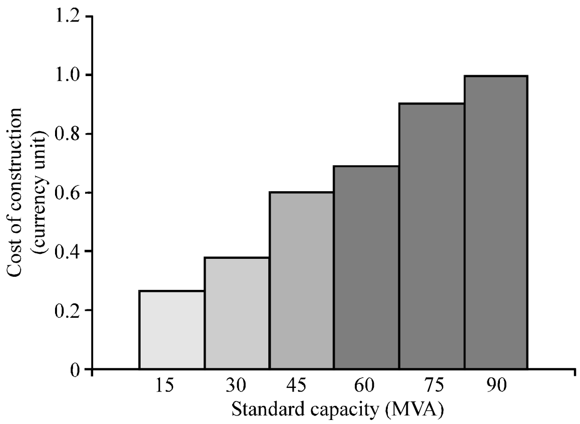

Fig. 1: Construction cost of substations vs. standard capacities

direct method (the possibility of negotiation of such distance is practically low) is not a reasonable method. To determine distance between subtransmission substations and load points we use the sum of vertical and horizontal distances. Distance between i th substation with coordinates (X_i,Y_i) and j th load point with coordinates (X_j, Y_j) is calculated by relation (17):

$$d_{ij} = \left|(X_i - X_j)\right| + \left|(Y_i - Y_j)\right| \quad (17)$$

Note that this model is discussed as a virtual feeder which is a representative of the actual feeder and not the actual one.

An effective factor in cost function is the cost of candidate substations and expansion of existing ones. Final cost of each existing standard capacities for subtransmission substations involves the cost of required land, equipments, building, transportation and installation. Diagram of construction cost of substations is sketched in Fig. 1.

Constraints of problem: The mentioned cost function for location and determination of optimal service area of subtransmission substations is minimized subject to below constraints:

- Demand of all load points must be supplied (there must be no distinct load point)
- Each load point is permitted to be supplied with just one substation
- Loading of substations must be in the minimum and maximum permitted limits of substations capacity

Problem solution conditions: Generally, obtaining global optimal solution is proved in numerical optimization techniques such as linear programming, but due to complexity of our problem and noting that the cost function is nonlinear and solution spaces are discrete, using mathematical programming methods is very complex and precise modeling of all practical facts of this problem is impossible. In this study, genetic algorithm is used for optimization.

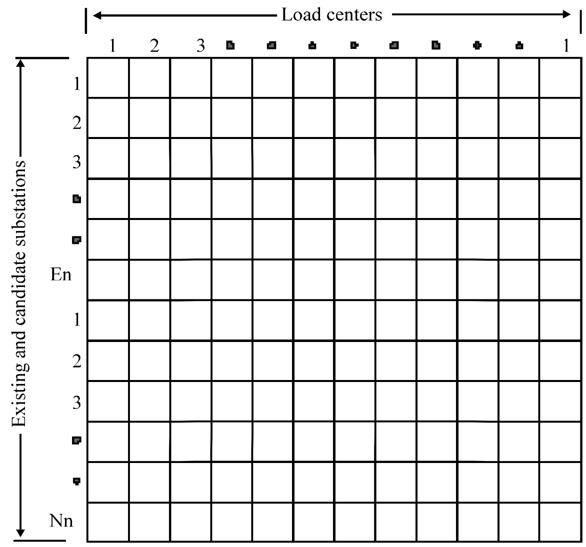

Fig. 2: Chromosome structure for coding of problem

Chromosome structure: For optimization of concerning problem, the considered chromosomes have matrix structure. In these chromosomes the number of rows equals to the number of substations (involving the existing and candidate ones) where En is the number of existing substations and Nn is the number of candidate substations, also the number of columns equals to the number of load points where l indicated the number of load points. Figure 2 shows the structure of these chromosomes.

The elements of this matrix can be zero or one. Each element represents a gene in the chromosome. If element ij in a matrix equals one, it means that substation i supplies load point j.

Each load point can be supplied by just one substation, thus in each column of the matrix there is just one 1 element.

Using the chromosome, it is possible to obtain the load amount connected to each existing or candidate substation. The procedure of calculating load amount connected to each substation is that in row related to supposed substation elements 1 are searched and the connected loads to the substation are recognized, then summing the amounts of these loads, amount of connected loads to the substation is calculated.

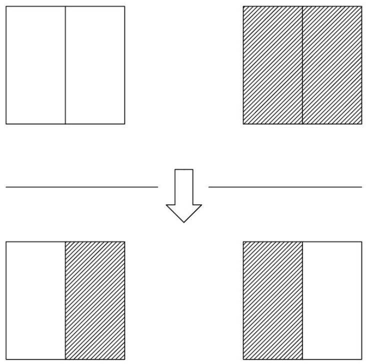

Fig. 3: Crossover between two chromosomes

Initial population: To have faster optimization, we must initially apply the most possible constraints of the problem thus in the generation of initial population selection of illegal cases avoided. Such constraints involve maximum permitted length for minimum voltage feeders which is analyzed at the start of the optimization. To perform this, a matrix named connection matrix is defined which shows the possibility of connection of load to substation. Having an element of this matrix equal to 1 shows that the load related to column of this element and the substation related to row of this element have connection possibility and having an element equal to 0 means that there is no connection possibility. Based on this matter and noting the structure of considered area, there is also possibility to consider geographical constraint for problem. Now, triangular distance between load points and substations is evaluated and if this distance exceeds the permitted value, the element which its row and column is respectively substation and load, is zeroed in the connection matrix. Considering this matrix, the initial population is generated and in procedures of crossover and mutation this matrix is considered too.

In procedure to generate the initial population, constraint of connection of all load points to substations and constraint of connection of each point to just one substation is satisfied. Also crossover and mutation operators act in such a way that these two constraints are satisfied and generation of illegal chromosomes is avoided. Furthermore, random connection of load points causes having almost balanced load distribution between substations and thus having less over load on the substations. In this way, the initial population without load distinction is generated.

Crossover: Figure 3 shows how crossover is acted on two chromosomes. Noting that in each column of chromosome, there is just one gene with value one (other genes of the column are zero), vertical crossover (Fig. 3) does not cause to contravene the constraint of supplement of each load point from just one substation.

In this research, one-point, two-point and multi-point crossovers are performed on selected chromosomes to generate new offspring.

Mutation: In this research two kinds of mutation as explained below are employed:

- Random selection of one column of a chromosome and zeroing the only gene with value 1 of that column and making another random gene of the column equal to one. Of course, performing the mutation, there is possibility to perform the mutation on several columns. Performing this mutation, load point is disconnected from one substation and connected to another.
- Random selection of one or more candidate substation in a chromosome (selection of rows related to candidate substations) and zeroing all genes of that substation and connecting the loads previously supplied by that substation, to another substations

Performing the algorithm using first mutation, the probability of omitting a candidate substation from candidates (zeroing all genes related to load point connection to it) is very low and almost zero. Thus, performing the algorithm, second mutation is used with rather low probability. This action has a positive effect on the speed of algorithm and reduction of the number of selected substations.

Fitness index of chromosomes: Chromosomes which more minimize the cost function merit more. For chromosomes which contravene one of problem constraints (infeasible solutions), a very large number instead of cost function is attached to the chromosome. Thus, the chromosomes which contravene at least one of problem constraints will have very large values in their cost functions. To prevent the presence of defective chromosomes in next generations, a subroutine is performed and the chromosomes with very large values in cost function are omitted form selection list.

LONG TERM SCHEDULING USING MULTI-PERIOD MODEL

Since the load of distribution system during the study period is time varying, the effect of time must be considered in scheduling and based on it the expansion schedule of system have to be presented. The employed method in this research for long term scheduling of system is multi-period model. In this method, at first, whole study interval is divided into several sequential periods. Then, for first period, optimization is performed with existing substations and their expansion possibility in base year and optimal location, capacity and service area of subtransmission substations are obtained. After optimization in first time period, to perform optimization in second time period, substations which are selected from candidates during first period and also the existing substations in base year are assumed as existing substations for this period. This procedure is repeated for next time periods too, i.e., selected substations of previous period will be considered as existing substations for current period.

EFFECT OF MEDIUM-VOLTAGE DISTRIBUTION FEEDERS ON OPTIMIZATION

In some solutions extracted from optimization procedure there is a number like 31.2 MVA for capacity of subtransmission substations transformers. In these cases, having standard capacities for transformers, (Fig. 1) first transformer with larger than or equal capacity like 45 MVA must be selected. In this case, although the value (31.2 MVA) is much closer to standard value 30 MVA, but since it is larger than nearest standard capacity, next standard capacity must be selected. Such cases can be solved under some special conditions. As follows, we will discuss how to use free capacities of medium voltage distribution feeders to have better optimization procedure.

In long term scheduling on distribution grids in a specified area, medium voltage feeders with below mentioned conditions are important:

- Medium voltage feeders which are branched of neighbor subtransmission substations and supply specified load points.
- Medium voltage feeders which are branched of the same subtransmission substations of under discussion area and supply specified load points in the same area and because of technical or economical reasons it is not possible to change the present arrangement of load points and substations.

In these cases, if we can use a part of the capacity of these medium voltage distribution feeders, it is possible to have better optimal location of subtransmission substations. Last cases are not considered in any of previous researches.

It is possible to use the free capacities of existing medium voltage feeders fulfilling below mentioned conditions:

- Medium voltage feeders which their free capacities are used, poses specified path and supply specified loads with specified subtransmission substations and there is no possibility to change their topology. Thus these feeders are not from medium voltage feeders which will be constructed after optimization.
- The capacity of these feeders must be examined from technical viewpoint and be denoted that if it is possible to use any part of their capacity or not. Usable permitted capacity for each medium voltage distribution feeder may be the values 1 MVA, 2 MVA or more.
- Location of these feeders must be investigated in under study area and the possibility of connecting feeders with free capacity to some of load points of under study area must be analyzed.

Finally, using the solutions extracted from long term scheduling stages, optimization is completed, i.e. proposed capacities for candidate substations or increment of capacity of existing substations are investigated and in the case which it is possible to use the free capacities of mentioned medium voltage feeders to help the capacity decrement of subtransmission substations transformers, the optimization is completed. Using the free capacity of medium voltage distribution feeders, results in reduction of investment costs by electrical companies.

Numerical studies: Proposed algorithm is performed for the city Tabriz, Iran. The study periods are two three-year periods and inflation rate and interest rate are supposed respectively 20 and 14%. In these Case studies, coefficients A1 to A6 are supposed equal to 1.0, 1.2, 0.2, 100.0, 100.0 and 0.02, respectively.

Case study 1: To evaluate the results of proposed optimization algorithm (genetic algorithm) and validating the result, the proposed algorithm is applied for a small area as Fig. 4 and its results are compared with results of direct search method in this area.

Direct search in the area is done for a three-year period, two existing substations and without expansion possibility, two candidate substations and ignoring loads growth.

Assuming the number of substations equal to m and the number of load centers equal to n, number of all

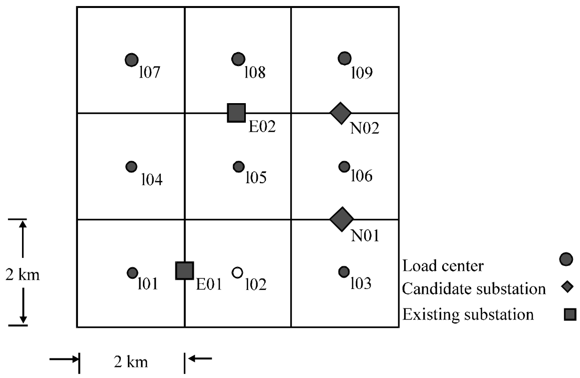

Fig. 4: The area for case study 1

Table 1: Load center data for case study 1

Load (MVA)	Load center name
10	A01
9	A02
8	A03
9	A04
7	A05
6	A06
10	A07
11	A08
12	A09

Table 2: Existing substation data for case study 1

Present capacity (MVA)	Existing substation name
30	E01
60	E02

Table 3: Candidate substation data for case study 1

Proposed installed capacity (MVA)	Candidate substation name
15, 30, 45, 60, 75, 90	N01
15, 30, 45, 60, 75, 90	N02

possible states will be m^n. All possible states for case study 1 are 262144. Characteristics of load points, existing and candidate substations are given in Table 1-3.

Results of direct search for case study 1 are given in Table 4. The same case study is performed with proposed genetic algorithm and in less than 5% of solution space; the same optimal point is obtained. Optimization procedure of cost function with running genetic algorithm for case study 1 is illustrated in Fig. 5.

Note that with larger search space, it is impossible to use direct search to find the optimal solution.

Case study 2: The proposed algorithm is performed for the Tabriz city supposing that existing substations are imposed with over loading and have no expansion possibility for them and also during second time interval new loads are added to under study area, these loads are located in northeast of the area. Candidate subtransmission substations 7 to 11 are located in this area.

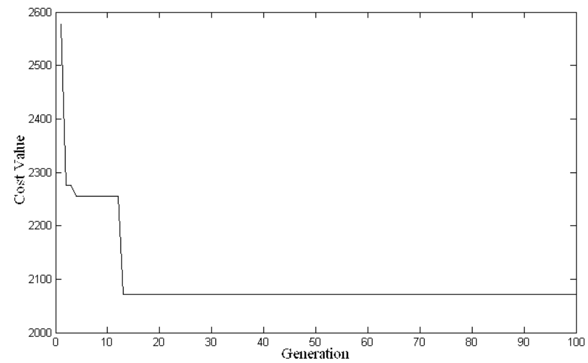

Fig. 5: Optimization procedure of cost function with running genetic algorithm for case study 1

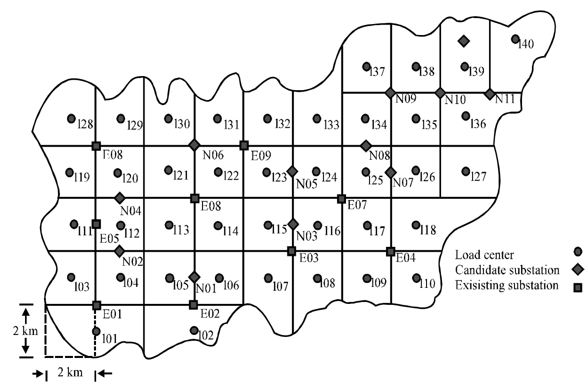

Fig. 6: The area for case study 2

Table 4: Result of direct search for case study 1

Allocated load centers	Proposed capacity (MVA)	Maximum loading	Present capacity (MVA)	Substation name
Existing subtransmission substation				
l 01, l 03, l 06	30	24	30	E01
l 02, l 04, l 05, l 07, l 08	60	46	60	E02
Chosen candidate subtransmission substation				
l 09	15	12	-	N02

Figure 6 shows the under study area. Characteristics of load point, existing and candidate substations are given in Table 5-7. In this study, the numbers of time intervals is two with tree years in each time interval and all candidate substations have standard capacities 15, 30, 45, 60, 75 and 90 (MW).

Table 8 and 9 show the results of long term scheduling for first and second time intervals. In first time interval, new regions have no load, also the load

Table 5: Load center data in base year for case study 2

Number	1	2	3	4	5	6	7	8	9	10
Load center name	A01	A02	A03	A04	A05	A06	A07	A08	A09	A10
Load in base year (MVA)	10	10	10	10	7	7	7	9	8	10
Load growth (%)	5	7	9	7	10	4	8	6	8	10
Number	11	12	13	14	15	16	17	18	19	20
Load center name	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20
Load in base year (MVA)	8	9	5	7	10	5	4	3	7	6
Load growth (%)	5	5	4	4	5	2	3	4	5	5
Number	21	22	23	24	25	26	27	28	29	30
Load center name	A21	A22	A23	A24	A28	A29	A30	A31	A32	A33
Load in base year (MVA)	10	7	3	8	10	10	6	8	10	8
Load growth (%)	7	4	4	6	8	8	7	4	10	5

Table 6: New load centers data in second time interval for case study 2

Number	31	32	33	34	35	36	37	38	39	40
Load center name	A25	A26	A27	A34	A35	A36	A37	A38	A39	A40
Load in base year (MVA)	12	10	8	12	12	12	10	8	9	10
Load growth (%)	10	10	11	11	10	11	10	12	12	10

Table 7: Existing substation data for case study 2

Present capacity (MVA)	Existing substation name
30	E01
30	E02
45	E03
30	E04
45	E05
45	E06
30	E07
45	E08
45	E09

Table 8: Result of proposed algorithm for case study 2 for first time interval

Allocated load centers	Proposed capacity (MVA)	Maximum loading	Present capacity (MVA)	Substation name
Existing subtransmission substation				
l 01, l 04	30	23.82	30	E01
l 02, l 05	30	21.56	30	E02
l 06, l 08, l 15, l 16	45	35.47	45	E03
l 09, l 10	30	23.38	30	E04
l 03, l 11, l 12	45	32.62	45	E05
l 07, l 13, l 14, l 32	45	35.62	45	E06
l 17, l 24, l 33	30	23.16	30	E07
l 19, l 20, l 28, l 30	45	34.99	45	E08
l 18, l 21, l 22, l 23, l 31	45	35.87	45	E09
Chosen candidate subtransmission substation				
l 29	30	12.59	-	N04

growth in existing regions is balanced and existing substations are imposed by overloading, thus it seems necessary to select new substation to vanish the overload. As the results of case study 2, after long term optimization, in this time interval the selected substation is located in existing regions. In second time interval we expect that considering the load of regions added in second time interval and also load growth of existing regions, some substations be selected around new and existing regions. In this case, as expected, after optimization with mentioned methods, some substations are selected in new and old regions.

Table 9: Result of proposed algorithm for case study 2 for second time interval

Allocated Load centers	Proposed capacity (MVA)	Maximum loading	Present capacity (MVA)	Substation name
Existing subtransmission substation				
l 01, l 06	30	22.25	30	E01
l 02, l 14	30	23.85	30	E02
l 07, l 08, l 16	45	29.49	45	E03
l 10, l 18	30	21.50	30	E04
l 12, l 13, l 19, l 20	45	35.8	45	E05
l 05, l 15, l 31	45	35.92	45	E06
l 09, l 17	30	17.46	30	E07
l 21, l 28	45	30.86	45	E08
l 22, l 23, l 24, l 30	45	32.98	45	E09
l 29	30	15.86	30	N04
Chosen candidate subtransmission substation				
l 03, l 04, l 11	60	42.47	-	N02
l 25, l 26, l 33	75	49.68	-	N07
l 32, l 34, l 35	90	61.73	-	N08
l 36, l 38	60	38.23	-	N09
l 27, l 37, l 39, l 40	90	68.11	-	N010

Case study 3: In this case study, proposed software is performed in Tabriz, assuming that there is expansion possibility for substations and also in second time interval some new load are added to under study area. Conditions of this case study (under study area shape, characteristics of load centers and candidate substations) are the same as case study 2. Characteristics of existing substations are given in Table 10.

Table 11 and 12 show the results of long term scheduling for first and second time intervals. In this case study, considering that the existing substations are expandable, optimization is performed. In first time interval, as the new regions have no load, existing regions have balanced load growth and existing substations are imposed with over loading, thus capacity increment in existing substations is

Table 10: Existing substation data for case study 3

Expandable capacity (MVA)	Present capacity (MVA)	Existing substation name
15, 30, 45, 60	30	E01
15, 30, 45, 60	30	E02
15, 30, 45	45	E03
15, 30, 45, 60	30	E04
15, 30, 45	45	E05
15, 30, 45	45	E06
15, 30, 45, 60	30	E07
15, 30, 45	45	E08
15, 30, 45	45	E09

Table 11: Result of proposed algorithm for case study 3 for first time interval

Allocated load centers	Proposed capacity (MVA)	Maximum loading	Present capacity (MVA)	Substation name
Existing subtransmission substation				
l01, l04, l05, l11	60	42.40	30	E01
l02, l06	30	20.12	30	E02
l07, l08, l15	45	31.11	45	E03
l09, l10	30	23.38	30	E04
l03, l12, l13, l20	45	35.93	45	E05
l14, l21, l22, l30	45	35.34	45	E06
l16, l17, l18, l24	30	22.57	30	E07
l19, l28, l29	45	33.29	45	E08
l23, l31, l32, l33	45	34.94	45	E09
Chosen candidate subtransmission substation				
-	-	-	-	-

Table 12: Result of proposed algorithm for case study 3 for second time interval

Allocated load centers	Proposed capacity (MVA)	Maximum loading	Present capacity (MVA)	Substation name
Existing subtransmission substation				
l01, l03, l04, l05	75	57.58	30	E01
l02, l14	30	23.86	30	E02
l07, l08, l15, l16	60	42.89	45	E03
l10, l18	30	21.51	30	E04
l11, l12, l13	45	29.10	45	E05
l06, l21, l31	45	33.98	45	E06
l09, l17, l23, l24, l25, l26	90	71.58	30	E07
l19, l20, l28, l29, l30	75	58.15	45	E08
l22, l32, l33, l34	75	59.73	45	E09
Chosen candidate subtransmission substation				
l27, l35	60	36.22	-	N07
l37, l38	45	33.50	-	N09
l36, l39, l40	75	57.92	-	N11

predictable. As the results of case study 3 show, after performing the optimization with genetic algorithm, some of existing substations are expanded and supplied the over load, which was expected. But, note that contrary to the results of first interval for case study 2, there is no new selected substation in first time interval of case study 3. In second time interval, the load of new added regions in second period is considerable and also we have load growth in existing regions, so it is expected to construct new substation or to increase the

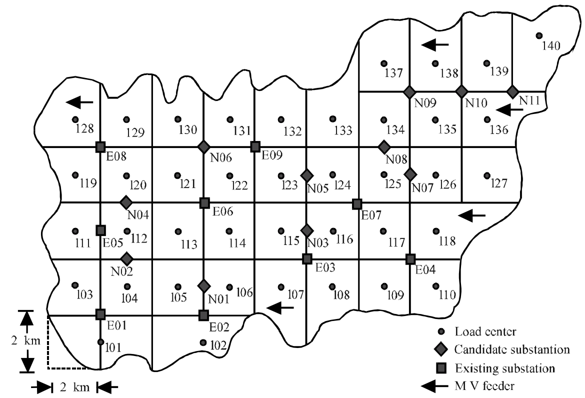

Fig. 7: The area for case study 4

capacity of existing substations. After optimization and considering the locations of existing and candidate substations and also expandable or installable capacities, the proper substations are selected.

Case study 4: To investigate the use of free capacity of medium voltage distribution feeders, case study 2 is repeated for the case in which the existing medium voltage distribution feeders are also used for optimization. Figure 7 shows the under study area for case study 4. As the figure, in some boundary regions, there are some medium voltage distribution feeders. Based on previously mentioned viewpoints, using part of free capacity of these feeders to have better optimization is permitted. Maximum usable permitted capacity of the feeders of this case study is 1 MVA. Conditions of this case study (load characteristics, existing and candidate substations characteristics) are the same as case study 2 and also existing substations are not expandable.

Table 13 and 14 show the results of long term scheduling for the first and second time interval. Using free capacity of some of medium voltage feeders in this case study, results in smaller capacities allocated to transformers of selected candidate substations. The expression feeder effect in some rows of Table 13 and 14 represents the use of free capacities of medium voltage feeders during optimization of related substation. Using free capacities of medium voltage distribution feeders for optimal location of subtransmission substations, we accomplish the following aims:

- Decrement of investment cost; because lower capacity is allocated to some selected substations.
- Decrement of the length of medium voltage feeders; because some loads, instead of supplement

Table 13: Result of proposed algorithm for case study 4 for first time interval

Allocated load centers	Proposed capacity (MVA)	Maximum loading	Present capacity (MVA)	Substation name
Existing subtransmission substation				
l 01, l 04	30	23.82	30	E01
l 02, l 05	30	21.56	30	E02
l 06, l 08, l 15, l 16	45	35.47	45	E03
l 09, l 10	30	23.38	30	E04
l 03, l 11, l 12	45	32.62	45	E05
l 07, l 13, l 14, l 32	45	35.62	45	E06
l 17, l 24, l 33	30	23.16	30	E07
l 19, l 20, l 28, l 30	45	34.99	45	E08
l 18, l 21, l 22, l 23, l 31	45	35.87	45	E09
Chosen candidate subtransmission substation				
l 29 (Feeder Effect)	15	12.00	-	N04

Table 14: Result of proposed algorithm for case study 4 for second time interval

Allocated load centers	Proposed capacity (MVA)	Maximum loading	Present capacity (MVA)	Substation name
Existing subtransmission substation				
l 01, l 06	30	22.25	30	E01
l 02, l 14	30	23.85	30	E02
l 07, l 08, l 16	45	29.49	45	E03
l 10, l 18	30	21.50	30	E04
l 12, l 13, l 19, l 20	45	35.8	45	E05
l 05, l 15, l 31	45	35.92	45	E06
l 09, l 17	30	17.46	30	E07
l 21, l 28	45	30.86	45	E08
l 22, l 23, l 24, l 30	45	32.98	45	E09
l 29	30	15.86	30	N04
Chosen candidate subtransmission substation				
l 03, l 04, l 11	60	42.47	-	N02
l 25, l 26, l 33	75	49.68	-	N07
l 32, l 34, l 35	90	61.73	-	N08
l 36, l 38 (Feeder effect)	45	36.00	-	N09
l 27, l 37, l 39, l 40	90	68.11	-	N010

by far substations, are supplied by existing and near feeders.

CONCLUSION

In this research an efficient comprehensive algorithm for optimal location of subtransmission substations and determination of capacity and service area of substations considering the effects of existing medium-voltage distribution feeders is proposed. At first, a comparative study on optimization algorithms of distribution grid has been performed and then a new model of problem has been described. In this model, the cost related to energy losses in coupling lines of subtransmission substations to upward grid with the possibility to have different values of subtransmission voltages has been presented for the first time. Also, search method based on genetic algorithm to optimize the problem has been proposed. To have faster convergence of genetic algorithm, generation of many illegal cases has been prevented in initial population generation. Using free capacity of medium voltage distribution feeder, to have better optimization is another innovation which is presented for the first time in this research.

The validity of proposed algorithm was evaluated by comparison of results of this method and results of direct search method, in some Case studies.

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