Design Philosophy Revision in Metropolises Distribution System by Comparative Chromosome Genetic Algorithm

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ABSTRACT

The significant values of power losses of low voltage distribution system in Iranian large cities, have been actuated the planning managers to use the small transformers and set them as near as possible to the load points to reduce the LV network. In this paper the correctness of this approach has been evaluated and the optimum ranges for distribution substation capacities with respect to the load density and dispersion in various areas of large cities have been determined. A three stage distribution network planning algorithm based on comparative Genetic Algorithm and prim method has been applied. Various random generated cases for location and values of the load points in different categories of load densities and dispersions have been studied to conclude the reliable relationship between these characteristics of the load and the optimum feeding transformer capacity.

INTRODUCTION

Nowadays the reduction of liquidity for network expansion due to the deregulation procedure besides the significant rate of growth of load density in Iranian metropolitans, high price and difficulty of access to suitable positions for installing new distribution substations are some of the dominant problems which the distribution companies are involved in. In addition it is noticeable that more than half of the distribution losses are due to the LV distribution system. These constraints have made the power system managers to attempt for reviewing the design philosophy to propose the optimal distribution network structure especially for Tehran metropolitan. One of the most popular suggestions in this area is to use of high number of small compact distribution substations just besides the main load points (instead of one large substation) in order to reduce the LV network length and consequently to reduce the related losses.

Regard to the similarity of Iranian distribution network and voltage levels to the European distribution system construction and lack of intermediate voltage (4-11 kV) in MV network in one hand and the congruity of the above mentioned proposed solution with the American distribution network construction on the other hand, the main target of this paper is to investigate the degree of correctness of the above suggestion. In fact, the purpose is to find the optimum ranges for distribution substation capacities with respect to the load density and dispersion. Thus the problem is in fact an optimal distribution network planning problem which is concluded the parts of substation sighting and sizing and LV and MV feeder routing. However, it is very important to solve the problem in the most general form. It means that we have to repeat the optimal planning procedure for a significant number of randomly generated cases with various locations and amounts of load points. It helps to avoid from the especial cases and to conclude the general rules.

In this paper several scenarios for the load distribution in the under-planned area have been generated in the various combinations of the following two categories.

From the dispersion point of view: 1) Low 2) Medium and 3) High dispersion

From the density point of view: 1) Low 2) Medium and 3) High density loads

The combination of these two categories create different classes which would cover every kinds of urban and suburban areas (from low density and high dispersion loads in marginal areas to high density and low dispersion loads in central and most populous areas). In each class the amount and location of load points must be generated randomly too.

Several distribution planning models have been proposed during the last three decades. From the view of considering the substation locating and sizing part and the feeder routing task together (integrated in one routine) or separately (in sequential subroutines), these algorithms would be divided into two categories [1]. However since the integrated routine for both foresaid tasks would increase the number of variables and also the degree of complexity of algorithm considerably, almost all of the integrated algorithms use significant amounts of simplification assumptions and totally the sequential algorithms are preferred by most of the researchers [1-4].

In this paper, a three-stage approach was used to determine the optimal location of substations and medium and LV feeders routing. Genetic algorithm was chosen for proposing the locations of substations in each iteration; The Prim algorithm was applied to MV feeder routing and the LV feeder routing uses of a simple algorithm which will be explained later. The total cost which included the sum of all initial investments and all operational costs were considered as the objective function that must be minimized during the solving procedure. Among the methods of economic evaluation, the annual uniform method was used to split the cost of the initial investment. A supervisory algorithm manages the whole optimization process.

METHODOLOGY

As mentioned above, Genetic algorithm (GA) has been used as the main algorithm for this optimization problem. Since the GA is one of the most well known subsets of evolutionary algorithms, the description about it has been omitted in this paper. Although theoretically, a genetic algorithm has the ability to analyze such optimization problem, but due to the high volume of data, too large chromosome string and hardware and software limitations, a three-stage approach were used to determine the optimal location of substations and medium and LV feeders routing. Thus the substation locating is done by a comparative Genetic algorithm, LV and MV feeders routing are performed by two different subroutines, and the selection of the number of transformers is done by a superior algorithm. It is important to note that the proposed number of substations is variable based on the LV routing restrictions and the superior algorithm decision, and consequently the length of chromosomes in the GA is variable and adaptive with the proposed number of substations. This approach helps to save the memory and time. The mentioned three parts of the procedure are continuously exchanging results with each other and depending on the results; each part can make changes to other parts mechanism.

MV and LV feeder routing

In this paper a simple algorithm has been used for LV feeder routing. Assuming the load point for consumers, each load will connect to the nearest possible substation, with regard to technical restrictions such as the maximum number of outgoing feeders for each substation, the maximum length and current of each feeder and so on. A compensating coefficient has been used in order to consider the slips from the straight paths due to the natural barriers in the city.

The MV feeder routing is indeed a minimum spanning tree problem which is still an open problem in mathematics. For this reason a known method in graph theory, Prim method is selected, improved and finally, for each solution (chromosome) provided by genetic algorithm, the answer of improved method is chosen as MV feeder routing solution. According to the above, it is clear that this solution is not certainly the global optimum and may be a local one.

Prim Algorithm

Prim's algorithm is based on a generic minimum spanning tree algorithm. It slowly grows a minimum spanning tree, starting from a single vertex and adding in new edges that link the partial tree to a new vertex outside of the tree. The Prim's algorithm has the property that the edges in the set *A* always form a single tree. We begin with some vertex *v* in a given graph *G = (V, E)*, defining the initial set of vertices *A*. Then, in each iteration, we choose a minimum-weight edge *(u, v)*, connecting a vertex *v* in the set *A* to the vertex *u* outside of set *A*. Then vertex *u* is brought in to *A*. This process is repeated until a spanning

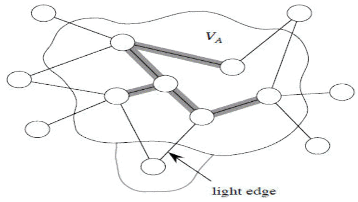

Figure 1- Growing of a minimum spanning tree with prim, Note that the degrees of "A" are shaded.

tree is formed. The Prim's algorithm builds one tree, so *A* is always a tree:

- It starts from an arbitrary "root" r.
- At each step, it finds a light edge crossing cut (VA, V − VA), where VA = vertices that A is incident on, adds this edge to A

Objective Function

As mentioned, the objective function is the sum of the system installation and operational costs.

$$FC = \sum_{p=1}^{P} TC_p + \sum_{m=1}^{M} MVC_m + \sum_{l=1}^{L} LVC_l$$

FC: Fixed cost (Total Capital Cost or initial investment); TC: Total cost of substation development; MVC: Total cost of MV feeder expansion; LVC: Total cost of LV feeder expansion:

The main factor in the operational cost is the total cost of losses that would formulated as follow:

$$LC = \left(\sum_{j=1}^{J} LL_j + OL \times \sum_{i=1}^{I} (NL_i + \alpha_i \times FL_i) \right) \times PP$$

LL: Total cost of losses in MV and LV feeders;
OL: Operational life time of the developed network;
FL & NL: Transformer full-load and no-load losses respectively; α_i*: Loading factor of transformer; PP: Price of unit of electrical energy*

As the final objective function, the total Equivalent Uniform Annual Costs (EUAC) has been considered. For this purpose, the present value of initial investment, in term of the annuity, with interest rate *i* and the effective operational life time *OL* as the number of annuities has been calculated, using the Capital Recovery Factor formula $CRF = {i(1+i)^n} \big/ {(1+i)^n - 1}$.

$$\min EUAC = LC + FC \times CRF$$

$$= LC + FC \times {i(1+i)^{OL}} \big/ {(1+i)^{OL} - 1}$$

i: Interest rate; LC: Total annual loss of system

Subroutines Interaction

Figure 2 shows the relation between three subroutines schematically. At below the relation between the sequential steps of the proposed method and the way of exchanging data between them are briefly explained:

1. At first, the algorithm begins with the minimum number of required substations which would be determined by dividing the sum of whole load in the area into the maximum allowed transformer capacity

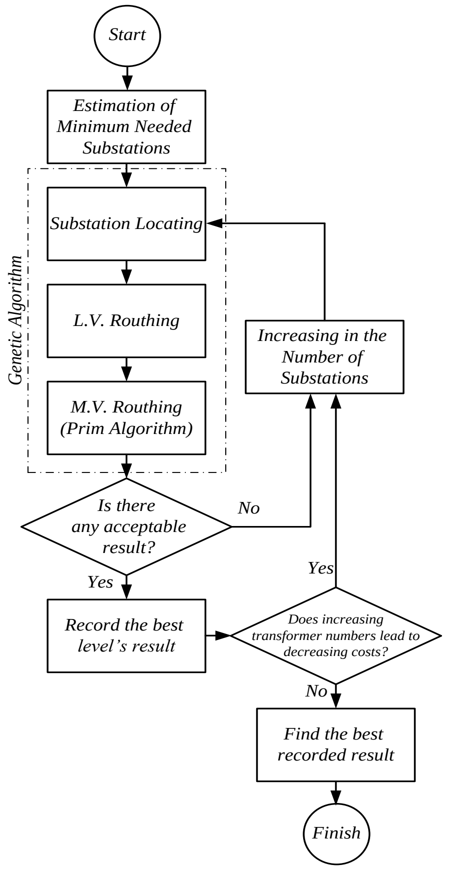

Figure 2- The flowchart of the applied algorithm

2) Optimization algorithm is carried out with determined iterations by considering different constraints in five following stages:

2-1- In each iteration, proposed location for distribution substations is offered according to the possible candidate points and the number of substations which has specified by the master algorithm

2-2- according to the LV feeder routing algorithm, all of the load points are connected to the nearest substation and so capacity of each substation are specified.

2-3- Substations with specific location are fed to Prim algorithm as inputs and MV routing is carried out.

2-4- In this stage after specifying the number of substations and their capacity and corresponding LV and MV feeder routing, and, fitness function in term of the total costs is determined and recorded.

2-5- If there is no acceptable result with the current number of substations, it will be increased and the algorithm returns to the stage 2-1 again. If the termination condition of this part of algorithm is met; the best result will be selected as the output corresponding to the current substation numbers, otherwise the routine should return to stage 2-1.

3) The best result of stage 2 is recorded and the sensitivity of decreasing costs with respect to increasing the number of substations is determined. If this index is positive, stage 2 will be repeated by increasing the number of substation. The GA would adopt the chromosome length of the location of substations with the current conditions.

4) When the ending condition of the master algorithm is satisfied, the best recorded result is suggested as the final result.

SIMULATION RESULTS

As it was mentioned above, the aim of this article is to determine the optimal range of distribution substation capacities with respect to the load densities and dispersions in various points of Iranian large cities. The simulations are in fact the optimum distribution network planning which has been done for a zone with $1000*800^{m2}$ area, by applying the three stages algorithm which was introduced above. Three categories of load dispersions (low, medium and high dispersions) have been considered in this study. From the load density point of view, in each category; sequential steps for load density from $50^{kVA/km2}$ (which represents the outlying loads in suburban area) to $30000^{kVA/km2}$ (which represents the aggregated commercial and residential loads in down towns) has been applied in 25 steps. It is noticeable that the average load densities in different 21 zones of the geographic region of Tehran Distribution Company are shown in Table 1 for comparison.

In each category and for each step of load density, five different cases have been studied by random generation of locations and values of load points. Farthermore in each case, the candidate set of points for distribution substation installation and the set of allowed routes for MV feeders have been generated randomly. Hence the case studies have preserved their random natures exactly.

The results are shown in Table 2 and Figure 3. In fact Table 2 shows the average of the various cases of dispersion. The results clearly indicate the selection of high number of small substations by the optimization algorithm in low density areas and changing the decision making process results toward selecting the significant number of large substations in high density conditions. It is noticeable that the effect of dispersion is not as dominant as the load density. Figure 4 shows schematic variations of the results in a geographical area for two different densities. The results indicate that in many situations, the amount of savings costs due to reduced LV network losses, in comparison to the initial investment costs of installing multiple small transformers is too less or even negligible. Therefore, these results would violate the overall assumption of reducing LV network to achieve minimum cost. The optimum ranges of distribution capacities for various classes of load density are indicated in Table 2 which gives a useful sense about the relationship of the load density with suitable capacities of substations for each area. It concluded that the economical optimum design completely depends on the circumstances and the distribution of the load. It is noticeable that the installation of small transformers in order to reduce the ratio of LV to MV network length is not valid for all situations.

CONCLUTION

This contribution developed a three stage optimal distribution network planning program and applied it for surveying the effectiveness of different defined categories of load densities and dispersions on the optimal ranges of distribution substation capacities in various regions of large cities in Iran. Large variety of case studies have been used in this study to extract the general rules for the relationship between the best capacities of distribution substations and the mentioned characteristics of the load.

Table- 1: The average load density of Tehran Zones

Zone Name	Average Load Density (kVA/km^2)	Zone Name	Average Load Density (kVA/km^2)
Azadi	600	Bahman	4052
Ghods	1013	Sa'adatabad	4176
Tehranpa	1847	Rudaki	5154
Afsariye	2057	Pasdaran	6481
Shemiran	2496	Daneshgah	6555
Sina	3310	Hefdahesha	7179
Narmak	3947	Booali	8752
Farabi	10527	Sohrevardi	11232
Beyhaghi	11719	Molavi	11822
Ferdowsi	15800	Khayyam	19189
Haftetir	1579		

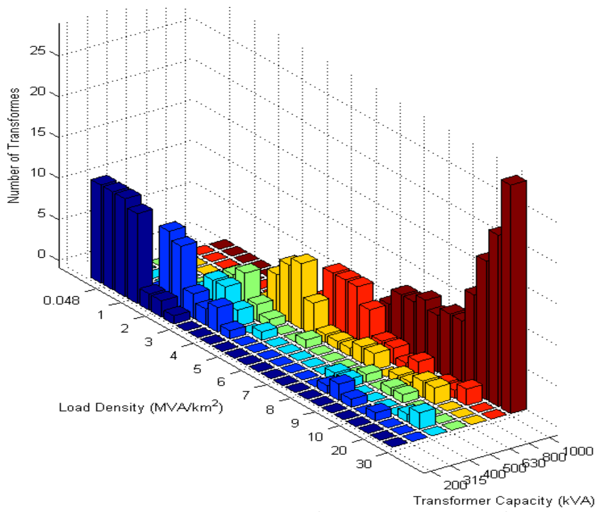

Figure 3- The number and capacity of selected substations for each load density

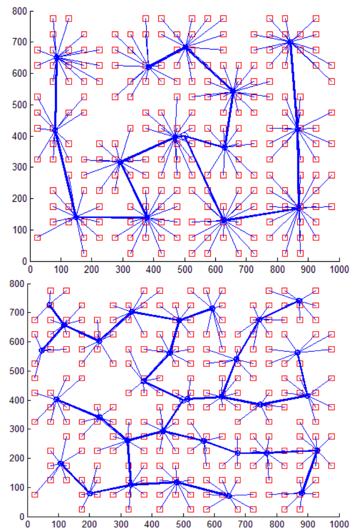

Figure 4- Optimal locations of substations for different load densities,a) $50\boldsymbol{kVA/km^2}$ b) $30000\boldsymbol{kVA/km^2}$

Table 2. The number and capacity of selected substations for each load density

Load Density	Number of Substations							Total Number
	200	315	400	500	630	800	1000	
50	12	0	0	0	0	0	0	12
300	12	0	0	0	0	0	0	12
1000	12	0	0	0	0	0	0	12
1500	11	1	0	0	0	0	0	12
2000	2	9	0	0	0	0	0	11
2500	2	8	2	0	0	0	0	12
3000	1	3	4	4	0	0	0	12
3500	0	2	4	5	1	0	0	12
4000	0	3	2	2	5	0	0	12
4500	0	1	0	1	7	2	0	11
5000	0	0	1	0	8	3	0	12
5500	0	0	0	0	4	7	0	11
6000	0	0	0	1	1	7	2	11
6500	0	0	0	0	1	7	3	11
7000	0	0	0	0	1	5	5	11
7500	0	0	0	0	2	2	7	11
8000	0	0	1	0	2	2	7	12
8500	0	1	1	1	0	1	8	12
9000	0	2	0	0	1	2	7	12
9500	0	1	0	1	1	0	8	11
10000	0	0	0	1	2	1	8	12
15000	0	1	0	0	2	1	12	16
20000	0	0	1	0	0	2	17	20
25000	0	0	2	0	0	0	21	23
30000	0	1	0	1	1	0	25	28

REFERENCES

[1] H.L. Willis, J.E.D. Northcote-Gren,1985, "Comparison of Several Computerized Dist Planning Methods," *IEEE Trans. Power System*, vol. 104.

[2] H. Ahrabian, A. Nowzari-Dalini, 2002, "Parallel Algorithms for Minimum Spanning Tree Problem", *Intern. J. Computer Math.*, vol. 79, 441–448.

[3] H. Temraz, V. Quintana, 1993, "Distribution System Expansion Planning Models: An Overview," *Electric Power Syst. Res.*, vol. 26, 61-70.

[4] G. Thompson, D. Wall, 1981,"A Branch-and-Bound Model for Choosing Optimal Substation Locations," *IEEE Trans. Power System*, vol. 100, 2683- 2688.