OPTIMUM PLANNING OF PRIMARY-SECONDARY DISTRIBUTION NETWORKS ACCORDING TO REAL MUNICIPAL MAPS

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ABSTRACT

Investments in power distribution systems constitute a significant part of the utilities expenses. For this reason, efficient planning tools are required to allow planners to reduce their utility costs. The existing tools however, have very modest considerations to the planning details of the network such as exact length and route of the LV and MV feeders and real and practical size and location of distribution substations. In this paper, an algorithm has been proposed which performs optimization in two MV and LV levels, co-optimizing the size and location of the distribution substations and the size and configuration of the feeders, all results are provided according to the real municipal maps. The algorithm that uses branch exchange technique is tested on three real cases consisting of residential-commercial distribution network and results for one of them are presented. One of the designations made by the algorithm has already installed in the field and confirms the capability of the developed algorithm in practical applications.

INTRODUCTION

Distribution system planning is a combinatorial optimization problem where the objective is to determine the optimum way of supplying a given set of loads. The existing distribution planning models include linear or nonlinear, deterministic or heuristic, continuous or discrete, or mixed- integer mathematical techniques [1-4]. All of these models try to overcome the complexities that were mentioned before. Among these models, the branch exchange techniques have been developed in order to avoid the complexity of practical large-scale optimization problems in distribution planning [1, 5, 6] . The branch exchange method (BEM), basically converts a radial network into a meshed network by connecting the tie lines. The radial structure is restored again by opening some other lines of the network to minimize an objective function. In this paper, the branch exchange technique has been used in the proposed algorithm. However, by making some modifications in the branch exchange concept, the proposed algorithm achieved to a high ability in recognition the distribution network structures. The main feature of the planning procedure proposed here is designing the distribution network, exactly complying with the municipal maps.

PROBLEM STATEMENT

Distribution systems in urban areas are surrounded by city streets and alleys whereas force the network planners to install and extend the distribution systems along the admissible paths inside the city. This necessity would make some of the optimum planned designs be useless if the municipal limitations and city regulations were not observed before. Any neglect in the real city limitations yields the inaccurate results because of two reasons. The first reason is in result of inaccurate feeder length, which is calculated based on direct distance between two ends of the feeder sections. This topic can be seen in Fig. 1. In Fig. 1 (and also Fig. 2) the squares with a cross denote the distribution (MV/LV) substations and triangles denote LV electrical loads. It is worthy to note that some references use a correction factor of transforming the direct distance to real distance, which reduces the errors between real distance and direct distance [7]. However, even using this factor, the errors still exist; because this factor is calculated based on difference between the real distance and direct distance averages and hence, comprises errors for feeder lengths calculation in different configurations.

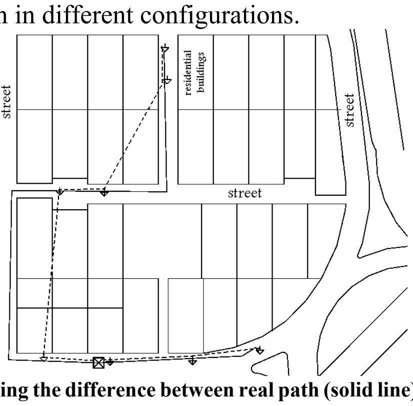

Fig. 1. Showing the difference between real path (solid line) and direct path (dashed line) of feeder in distribution network plan

The second reason that makes the results of such optimization algorithms, which do not consider the municipal maps, be inaccurate is intuitive judgment for network installation in some parts where more than one possibility for the network installation exists. For example, the result of an optimization algorithm yields the feeder with solid line in Fig. 2.

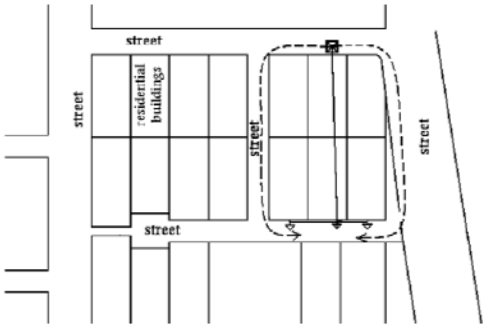

Fig. 2. Feeder path alternatives for an nonimplementable feeder path

As can be seen in Fig. 2, since the feeder has direct path from distribution substation to electrical loads, therefore, it has been passed through the residential buildings and it is apparently clear that this design cannot be implemented and installed. Thus, it is necessary to find alternatives for feeder path. Here, there are two alternatives, which are shown with left side and right side arrows. However, it is not clear that which one of them is the optimal path. In addition, if the related algorithm knew the real path and configuration of this feeder, does it still select this configuration as an optimal configuration? These problems force a requirement to take into account the real municipal maps in the optimum distribution planning process. All of the aforementioned constraints should be implemented in an optimization approach. This approach should also consider other several factors. Some of these factors are power and energy losses, repair and maintenance costs, outage costs, etc. However, there is another factor, to which the attention should be paid and that is the simultaneous design and optimization of primary (MV) and secondary (LV) network; because the researches show that this factor can mainly affect the result of the optimization process [2]. This effect could be salient when the real municipal maps are taken into account. In the following sections of this paper, an approach for responding to this requirement has been described and the results have been presented and compared. The proposed approach has been implemented in software and is going to be used as practical software in the field of distribution network planning in distribution utilities of Iran.

OPTIMIZATION PROBLEM

The problem of optimal distribution system planning is to minimize an objective function under the constraints of:

(1) Line and transformer current capacities,
(2) Voltage drop at each load point,
(3) Demand/supply balance
(4) Radial configuration, and
(5) City regulations, municipal map limitations.

The optimization process is based on minimizing an objective function that should have terms to satisfy the planning goals completely.

OBJECTIVE FUNCTION COMPONENTS

Objective functions that are used in distribution planning problem have two significant parts. One is the *Investment Costs* and another is the *Operational Costs*. The investment costs consist of construction, equipment and other costs which are expended at the start of the distribution system projects. Operational costs are expended during the lifetime of the distribution network and vary during this time. They include the cost of energy losses in the MV and LV networks, the cost of repair and maintenance of distribution substations, circuits and transformers, and the outage costs due to fault occurrence in the network. Regarding to the aforementioned parameters, the objective function is constituted as below:

$$TC = C_f + C_{sub} + C_{EL} + C_{PL} + C_{\text{maintenance}} + C_{outage} \quad (1)$$

Where, TC is total cost, C_f is cost of feeder installation, C_{sub} is cost of substation installation, C_{EL} is cost of energy loss, C_{PL} is cost of power loss, $C_{maintenance}$ is cost of maintenance and C_{outage} is cost of outages.

DISTRIBUTION PLANNING ALGORITHM

Rule of feeder routing according to municipal map

All the possible paths for passing the MV and LV feeders are specified on the municipal map as an input for the planning algorithm by their start and end points. These paths contain streets, avenues and other paths that the feeders could pass along them to energize customers. In order to describe the method of including the municipal maps into the optimal planning process of distribution network, the rule of feeder routing in the modified branch exchange method is explained. This rule is explained using an example (Fig. 3). As shown in Fig. 3, only two distribution substations and one of their feeders are represented (circles are substations and lines are LV feeders).

At the first step, the algorithm traces the branches of the electrical feeders and makes an individual path matrix for each path. The path matrix contains the coordinates of start and end points of the related path branches inserted in each row. For example, the network that is shown in Fig. 3 would have four feeder path matrices just like below:

$$path_{11} = \begin{bmatrix} A(x1, y1) & B(x2, y2) \\ B(x2, y2) & C(x3, y3) \\ C(x3, y3) & D(x4, y4) \end{bmatrix} \quad (2)$$

$$path_{12} = \begin{bmatrix} A(x1, y1) & B(x2, y2) \\ B(x2, y2) & C(x3, y3) \\ C(x3, y3) & G(x7, y7) \end{bmatrix} \quad (3)$$

$$path_{21} = \begin{bmatrix} J(x10, y10) & F(x6, y6) \end{bmatrix} \quad (4)$$

$$path_{22} = \begin{bmatrix} J(x10, y10) & K(x11, y11) \end{bmatrix} \quad (5)$$

Where *Xn* and *Yn* are the x-coordinate and y-coordinate of the start and end point of the feeder branches, respectively. *n* is the index number of points. $Path_{11}$ and $path_{12}$ belong to substation 1 and $Path_{21}$ and $Path_{22}$ belong to substation 2. Now, for performing the optimization process, which is described in the next section, the algorithm will start forming different structures of the network by using branch exchange method (BEM). BEM constitutes a matrix that finds several paths between two different feeders. This matrix is named *intermediate matrix*. The construction of this matrix is similar to path matrixes but starts from the middle or end of a feeder and ends to the end of another one. In each step, one intermediate matrix is constructed and is attached to the path matrices of its two origin feeders. By this method, new configurations will be created. An example of an intermediate matrix regarding to Fig. 3 is shown here:

$$\text{intermediate matrix} = \begin{bmatrix} K(x11, y11) & G(x7, y7) \\ G(x7, y7) & C(x3, y3) \end{bmatrix} \quad (6)$$

If this matrix attaches to $path_{22}$, then $path_{22}$ converts to:

$$path_{22} = \begin{bmatrix} J(x10, y10) & K(x11, y11) \\ K(x11, y11) & G(x7, y7) \\ G(x7, y7) & C(x3, y3) \end{bmatrix} \quad (7)$$

It means that a new configuration has been born which is shown in Fig. 4. Then, all of the planning calculations are performed for this new configuration. The proposed structure for intermediate matrix causes that some configurations, which may not be available in normal branch exchange, is constructed here. In other words, the BEM with mentioned intermediate matrix can seek and specify several paths between two specific nodes of the feeder(s). This capability is because of the fact that BEM can exchange several branches in one step by exchanging the rows of the *intermediate* matrix between *path* matrices. Secondly, unlike the conventional BEM (that branch exchange occurs between two end points of the feeder), this BEM can perform the branch exchange process between two mid or end points and does not have any limitation for selection of points that should be exchanged between feeders. These two main capabilities have enriched the BEM in routing the MV and LV feeders in a real urban area with a real municipal map. At the following section, the optimization algorithm that uses this BEM is explained.

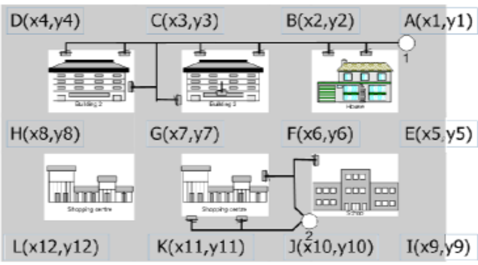

Fig. 3. Schematic view of a distribution LV network

Fig. 4. A new configuration that has been created by BEM

Optimization Algorithm

An iterative algorithm is used for optimization of distribution system planning. The general flowchart of this iterative algorithm is shown in Fig. 5. As can be seen in Fig. 5, in order to achieve the final optimum distribution system plan, there are several internal loops that links the MV and LV designing process to each other and causes that all the designing stages (containing distribution substation sizing and locating, MV and LV feeder sizing and routing) are done reciprocally.

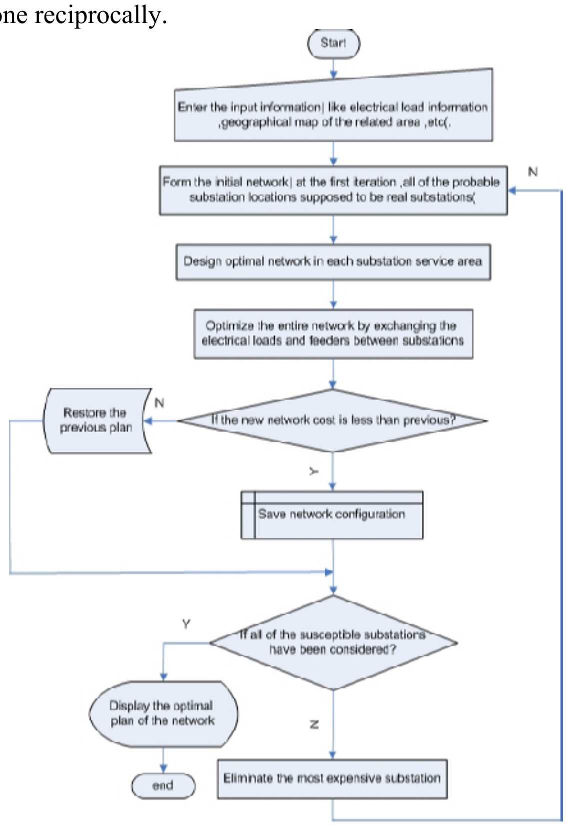

Fig. 5. Flowchart of optimum distribution network planning

RESULTS

The results of applying the proposed algorithm to a real case are presented here. Geographic dimensions of this area are about 250×340 meters. There are 811 residential and commercial consumers with the total load of about 1 MW. In this case, all the candidate locations for distribution substations are 24 places. Two points are suggested for MV T-joint (junction) places. Location of loads, candidate locations for distribution substations and T-joint places are shown in Fig. 6. The optimum LV (400 V) and MV (20 KV) networks are shown in Fig. 7. The trend of cost variation until achieving to the minimum cost is shown in Fig. 8. As shown in this figure, in each stage, the most expensive distribution substation will be found and eliminated until the minimum cost is achieved by 11 distribution substations. Since the objective function of the optimization algorithm consists of power and energy loss costs, these terms also are decreased in the final plan.

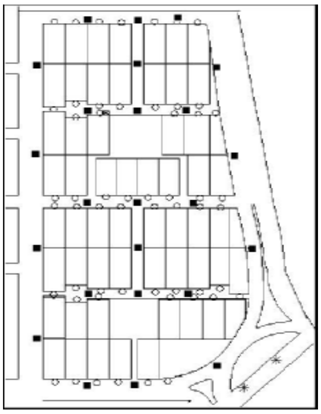

Fig. 6. Location of loads (circles) and candidate locations for substations (black squares) and T-joint places (stars)

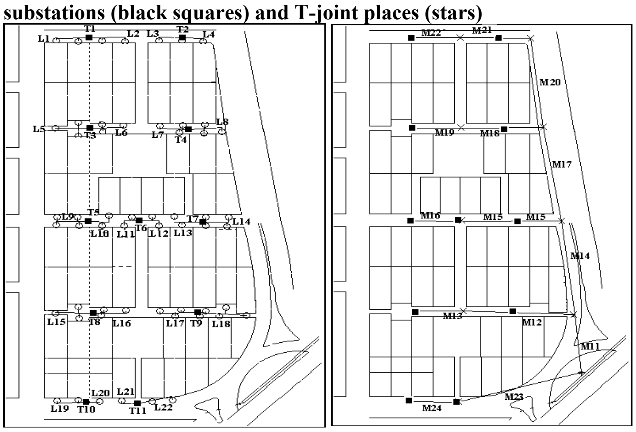

Fig. 7. Optimum designed distribution network (left picture: LV plan, right picture: MV plan)

The network loss results of the optimization process for the aforementioned real case and two other ones are presented in Table 1.

Table 1. result of loss reduction in three real case study

Case study	Energy loss [%]		No. of customers
	Before optimization	After optimization	
CASE 1	6.6	3.0	811
CASE 2	10.5	4.7	1886
CASE 3	11.1	3.6	3429

Case No. 3 of Table 1 is implemented in north-west of Iran through a 4-year project and the network measurements are in good accordance with the values of Table 1. A sample picture of installed network is shown in Fig. 9.

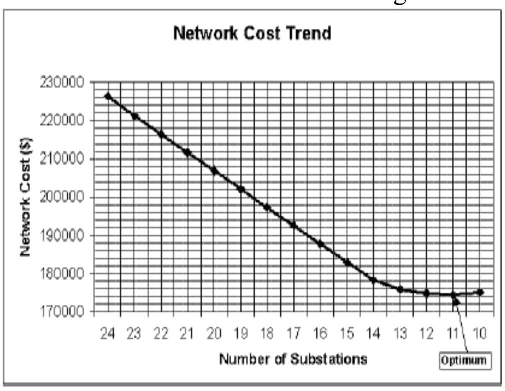

Fig. 8. Descending trend of the network cost, during the designing process

Fig 9. Installed network in north-west Iran, which is designed by the proposed algorithm

CONCLUSION

A branch exchange based optimization algorithm has been presented in this paper. The prominent advantage of the proposed algorithm is the ability of providing the practical plans of distribution networks on the municipal map of the urban areas. This ability can significantly decrease the problems existing in the process of converting the optimal plan from designing step to implementation step. This algorithm also co-optimizes the size and location of distribution substations and the size and configuration of feeders. This optimization is done in two levels (MV and LV networks). A computer program that uses this algorithm is developed and results presented point out the potential of this tool for practical optimum designing of the distribution networks.

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