Chapter 2
Optimal Expansion Planning of Distribution Substations Using Loading Gravity with Genetic Algorithm

Hui-Jen Chuang, Wen-Yuan Tsai, Chao-Shun Chen, Chin-Yin Ho, Chia-Chung Lin and Yi-Pin Tsai

Abstract This paper has presented a methodology to solve the optimal substation capacity expansion problem for distribution system by using the genetic algorithm (GA). The S curve with different time constant is used to represent the load growth of each customer class for the load forecasting of each fence area. The load flow analysis is performed to find power demand of each fence area for annual system operation over the study period. The overall costs of power loss and substation investment are included in the objective function, and each feasible solution is expressed as a chromosome in the GA simulation process. The fitness is then enhanced by considering the diversity of chromosomes so that the global optimization during the solution process can be obtained. The proposed approach has been tested on Taipei Distribution System through the utility data. Test results demonstrated the feasibility and effectiveness of the method for the applications.

Keywords Substation planning · Genetic algorithm · Distribution system

2.1 Introduction

Due to Taiwan's economic development in the past decade, more and more air conditioners are used by the commercial and residential customers, which have resulted in dramatic load growth in several metropolitan areas. To meet load

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demand, and achieve the reliability and efficiency of distribution system operation, substation expansion planning has become a very important issue for Taiwan Power Company (Taipower). To support distribution system planning more effectively, the Outage Management System (OMS) [1] in Taipower, which has stored all of the distribution components with attributes in the Automated Mapping/Facility Management/Geographic Information System (AM/FM/GIS) [2] database, has been applied for load forecasting. Information for all of the customers residing in each fence area is retrieved from the OMS database, and the load demand of the fence area can therefore be derived according to the energy consumption and service types of customers served. The S curve with different time constant is used to represent the load growth of each customer class for the load forecasting of each fence area. The load flow analysis is performed to find power demand of each fence area for annual system operation over the study period. The substation expansion planning has to determine the capacity of substations to meet annual peak demands over the whole planning periods. This becomes a network design problem with a dynamic dimension because of the interaction existing between annual load demands, substations and the different periods to be considered for the global solution.

To solve the problem of optimal substation expansion for distribution systems, the GA is used in this paper to improve the efficiency of simulation process [3–5]. The overall costs of power loss and substation investment are included in the objective function, and all feasible solutions are expressed as chromosomes in the GA. The genetic operators which include crossover and mutation are then processed to produce individual of the population in a feasible space. The fitness is then enhanced by considering the diversity of population so that the global optimization during the solution process can be obtained.

2.2 Problem Description

2.2.1 The Annual Load Forecasting of Each Small Area

According to the historical load demand of different customer classes in Taipower, it will take 7.99, 5.07, 3.8 and 3.2 years for the load demand of the residential area, commercial area, education area and administrative area to reach 63.2 % of the saturated load demand, respectively [6]. The annual load demand of each customer class is then determined by considering the corresponding load growth patterns and the load forecasting of the small area is then obtained by the summation of annual load demands of all customer classes. Figure 2.1 shows load forecasting for each different land use, as well as the whole fence area. It is found that the area load demand becomes saturated after 16 years with load demand of 6590 kVA.

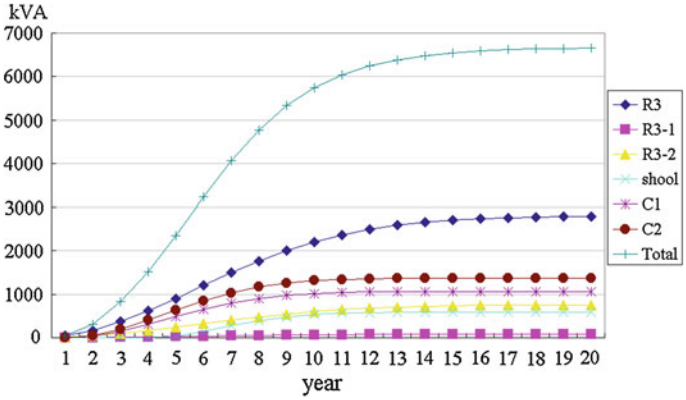


Fig. 2.1 The load forecasting of the fence N6348

2.2.2 *Equivalent Loading Gravity Center*

With the load demand of customers determined by load forecasting for each land base, the gravity method is applied to find the equivalent location of total load demand within each small area by:

$$u_j = \frac{\sum_{i=1}^{n} x_i \times S_i}{\sum_{i=1}^{n} S_i} \tag{2.1}$$

$$v_j = \frac{\sum_{i=1}^{n} y_i \times S_i}{\sum_{i=1}^{n} S_i}. \tag{2.2}$$

Here, S_i represents the load forecast of land base i at location (x_i, y_i) and the corresponding coordinates of loading center of small area j is calculated as u_j and v_j respectively.

2.2.3 *Objective Function*

For the study period of y years with m substations candidates, the total cost of power loading loss and the possible substation investment cost are represented in the objective function as:

$$\min \mathrm{C} = \sum_{y=1}^{y} \left(\sum_{i=1}^{m} \mathrm{X}_{yi} \mathrm{C}_{inv,i} + \mathrm{C}_{loss,y} \right). \tag{2.3}$$

2.2.3.1 Equivalent Power Loss Cost

The cost of power loading loss for the substations to serve the load is represented by Eq. (2.4).

$$\mathrm{C}_{loss,y} = \sum_{k=1}^{m} \mathrm{X}_{yk} \sum_{j=1}^{nm} \left(\frac{\mathrm{S}_{yj}}{\mathrm{V}_{yj}}\right)^2 \times \mathrm{r} \times [(\mathrm{u}_k - \mathrm{u}_j)^2 + (\mathrm{v}_k - \mathrm{v}_j)^2]^{\frac{1}{2}} \times \mathrm{W} \times 8760. \tag{2.4}$$

Here, m is the number of substation for the final target year, nm is the number of fence areas (all the load points), and X_{yk} is the variable of commitment for substation k at year y. The integer variables X_{yk} uses values of 1 or 0 to represent whether substation k is to be taken away or remained in the system, respectively.

2.2.3.2 Investment Cost of Substations

To simplify the substation expansion planning of distribution systems, the standard substation with two main transformer of 2*60 MW has been adopted by Taipower. The procurement cost of main transformers linearly depreciates over their lifetime of 20 years and the capital investment cost of state with j units of main transformers for year i is expressed as:

$$\mathrm{C}_{inv,i} = \frac{\mathrm{I}}{20} \times \mathrm{j}. \tag{2.5}$$

2.3 Genetic Algorithm [3–5]

In this paper, the GA is proposed to find the optimal substation capacity expansion problem by minimizing the overall cost of power loading loss and investment cost of substations for distribution systems. With the GA method, the objective function and feasible substation planning strategies are represented as population in the GA. The genetic operators which include crossover and mutation are then processed to produce individual of the population in a feasible space. The fitness is then enhanced by considering the diversity of population so that the global optimization during the solution process can be obtained.

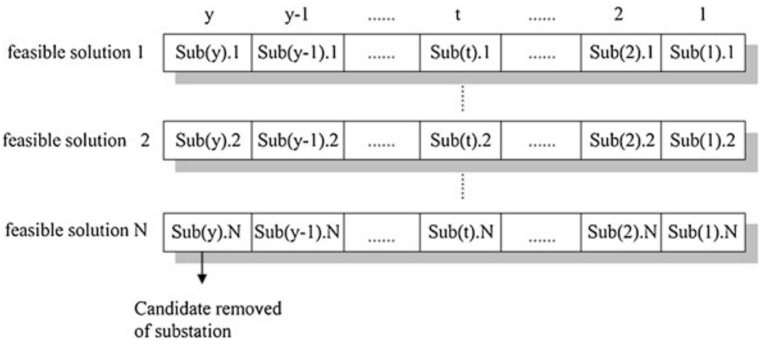


Fig. 2.2 Data structure of GA genes

The data structure of GA genes is depicted in Fig. 2.2, where Sub(y). N represents the candidate number of substations to be removed for year y. For a distribution system with N possible strategies of substation planning over study periods of y years, there will be N feasible solutions with y genes in the pool of genes.

The computsation procedure of GA method is executed as follows:

Step 1: Create an initial population with randomly generated string and set up control parameters of genetic algorithm.
Step 2: Evaluate all of the individuals with the objection function.
Step 3: Select a new population from the old population based on the fitness of the individuals as given by the evaluation function.
Step 4: Apply genetic operations of mutation and crossover to members of the population for creation of new solution.
Step 5: Evaluate the newly created individuals.
Step 6: Check if termination criteria are met. If not, go to Step 3. If yes, output the results.

2.4 Numerical Analysis and Results

To improve the operation efficiency of distribution systems, the unit commitment of main transformers must occur to provide sufficient capacity to meet the loading demand and maintain service reliability for annual power loading over the study years. After that, the GA algorithm is used to solve the optimal expansion planning of substations to achieve the minimization of investment cost. To demonstrate the effectiveness of the proposed methodology, the distribution system of Taipei City District of Taipower is selected for computer simulation.

Figure 2.3 shows the installation locations of standard substations with a capacity of (2*60 MVA) for the target year in Taipei City area. There are 23

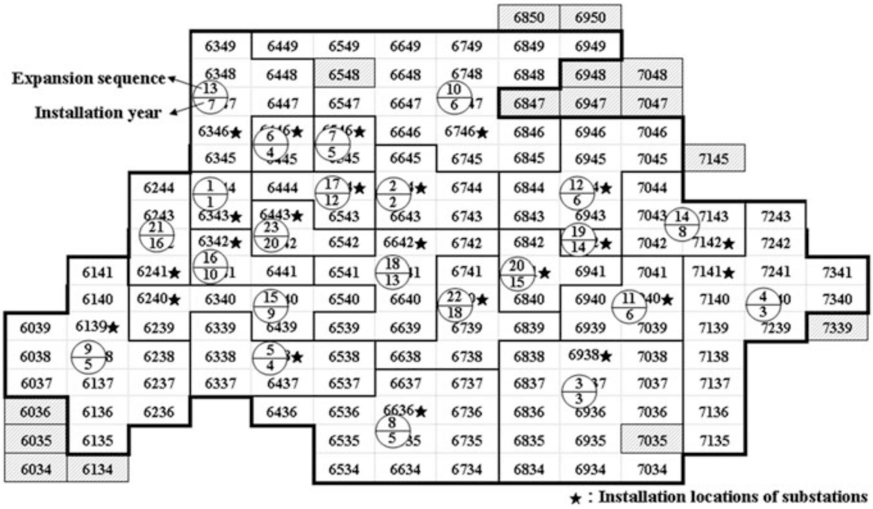
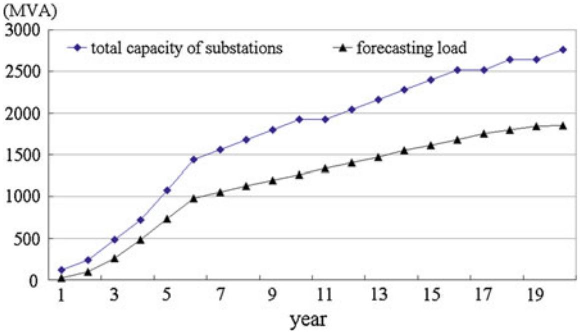


Fig. 2.3 The optimal expansion planning of distribution substations for Taipei City by GA methods

Fig. 2.4 Load forecasting and total capacity of distribution substations to be installed over the study years



substations required to cover the saturated loading of 1894 MVA. Each substation serves several fence areas. For the downtown area with high load density, one substation may serve only two fence areas. For the outskirt area with light load density, one substation may serve more areas.

With the installation of substations to cover the load demand for the final target year, the expansion sequence of substations is derived according to the annual load forecasting of each fence area. After formulating the objective function by considering the investment cost of main transformers and power loading loss of substations to serve the load demand of each fence area, the GA method is then applied to derive the proper year for each substation to be committed. The investment cost of $4.27 M for a main transformer with 60 MVA capacity is used in Eq. (2.3) for the objective function. In this paper, the proposed GA algorithm is implemented with Matlab on a Duo CPU 2.4 GHz personal computer. In the GA method, the feasible solution pool, the crossover rate, and the mutation rate are 100, 0.8, and 0.1, respectively, based on the simulation of various case studies in this paper. The total system cost has been obtained as \$133.3 M by GA methodology, the GA method is converged after 39 generation. $\frac{\mathrm{Y}}{\mathrm{X}}$ in Fig. 2.3 shows that the substation should be committed in year X with expansion sequence of substation Y. For instance, a new substation should be installed in fence 6642 in year 13. With the annual load growth in each fence area, new substations are installed when the loading factor of existing substation is greater than 70 % of the main transformer capacity and the service areas of each substation are adjusted accordingly to minimize power loading loss. Figure 2.4 shows the annual load forecasting of Taipei City and the capacity of substations over the study years.

2.5 Conclusion

In this paper, the unit commitment of substations to serve the power demand of distribution system in Taipei Taiwan has been proposed. The Genetic Algorithm has been applied to derive the proper expansion planning of substations by minimizing investment cost of substation without violation of operation constraint. The S curves with different time constants are applied to represent load growth for each customer class for the forecasting of annual load within each fence area. The objective function which has been formulated by considering the annual power loading loss and investment cost of main transformers over the study years. By using the GA algorithm, the optimal unit commitment strategy of substations has been solved to achieve best cost effectiveness of expansion planning of substations. With the proposed capacity expansion planning, the minimization of total system loss has been achieved.

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