Original Article

Time-Based Development Plans on a 17-Bus Radial Distribution Network with Genetic Enhanced Algorithm

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ABSTRACT

In this paper, a time-based model for distribution network development planning is proposed, considering the possibility of using distributed electricity generation technologies and the existence of capacitor banks. The proposed model specifies the location, capacity, and timing of the use of distributed generation technologies and capacitor banks as well as the schedule for increasing the capacity of the grid lines. The Genetic Enhanced Algorithm is used to solve the stated problem to optimize the network development plan including the time, location and capacity of DG and capacitor banks in the distribution network as well as to optimize the investment cost and operating cost. It was also implemented in a MATLAB programming environment to validate and evaluate the effectiveness of the proposed solution to the problem of distribution network development planning on a 17-bus radial distribution network.

Introduction

The purpose of planning the development of the distribution system is to strengthen it by adding new equipment to meet the growth in load consumption at the lowest possible cost and with the most reliable reliability. In the overall planning process of power systems integrated at the production, transmission and distribution levels, network load growth must first be anticipated in the coming years so that network development can be done correctly.

After performing load prediction, the amount of power generation increase is studied to increase the capacity of existing plants or build new ones if needed. For this purpose, finding the right points for deployment of new power plants is of great importance because if the new plants are not deployed in the right places, the cost of operating the network will be higher. One of the important points to note after this step is to increase the capacity of the new posts and lines. For this purpose, each of the stages of development of substation and transmission line planning is carried out with the aim of

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minimizing the cost of development and meeting network needs [1-10].

Given the significant advantages of electric power over other energies, it is predicted to be simple and convenient for long-distance distribution and transferability, with the largest energy consumption in the next century being electricity and the distribution network responsible for providing electricity. Consumers, as one of the main components of the power system, are of great importance and value. In a power system, it typically accounts for half of the losses in the distribution network, and distribution networks are expanding as demand for power increases.

The annual investment in this field amounts to billions of dollars. Inadequate financial resources in this sector, inappropriate design, and operation strategy, as well as the prevalent culture of craftsmanship, have made the country's distribution networks unsuitable. Thus, when the two factors, namely large-scale investment and losses, come together, it will be clear that reforming even a small part of the design methods of this system will lead to a fundamental change in power distribution companies.

The purpose of the design principles of distribution networks is to provide a design that guarantees the growing need for electric power in a technically and economically acceptable manner. Thus, the design of the distribution system, on the one hand, is related to load growth parameters, spatial distribution of consumption points and on the other hand, to technical factors such as the values of lines and feeders, the capacity and location of the over-distribution substations, the desired voltage levels, and reliability levels.

Also, economic aspects such as the cost of purchasing and installing equipment, the cost of annual energy losses, interest rates, and so on, must be taken into account to be viable. To thoroughly examine the distribution networks that ultimately lead to the design of the proper principles and methods for their design, it is necessary to determine the structure of the network throughout the power system [11-15]. In a power grid, the power generation capacity passes through the transmission grid to the transmission grid through substations, where it travels to the grid-connected to the grid after crossing the grid.

The total power passing through each post should not exceed the maximum permissible capacity of the equipment installed in the post, such as motor transformers, switches, rails, etc. On the other hand, the growth of loads or the construction of DGs may cause problems for existing posts. In this case, the development of existing posts or the construction of new posts on the network can improve the network status. The amount of load that is delivered by each distribution post depends on how the distribution network is arranged and the layout of the substation.

Therefore, scheduling the development of posts will not be complete without removing the limitations of the lines. In the development of substation planning, it should be specified how much and at what time the equipment capacity of the network substations should be constructed and added to the existing set of networks [16-18].

The Objective Function

The objective function of the proposed model to solve the stated problem is to minimize the total investment and operation cost of the distribution network and DG units and capacitor banks over a specified planning period. Project investment costs include the cost of DG units investment, the cost of capacitor banks investment and the cost needed to increase the capacity of the distribution lines. Operating costs also include the cost of energy purchased from the upstream grid and the cost of operating the DG. In short, the objective function (OF) is:

$$OF = INC + OC \qquad (1)$$

In this respect, INC is the total investment cost including DG investment cost, capacitor investment cost, and feeder reinforcement cost, and total operating cost (OC) includes the cost of purchasing power from the upstream grid and the maintenance cost of DGs in Equation (1). INC details are as follows:

$$INC = \sum_{t=1}^{T}\sum_{i=1}^{N_{LB}} \beta(t) \times \{[IN_{DG} \times \left(S_{DG,i}^{M} + BK\right) \times \sigma_{DG,i} \times \left(M(t - IY_{DG,i} + 1) - M\left(t - IY_{DG,i}\right)\right)] + [IN_{CAP} \times \left(C_{CAP,i}^{M}\right) \times \sigma_{CAP,i} \times \left(M(t - IY_{CAP,i} + 1) - M\left(t - IY_{CAP,i}\right)\right)] + [B_{r,i} \times \sigma_{R,i} \times (M(t - VY_i + 1) - M(t - VY_i)]\} \quad (2)$$

This relationship consists of three parts, the first part of which is the cost of DG investment. The second part deals with the cost of investing capacitors and the third part about the cost of reinforcing feeders.

In relation (2), the decision variables $\sigma_{DG\ i,t}$ and $\sigma_{CAP\ i,t}$ represent the presence or absence of DG in the bus *i* and the presence or absence of capacitor C in bus *i*, which are binary variables. Also, the variables $S_{DG,i}^{M}$ and $C_{CAP,i}^{M}$ indicate the DG installation capacity of bus *i* and the capacitance (C) installed in bus *i*, which are integers. These decision variables are determined by the optimization algorithm. IN_ constant (DG) is the investment cost of DG and IN_{CAP} is the capacitor investment cost. The investment cost is obtained by adding the annual investment cost over the planning period. A DG is also considered as an extra backup (*BK*) (for emergencies). Also, the function *β(t)* of the financial cost-conversion function in year *t* is equivalent to its present value as follows:

$$\beta(t) = \frac{1}{(1+d)^t} \quad (3)$$

If $IY_{DG\ i}$ and $IY_{CAP\ i}$ are determined by the algorithm as DG installation year and capacitor installation year, then the DG investment cost and capacitance will be as follows:

$$\beta\left(IY_{DG,i}\right) = \frac{1}{(1+d)^{IY_{DG,i}}} \quad (4)$$

$$\beta\left(IY_{CAP,i}\right) = \frac{1}{(1+d)^{IY_{CAP,i}}} \quad (5)$$

In the third part of the equation, which relates to feeder reinforcement cost, VY_i represents the year of increasing the capacity of the bus line *i* and $B_{r\ i}$ the cost of increasing the capacity of the bus line *i* and also the variable $\sigma_{R,i}$. The choice of whether or not to select bus *i* is to increase capacity, is also a binary variable. The details of the *OC* operation part in relation (6) are as follows:

$$\text{OC} = \sum_{t=1}^{T} \beta(t)[\sum_{k=1}^{N_{kk}}(US_{t,k} \times LD_k \times CS_{t,k}) + \sum_{i=1}^{N_{LB}}\sum_{k=1}^{N_{kk}}\left(OPC_{DG} \times S_{i,t,k}^{DG} \times LD_k\right)] \quad (6)$$

$$US_{t,k} = SS_{t,k} + Sloss_{t,k} - \sum_{i=1}^{N_{LB}}\left(S_{i,t,k}^{DG}\right) \qquad \forall k \in N_{kk}, \forall t \in NY \quad (7)$$

$$Sloss_{t,k} = \sum_{i=1}^{N_{LB}}\sum_{j=i+1}^{T} Lf((V_{i,t,k} - V_{j,t,k}) \times I_{ij}^{*}(t,k)) \qquad \forall k \in N_{kk}, \forall t \in NY \quad (8)$$

Relation (6) also consists of two parts, the first part being the cost of purchasing energy from the upstream grid. Each DG unit is assumed based on its operating costs compared to other available power sources (such as upstream or other power supplies), where $US_{t,k}$ and $CS_{t,k}$ the active power purchased from the upstream grid, respectively, and the price of electricity at the load level *k* of year *t*, and LD_k is the time constant of the load level *k*, expressed in hours. In the next section of this relationship, OPC_{DG} shows maintenance costs for DG units. Backups will be excluded from this calculation assuming maintenance costs are free and used only in emergencies. $S_{i,t,k}^{DG}$ represents the output power of DG at bus *i* and at the load level *k* of year *t*, expressed in KW [19-21].

Proposed Algorithm Optimization Method

In this algorithm, they are first classified as primary populations by generating a set of random variables, including DG locations and capacitor locations as well as their installation time. These decision variables then move on to the next optimization to obtain their optimal capacity. This step is accomplished using the proposed model by adding a compound cost value (objective function value) to each decision variable, which represents the proportion and best DG capacities and capacitors capacities. Obviously, since the algorithm used in this problem processes binary variables, after changing the binary variables and the integer available for each algorithm response, the integer variables are converted to their equivalent binary form. Here the constraints of the problem are examined, and if the obtained parameters apply to the defined constraints, the values obtained are accepted and entered into the next step of the algorithm, otherwise they are removed from the set of possible problem solvers and then proceed to the next step of the algorithm. In this way, the algorithm continuously searches to satisfy all constraints defined in the problem and minimizes the objective function without violating the constraints [22-25]. As stated above, after generating acceptable initial populations, they are ranked based on their fitness values and some are selected for intersection and mutation stages. After the intersection and jump operations, a new generation is obtained that is referred to the optimization process for the best value and evaluation of the fit value. New solutions are selected by combining the best of them into new and old populations. This method is repeated frequently and the best response is stored at the end of each iteration so that the last iteration can be solved. Figure 1 shows the structure of the optimization algorithm.

System studied

In this paper, a 17-bus radial distribution network is intended for simulation. In this grid, a 23KV feeder with 17 bus, including 16 bus and a slack bus, is provided from the 63.23kV substation as shown in Figure 2. The specifications of this system are presented in Table 1. Also, the planning period and annual growth rate are 4% and 5%, respectively. Gas generators are used as DG units with DGs installed capacity of 3, 2, 1 and 4MW combined with one MW units and their investment costs 0.89 M$/MVA at a rate of 10 $/MWh. It is assumed for the maintenance costs of the units. Also, a 1 MW unit is considered as a reserve unit that does not include maintenance costs. The annual cost of 5.5 $/KVar capacitance and the cost of generating active power at 120 $/KW peak as well as the cost of power purchased from the upstream grid 0.7541$ were considered. The heat capacity of grid feeders is 12 MW for 0.15 $M/km to strengthen each feeder [25-28].

Analyzing the Results of the Proposed Algorithm

The numerical results obtained for the best response of the proposed 17-bus distributed programming problem-solving method are shown in the following analysis. In the simulation performed in this section, the effectiveness of the proposed genetic algorithm for solving the problem of distribution network development planning is evaluated. For this purpose, the results of the proposed algorithm are implemented for the 17-bus system. Table 2 shows further details of the optimal solution algorithm for the 17-bus system. In the development planning problem, DGs determine the capacity and position of the DG for each year from the planning horizon and the capacity and position for each of the capacitor banks as well as the feeder reinforcement time along the development planning horizon.

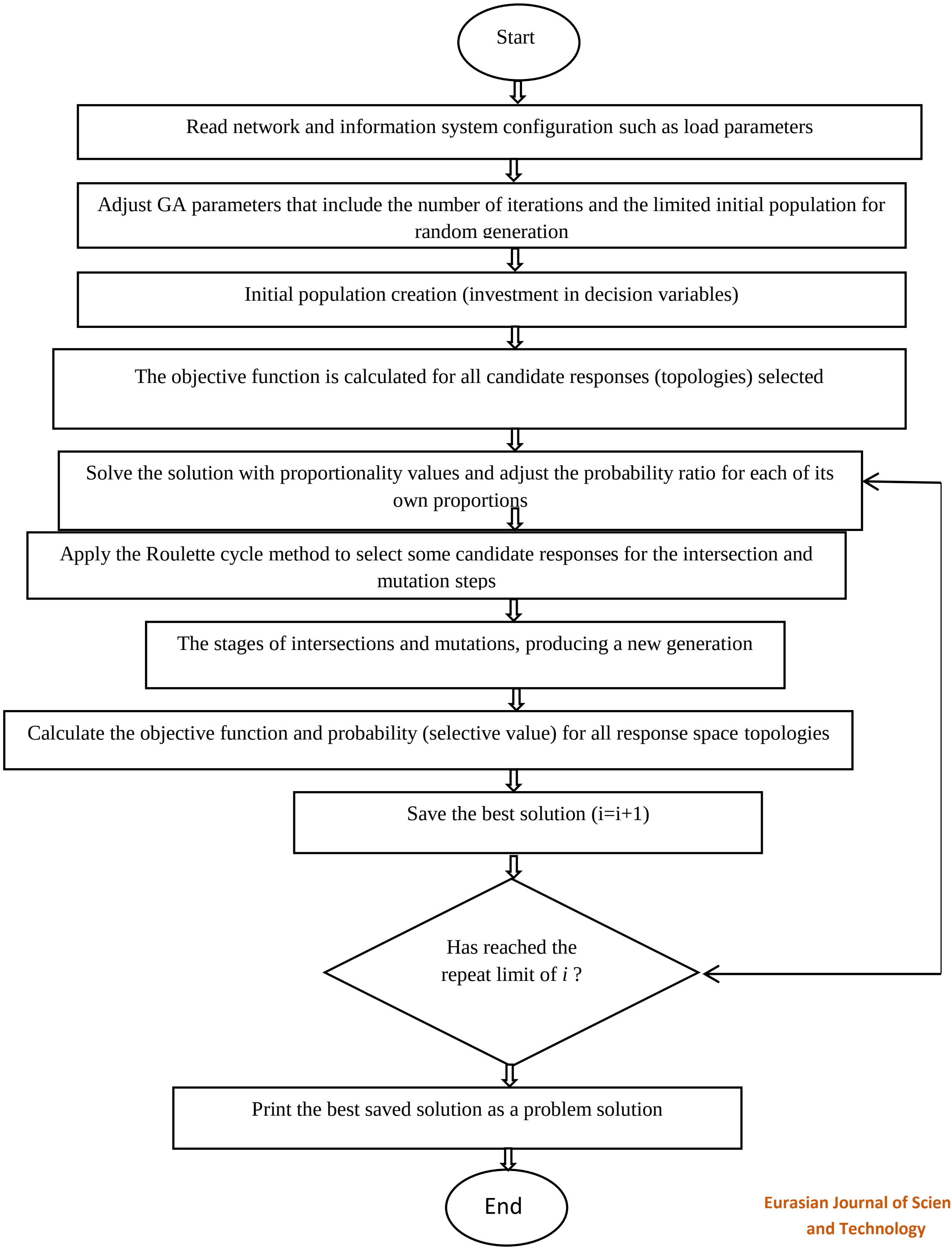

Figure 1 Optimization algorithm structure

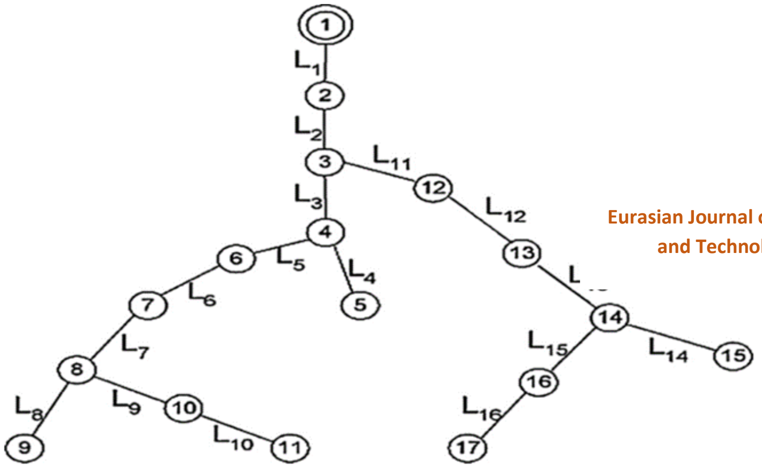

Figure 2 Single-line diagram of 17-bus distribution system

Table 1 Parameters used for 17-bus network

Bus Number	From	To	R(ohm)	X(ohm)	P(MW)	Q(MW)
1	1	2	0.05	0.05	0.8	0.6
2	2	3	0.11	0.11	0.8	0.6
3	3	4	0.15	0.11	0.8	0.6
4	4	5	0.08	0.11	0.8	0.64
5	8	6	0.11	0.11	1.2	0.16
6	6	7	0.04	0.04	0.8	-0.16
7	7	8	0.80	0.11	0.6	0.48

Table 2 Numerical results of the best response by proposed genetic algorithm solution in 17-bus distribution network

The cost of increasing the capacity of the lines	0.8474
Cost of electricity purchased from upstream grid	7.3651
DG Investment Cost	1.5621
DG operating cost	0.08712
Capacitor bank investment cost	0.7214
Price losses	0.9632
Location planning, capacity, and optimal year of installation with DG	Second year:-- Third year:--
Optimal location, capacity, and year of installation of the capacitor bank in the planning horizon	First year:-- Second year:-- Third year:-- Fourth year: 1.2 and 0.83MVAr in line 4 and 7
Schedule for increasing the capacity of the lines	First year: Lines 3 and 8 Second year: Lines 6 and 14 Third year: Line 12 Fourth year: Line 7, 9, 10 and 15
The objective function (OF)	10.2631

Conclusion

This paper presents a new model for the problem of distribution network development to determine the optimal design of distribution network development over a specified period using distributed generation technologies and the existence of capacitive banks. Planning the development of distribution networks is a multivariate optimization problem involving both a spectrum of discrete and continuous decision variables. As such, the objective function of the proposed model is equivalent to minimizing the total investment and operational costs of the project using the proposed solution method. Also, the technical constraints governing the network, capacitor banks and DG units make the above model a nonlinear, rugged and complex integer optimization problem. So, solving this problem with conventional analytical methods would be a complicated task. For this reason, in this paper, a genetic algorithm solution is used to minimize the total cost by choosing the best solution. The proposed model and solution method was implemented on a 17-bus distribution network.

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