Development and testing of the genetic algorithm to select a scenario of distributed generation power supply system

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Abstract. The rapid development of small distributed energy economy requires the justification and design of methods and models for planning the development of energy systems using distributed generation sources. We have studied the possibility of using the genetic algorithm to solve the problem of selecting a scenario of distributed generation power supply system. To do this, a problem-solving mechanism was developed in the MATLAB environment based on the genetic algorithm and its program code was built. In order to test the created genetic algorithm for a hypothetical large consumer of electrical and heat power with typical load curves, an optimal scenario of a power supply system based on distributed generation was searched. The analysis of the calculation results carried out using the proposed algorithm, evaluation of the model's behavior when the initial data changes, indicate its efficiency and effectiveness.

1. Introduction

Consumers’ transition from the solely centralized power supply to the use of on-site generating plants for full or partial meeting the needs of heat and electrical power is an actively developing global trend [1–3]. One of the reasons for the increased popularity of small distributed energy is the economic benefit associated primarily with increasing the energy efficiency of facilities and the reliability of their energy supply [4, 5], and the systemic impact for the region’s energy system as a whole [6, 7].

The problem for selecting a scenario of the distributed generation (DG) power supply system is difficult due to the infinite variety of possible solutions, a number of which is provided for a large number of factors influencing the selection result [8–10]. So, for example, if the implementation of on-site generating facilities is considered to meet the need for electric and heat power with the possibility of placing one to five generating plants at five different sites, then, conventionally speaking, the problem comes down to analyzing of many thousands of scenarios. The final result depends on many factors, such as load curves, technical limits (capacity of transformers and transmission lines, equipment location, fuel supply, etc.), customer’s economic opportunities, long-term plans, etc. There are no analytical solutions of problems of this kind, and search of all possible scenarios requires an enormous amount of machine time and can only be used in practice for solving the elementary problems with a small number of possible scenarios.

Based on the previous experience, the authors study the possibility of using a genetic algorithm to optimize a distributed generation power supply mains.

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2. Problem definition
The modeling problem is to determine the optimal distribution generation mains structure (selection of a location, a number and type of DG sets) taking into account the possibility of purchasing energy from the utility company and selling excess energy to a third-party consumer under the market conditions. It is necessary to take into account the integer variables (a number of sets and their rated power row), probability of local extremes of the objective function, uneven and in many cases stepwise and intermittent changes in the system properties, a large number of different scenarios of a number, type and location of the blocks. Methods of selecting and designing power supply systems using various optimization techniques are widely described in the literature [11–14].

2.1. Objective function
As a rule, the DG implementation does not require a large scope of construction and commissioning works, therefore, investments in building of power plants and their commissioning are carried out in one year, and sometimes – in months. The generation implementation to cover own needs does not bring profit in an explicit form, and the effectiveness of such measures should be evaluated in the form of savings compared to the cost of purchasing energy from the utility company. In case the excess energy may be purchased to a third-party consumer, this should be taken into account when calculating.

As a optimality criterion, the minimum of reduced costs was adopted [15]:

\[ C_{R} = \frac{1}{T} \cdot I + C_{op}, \]

where \( C_{R} \) is the total investment in the construction and commissioning of the DG facility; \( C_{op} \) are annual costs, also taking into account the sales proceeds from the electric or heat energy to a third-party consumer, and the estimated cost of purchasing the consumed energy from the utility company without using the distribution generation DG (to determine savings); \( T \) is a design service life or other estimated length of time.

2.2. Limitations
When optimizing the DG mains, taken into account the following limitations [16, 17]:
- for a number of sets on one site and final number of equipment sites, it is also necessary to ensure that these values have a non-negative value;
- for a power lines capacity determined by the long-term permissible current, therefore, when building a model, it is necessary to check the condition that the transmission is not overloaded;
- generator power can not take negative values
- equality at any time of generation and consumption power (taking into account a power received from and delivered to the mains).

3. Method
A common and extremely effective method for solving problems of optimization and modeling of complex systems is the genetic algorithm (GA). The principles laid down in the GA are simple, in many cases, they are similar to the processes occurring in populations of living beings [18, 19]. The search for a solution associates the evolution with its characteristic generation of individuals, mutations, and natural selection.

The main stages of building the genetic algorithm are described in detail in the literature and are listed below [20–22]:
- formation of a new generation;
- objective function calculation;
- sorting individuals according to their degree of fitness;
- cross operation;
- mutation;
• completion (stop) of the calculation.

Parameters of the developed GA: population size – 1000 individuals; a proportion of descendants in the population – 20%; a proportion of mutant individuals in the population – 35%; stop criterion – 4.

To build the model, the MathWorks development environment and the MATLAB programming language were chosen. This software product has a built-in function that implements a genetic algorithm, however, as part of the study, for the most complete and deep understanding of the method used, the GA was built using open code. A similar approach allowed for detailed monitoring of the calculation parameters, to perform the necessary intermediate results that are necessary for program debugging and analyzing the effectiveness and applicability of the GA method for solving the problem.

4. Calculation results

4.1. Calculation conditions

A large electrical and heat power consumer, which has the typical curve of electrical and heat loads, and is located at a some distance from large cities, was selected as a calculation example. Rates and prices for resources, equipment and fuel are determined as typical values of these indicators for the European part of Russia.

To study the possibility for using the model to solve the given task, the calculations were carried out under the following scenarios:

• “Scenario 1” – the initial data for calculations under the baseline scenario are given in Table 1-5, the scenario provides for the possibility of transferring excess heat and electrical power to third-party consumers.

• “Scenario 2” – compared to the first scenario, there is no possibility of transferring excess heat and electrical power to third-party consumers.

• “Scenario 3” — compared to the first scenario, the gas rate was increased by 20%.

Table 1. Parameters of cogenerators which are being used.

| Grade          | Power, kW | Price, thous. rub. | Weight, kg |
|----------------|-----------|--------------------|------------|
| Caterpillar G3512 | 770       | 27866              | 9166       |
| Caterpillar G3508 | 510       | 9560              | 7626       |
| Caterpillar G3412C | 360       | 7640              | 6356       |
| Caterpillar G3406 | 103       | 4120              | 4082       |

Table 2. Initial calculation parameters.

| Parameters                                  | Value      | Unit of measurements |
|---------------------------------------------|------------|----------------------|
| Period under review                         | 6.5        | year                 |
| Electrical efficiency of cogenerators       | 0.391      | p.u.                 |
| Heat efficiency of cogenerators             | 0.447      | p.u.                 |
| Rate for connection to electric mains       | 18.578     | thous. rub./kW       |
| Rate for mains redundancy                   | 15.5       | thous. rub./kW       |
| Rate for power purchase                     | 0.00353    | thous. rub./kWh      |
| Rate for power supply                       | 0.0015     | thous. rub./kWh      |
| Natural gas price                           | 5747       | rub./thous. m³       |
| Parameters                          | Value  | Unit of measurements |
|------------------------------------|--------|----------------------|
| Rate for heat power purchase       | 1.62   | thous. rub/Gcal      |
| Rate for heat power supply         | 0.52   | thous. rub/Gcal      |
| Winter share in year duration      | 0.6    | p.u.                 |

Table 3. Maximum consumer load and maximum possible number of sets in the network nodes.

| Node   | Maximum electrical load kW | Maximum heat load Gkal/h | Maximum possible number of sets (a number of sites) |
|--------|----------------------------|--------------------------|-----------------------------------------------------|
| No. 1  | 630                        | 0.62                     | 3                                                   |
| No. 2  | 1860                       | 0.83                     | 3                                                   |
| No. 3  | 762                        | 0.31                     | 2                                                   |
| No. 4  | 926                        | 0.41                     | 2                                                   |

Table 4. Length of communication between the network nodes, m.

| Indicator                                      | Value |
|------------------------------------------------|-------|
| Length of communications between the connection point and the first node | 600   |
| Length of communications between the connection point and the second node | 400   |
| Length of communications between the second and third nodes | 400   |
| Length of communications between the second and forth nodes | 550   |

Table 5. Daily load curve factors.

| Schedule       | Electric load curve factors | Heat load curve factors |
|----------------|-----------------------------|-------------------------|
| Winter-day     | 0.95                        | 0.9                     |
| Winter-night   | 0.25                        | 0.9                     |
| Summer-day     | 0.7                         | 0.15                    |
| Summer-night   | 0.15                        | 0.15                    |

4.2. Calculation results

Basic results of calculation performed with the developed algorithm are given in Table 6.

Table 6. Calculation results.

| Indicator | Scenario 1 | Scenario 2 | Scenario 3 |
|-----------|------------|------------|------------|
| Installed capacity, kW: |            |            |            |
| Assembly No. 1 | 1530       | 1020       | 1020       |
| Assembly No. 2 | 1530       | 1020       | 1020       |
| Assembly No. 3 | 1020       | 1020       | 1020       |
| Assembly No. 4 | 1020       | 1020       | 1020       |
| Indicator                          | Scenario 1       | Scenario 2       | Scenario 3       |
|-----------------------------------|------------------|------------------|------------------|
| Generator type                    | Caterpillar G3508| Caterpillar G3508| Caterpillar G3508|
| Fuel costs, thous. rub.           | 58761.9          | 31097.2          | 70754.4          |
| Cash flow from the electric power purchase/sale (“+” costs, “-” revenue), thous. rub. | -37917.6         | -                | -24514.7         |
| Cash flow from the heat power purchase/sale (“+” costs, “-” revenue), thous. rub. | -21181.3         | 3942.6           | -15699.5         |
| Given annual costs, thous. rub.   | 26775.9          | 54681.9          | 55598.1          |

The performed studies allow making a conclusion that the model adequately presents the properties of the electric power system under studying.

In the first scenario, despite the extremely low rate value for power supply to a third-party consumer, it is rational to supply an energy part to the mains, which indicates the low cost of power produced at its own power station based on gas engine generators. For comparison note that annual costs for facility power supply would be 66,212 rub, when powered from the mains as per the adopted rate. The most profitable was the use of Caterpillar G3508 generating sets with nominal capacity of 510 kW. This result is a consequence of the lowest specific investments.

The inability to transfer excess electrical and heat power energy to third-party consumers in the second scenario led to decreasing the installed capacity. The total installed capacity of the sets is 4,080 kW, which is sufficient for self-sufficiency with the peak load of 3,969 kW preset by the initial conditions. An amount of generated heat energy by means of cogeneration to cover the facility needs is not enough; in this case it is most efficient to purchase heat from the utility company.

The gas prices increase in the third scenario led to increasing in operating costs in terms of fuel costs. The scope of electrical and heat energy supplied to third-party consumers has decreased in comparison with the first scenario, which is explained by the increase in the prime cost of own production of energy resources. The construction and operation of two “additional” sets in this scenario is inexpedient.

5. Conclusion
In this study, the genetic algorithm was developed and tested to select a scenario of distributed generation power supply system. To implement the algorithm in the environment MATLAB, the program code was created. The genetic algorithm has showed extremely high efficiency in solving these problems; its flexibility and versatility make it possible to adapt the mathematical model to absolutely any design conditions. The GA is the only method for optimization of the mathematical model without any restrictions on the objective function type.

The work is the result of synthesis of knowledge in various fields of science, such as economics, energy and computer.

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