The use of GA in the problems of circuit-mode optimization of electrical networks

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Abstract. A method for determining the optimal state of the electrical network according to the criterion of minimum active losses using a genetic algorithm is presented. The algorithm is implemented in the programming language Visual Basic. The advantages of the proposed approach in comparison with the brute force are the reduced brute force required to determine the optimal scheme, the flexibility of setting the user controlled values. The practical significance lies in the possibility of implementing the approach of a distribution grid company and solving optimization problems in a timely manner. The algorithm was tested on 10-35 kV electrical network diagrams.

1. Introduction

Electricity losses are the most important indicator of the efficiency of the electrical network. The level of electrical energy losses depends on the level of efficiency of electrical networks, namely: reliability and uninterrupted power supply to consumers, power quality, tariffs and profits of grid companies.

Despite the presence of a large number of measures to minimize the total losses in the electrical network, the most effective in practice is the improvement of network operation modes, since this measure does not require significant costs and is easily implemented under the conditions of the existing power supply system. One of the methods with this approach is the normal opening of a number of branches of the electrical network and (or) the commissioning of branches in reserve.

In most cases, in practice, the position of the structural change sites is determined empirically, based on personal experience and intuition of the maintenance personnel, so as to ensure the necessary operating conditions or the possibility of the quick restoration of power supply in an accident [1].

If this problem is solved by brute force, each branch can have four states: 0 - enabled, 1 - disabled, 3 - open at the end, 4 - open at the beginning. Therefore, the number of possible network states is calculated by the formula:

\[ N_{BF} = 4^n \] (1)

where \( n \) - the number of branches that can be changed.

Due to the large number of possible network options, the exhaustive brute force algorithm requires significant computational resources and time to calculate the mode parameters [2-3]. The use of a genetic algorithm (GA) will reduce the search by eliminating individuals with a fitness-function value that is higher in the process of optimization than in an individual with the best fitness-function during the entire calculation period. Reducing the enumeration will allow to solve the tasks for real time [4-7].
2. Implementation GA

We introduce into consideration for each \( i \) (\( i = 1, N \)) node:
- \( U_i \) - nodal voltage determined by the calculation mode, kV,
- \( U_{\text{min}}, U_{\text{max}} \) - permissible limits of change of the nodal voltage, kV,
- \( \Delta U_i \) - deviation of the node voltage from the nominal, %,

for each \( j \) (\( j = 1, L \)) branches: \( I_{\text{load},j} \) - branch load current, %, and for mode parameters:
\( \Delta U_{\text{min}}, \Delta U_{\text{max}} \) - maximum permissible deviation of nodal voltage, %.

Consider also:
\{\( N_{\text{Mark}} \)\} - variety of nodes, which can be entered or derived from the design scheme in the optimization process;
\{\( N_{\text{Stat}} \)\} - variety of markers for all the nodes of the scheme, showing the current state of the node (the node is connected to the scheme or the node is disconnected to the scheme);
\{\( N_{\text{Control}} \)\} - variety of nodes where the effective voltage value is monitored;
\{\( L_{\text{Mark}} \)\} - variety of branches, which can be entered or removed from the design scheme in the optimization process;
\{\( L_{\text{Stat}} \)\} - variety of markers for all branches of the scheme, showing the current state of the branch (on, off, open at the beginning, open at the end);
\{\( L_{\text{Control}} \)\} - variety of branches in which the control of the current load of the branch is performed.

The variable to be optimized is determined by the vector \( p = (p_1, p_2, \ldots, p_j)^T \in L \) - the state of the branches of the scheme, called chromosome in the framework of the accepted terminology. Each \( p_j \) variable in the chromosome plays the role of a separate gene, where the genes of the assigned vectors are the set of possible branch states. The minimized functionality (fitness-function) \( \Delta P(p) \) is the value of the total active network loss. The association “chromosome + fitness-function” is an individual, and the totality of all individuals \( (p_j, \Delta P(p_j)) \) forms a population.

In view of the global minimum \( \Delta P(p) \) is located in the vicinity of the chromosome, all genes of which specify the position of the branch "on", we will take it as the initial parent chromosome.

In the proposed evolutionary style, the population, the individual of which has the best indicator \( \Delta P(p) \) during the entire evolutionary process, acts as a parent, the generation of a new generation is carried out in two ways: by crossing and mutation. The method of chromosome formation is chosen randomly with a 70% mutation probability. The number of new individuals in each generation is taken equal to the number of branches.

In the case of crossing, a pair of individuals from the parental generation is randomly selected, the chromosomes of the parents are torn at one random point and the resulting sections are stitched crosswise in the chromosomes of two descendants. An example of the implementation of the cross is shown in figure 1, a.

For the emergence of new genes in the chromosomes of descendants (changes in the values \( p \)), a mutation is applicable. During mutation, some genes in the chromosome of an individual are changed to a value that is different from the value in the parent individual. For the number of mutating genes \( n_{\text{mut}} \), we take the number of marked branches. An example of mutation implementation is shown in Figure 1, b.
For each chromosome of the new generation, we will make a calculation $\Delta P(p)$ and we will check that the calculated parameters fall into the boundary conditions. In the case when at least one of the parameters does not correspond to the established limits, we will decrease the chromosome survival rate by adding to the value of its fitness-function $10^6$. Such an event will reduce the possibility of the current population to participate as a parent. In the case when in the current generation the individual with the best survival $\Delta P(p)$ rate is higher than the analogous individual of the parent generation, we reduce the number of mutating genes by one, when calculating the next generation. The stopping criterion is $n_{mut} = 0$ [8-9].

The number of iteration of the genetic algorithm will find the formula:

$$N_{GA} = n_{min} n_{gen},$$  \hspace{1cm} (2)

where $n_{gen}$ - number of generations.

3. Results of application of GA and their discussion

The algorithm is implemented in the programming language Visual Basic. Calculation of modes produced in the RastrWin3. A 35 kV electrical network was considered with the voltage control of all nodes in the range $\pm 10\% U_{nom}$ and the monitoring of the current load of all branches:

Table 1 shows the network optimization parameters.

| Number of generations | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   | 11   |
|-----------------------|------|------|------|------|------|------|------|------|------|------|------|
| $\Delta P_{min}$, MW  | 2.097| 2.097| 1.241| 2.097| 1.232| 1.236| 1E+6 | 1.232| 1.232| 1.236| 1.236|
| Number of mutating genes | 7    | 7    | 7    | 6    | 6    | 5    | 4    | 3    | 2    | 1    | 0    |

The initial and optimal schemes are shown in Figure 2.
Analysis of the results showed that the maximum voltage deviation is -9.1% at node 4, maximum current load of 24% in branch 2-5. The optimal individual is found in the ninth generation. Active losses in the optimal scheme are lower by 0.861 MW compared to the original.

We also give the results of GA operation for the 10 kV network presented in figure 3. Let us set the limits of permissible voltage $\pm 5\% U_{\text{nom}}$ at nodes 5, 7, 8. Current load control and their status mark are set in all branches.

Table 2 shows the network optimization parameters.

| Number of generations | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|-----------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|
| $\Delta P_{\text{min}}$, MW | 7.5 | 8.3 | 1E+6 | 2E+6 | 2E+6 | 6.1 | 6.1 | 6.1 | 6.1 | 7.5 | 7.5 | 6.1 |
| Number of mutating genes | 10 | 9 | 8 | 7 | 6 | 6 | 6 | 5 | 4 | 4 | 3 | 2 | 1 | 0 |

The initial and optimal schemes are shown in Figure 3.
Analysis of the results showed that in the generations 3-5 and 8, the value of the voltage deviation in node 5 does not fall into the specified, which led to an increase in fitness function. The maximum deviation of the voltage of the controlled node in the optimal scheme is 9.4% at node 5, the maximum current load is 32% in branch 3-4. The optimal individual was found in the sixth generation. The fitness function of the optimal individual is lower by 1.4 MW in relation to the reference one.

4. Conclusion
Analysis of the GA operation showed that as a result of its operation, the monitored values are in the specified ranges, the losses in the optimal circuit are reduced by 0.861 and 1.4 MW, respectively. Determine how many times the number of enumeration was reduced when calculating GA, than when calculating BF:
- for 10 kV network: $\frac{N_{BE}}{N_{GA}} \approx 220$;
- for 35 kV network: $\frac{N_{BE}}{N_{GA}} \approx 7500$.

In view of the significant reduction in the number of enumeration, it can be concluded that the tasks assigned can be solved in operational time, which amounted to 3 and 5 seconds for the schemes presented, respectively.

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