Optimization of energy supply schemes using GA

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Abstract. Presented a methodology for determining the optimal configuration of electric circuit by criterion of minimum active power losses in circuit using genetic algorithm. The advantage of the proposed approach is the reduction of number of operations required to calculate the parameters of the electric network mode and as a result increase the speed of search. The theoretical significance lies in the possibility of explicit determination of sensor elements when defining nodal loads by resistances. Practical significance lies in the possibility of applying the approach by electric grid organizations. The algorithm is tested on a model of an electric network with a voltage of 110 kV.

1. Introduction

Power losses are the most important indicator of the efficiency of the electrical network. The magnitude of losses is an indicator of the efficiency of the electric grid and tariffs and profits of grid companies depend on their level.

In practice the level of losses can be controlled by changing the parameters of elements equipped with adjustment devices the introduction of flexible alternating current transmission systems (FACTS), changing the structure of power supply [1].

The power supply structure of most modern circuits is the result of alternately connecting individual nodal loads as they appear to the current network configuration. Changing the structure can not only reduce losses in the circuit but also provide the best indicators of quality and reliability of electricity.

A configuration change should be understood not only as the elimination of inefficient nodal connections but also the creation of new.

The minimized value in the work adopted the level of active losses in the circuit. The optimized variable is the vector of longitudinal resistances of the power elements of the power grid. The transverse conductivities will be calculated according to their longitudinal resistances.

According to the results of calculating the optimized variable the mathematical model of the network configuration may undergo changes - the number of columns will increase which corresponds to the formation of new internode links or the number of columns will decrease - the exclusion of inefficient connections. The best parameters of power elements for existing connections can also be determined [2-4].

In order to reduce the number of complete enumeration, optimization should be carried out using a genetic algorithm [5-8].
Due to the constancy of the values of nodal loads during optimization, they are introduced into the calculation by the values of their resistances. This approach will reduce the number of operations required to calculate and control the mode parameters.

2. Implementation

The mathematical model of the network configuration is a matrix, the number of rows of which corresponds to the number of nodes in the circuit; the number of columns is the number of its branches. To calculate the optimal power supply scheme, it is proposed to increase the number of columns of its mathematical model to the maximum possible level of connectivity of nodes.

Note that in order to create one inter-node connection, two nodes are required, then the maximum number of branches \( N_{\text{max}} \) in the circuit is defined as the number of combinations from the set of circuit nodes \( q (q=2, N) \) in 2:

\[
N_{\text{q}}^2 \frac{q!}{2(q-2)!} \max
\]

where \( ! \) - symbol of factorial function.

Define a matrix \( A_{\text{max}} \) with maximum connectedness of nodes. It represents the supplemented original matrix \( A_{\text{orig}} \) by the number of columns \( N_{\text{new}}=N_{\text{orig}}+N_{\text{max}} \), where \( N_{\text{orig}} \) is the number of columns of the matrix of the original configuration, \( N_{\text{max}} \) we calculate by the formula (1). In added columns should indicate relationships that are missing from \( A_{\text{orig}} \).

We introduce for each i \((i=1,N)\) node:
- \( X_i \) - circuit node abscissa;
- \( Y_i \) - ordinate of the circuit node.

Then the lengths of each \( k (k=1,N_{\text{max}}(i)) \) relationship are determined by the formula:

\[
L_{mn,k}=[(X_m - X_n)^2 + (Y_m - Y_n)^2]^{1/2}
\]

where \( L_{mn,k} \) - length of section between nodes \( m \) и \( n \); \( X_m, X_n \) - abscissas of nodes \( m \) и \( n \); \( Y_m, Y_n \) - their ordinates.

Consider the same:
- \( Z_{\text{tabl}} \) - tabular linear resistance vector;
- \( Y_{\text{tabl}} \) - tabular transverse conductivities vector.

Note that in \( Z_{\text{tabl}} \) and \( Y_{\text{tabl}} \) should be included with the same indices elements \( \infty \) and 0, respectively. This will eliminate the connection between the elements in the optimal configuration plan, based on the values of the optimal resistance vectors of the sections.

To calculate the parameters of new sections or change the brand of existing wires, we use the formula:

\[
Z_{\text{opt},k} = L_{mn,k}Z_{\text{tabl},k}
\]

\[
Y_{\text{opt},k} = L_{mn,k}Y_{\text{tabl},k}
\]

To control the mode parameters, we introduce:
- \( \{N_{\text{NControl}}\} \) - many of nodes in which the monitoring of the actual voltage value is performed;
- \( \{L_{\text{LControl}}\} \) - many of branches in which the current load of the branch is controlled.

In order to reduce the operations required for calculating the mode parameters, we introduce node loads into the equivalent circuit of their resistances. To do this we should initially calculate the node voltage of the original circuit:

\[
\hat{U}_y = -Y_y^{-1}(J_y + U_d^{-1}S_y)
\]

where \( Y_y \) - matrix of node conductivities of the original circuit; \( J_y \) - column vector of currents of current sources.
Then the resistance of load is determined by the formula:

\[ Z_{\text{load}} = U_d^{-1} S_y \]  

(6)

where \( S_d \) - diagonal matrix of load of node; \( U_y \) - vector of voltage of node; \( * \) - symbol of conjugate.

To account for loads by resistances, it is necessary to expand the number of branches of the matrix \( A_{\text{max}} \) and the number of rows of the vector of resistance of branches \( Z_{\text{branch}} \).

The number of additional columns matrix \( A_{\text{new}} \) will correspond to the number of nodes in the circuit due to the addition of links between network nodes and zero potential. Then the new matrix of compounds will be formed by augment of \( A_{\text{max}} \) and the diagonal unit matrix \( E \):

\[ A_{\text{new}} = \text{augment}(A_{\text{max}}) \]  

(7)

The vector of new branch resistances will also be formed by stack \( Z_{\text{branch}} \) and \( Z_{\text{load}} \). In this case, the resistance of the branch containing the power source is assumed to be zero.

\[ Z_{\text{new}} = \text{stack}(Z_{\text{branch}}, Z_{\text{load}}) \]  

(8)

Then the vector of voltage of node will be calculated by the method of nodal potentials:

\[ \dot{U} = (A_{\text{new}} \dot{Z}_{d,\text{new}} A_{\text{new}}^{-T})^{-1} A_{\text{new}} \dot{Z}_{d,\text{new}}^{-1} \dot{E} \]  

(9)

where \( \dot{E} \) - vector RMS of AC power.

Current vector in the branches of the circuit:

\[ \dot{I} = \dot{Z}_{d,\text{new}}^{-1} (\dot{U} + \dot{E}) \]  

(10)

Power loses in branches:

\[ \Delta S = U_d \dot{I}^* \]  

(11)

where \( \dot{U}_d \) - diagonal matrix of voltage of node.

Elements \( \Delta S_k \) represent power losses in the power elements of the circuit. The remaining elements are power generation capacities and load of nodes. Thus, active losses in the circuit

\[ \Delta P = \sum_{n=1}^{N_{\text{max}}} \sum \text{Re}(dS_n) \]  

(12)

The optimized variable is determined by the vector \( \dot{Z}_{\text{opt}} \) - the parameters of the force elements, which is called the chromosome in the framework of the accepted terminology. Each variable \( Z_{\text{opt},k} \) in the chromosome plays the role of a separate gene, where the genes of the given vectors is the set of possible parameters of power elements. The minimized functional (fitness function) is the value of the total active losses in the circuit \( \Delta P(\dot{Z}_{\text{opt}}) \). The combination «chromosome + fitness function» is an individual, and the totality of all individuals forms \( (\dot{Z}_{\text{opt}}, \Delta P(\dot{Z}_{\text{opt}})) \) a population.

The number of new individuals in each generation is assumed equal \( N_{\text{max}} \). For each individual of the first generation, its chromosomes are randomly assigned from the elements of the vector \( Z_{\text{tabl}} \). When calculating a fitness function, the vector elements \( Y_{\text{opt}} \) will be the vector elements \( Y_{\text{tabl}} \) whose indices correspond to the indices \( Z_{\text{tabl}} \). If the calculated parameters of the regime do not match the required, the individual will be excluded from the population. We will sort the individuals in ascending order \( \Delta P \). We will take individuals with the best (minimum) value of the fitness function as parents for the formation of descendants.

The generation of a new generation is produced in two ways: crossbreeding and mutation. The method of chromosome formation is randomly selected with a probability of mutation of 70%.
In the case of crossing, a pair of individuals from the parent generation is randomly selected, the chromosomes of the parents are broken at one random point, and the resulting regions are stitched crosswise in the chromosomes of two descendants. In the case of a mutation, an individual will be randomly selected and replaced with an excellent chromosome.

We will continue the evolution process until 10% of the generation have the same set of chromosomes, which is an indicator of the predominance of optimal individuals.

Upon completion of the optimization, we will refine the matrix $A_{new}$. To do this, check the elements of the $Z_{opt}$ vector. In the case when the element of the vector $Z_{opt}$ is equal $\infty$, it is necessary to exclude the column of the corresponding index from the matrix $A_{new}$ and the element of the same index from the vector $Y_{opt}$. After refinement, the matrix $A_{new}$ is optimal.

3. Results of application

For the approbation we use the scheme figure 1, a with the number of nodes $q = 4$. For it $N_{max}$. In figure 1, b shows scheme where load of nodes is given by resistances.

The steps for converting the network configuration matrix are shown below.

$$A_{vect} = \begin{pmatrix}
1 & 1 & 0 & -1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
-1 & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 0 & 0 \\
0 & -1 & 1 & 0 & -1 & 0 & 0 & 1 & 0 \\
0 & 0 & -1 & 1 & 0 & -1 & 0 & 1 & 0 & 0
\end{pmatrix}$$

Table 1. Coordinates of nodes.

| Element | ST | SST1 | SST2 | SST3 |
|---------|----|------|------|------|
| X, km   | 40 | 40   | 20   | 60   |
| Y, km   | 30 | 10   | 50   | 40   |

Table 2. Lengths of branches.

| Branch  | ST - SST1 | ST - SST 2 | ST - SST 3 | SST 1 - SST 2 | SST 1 - SST 3 | SST 2 - SST 3 |
|---------|-----------|------------|------------|--------------|--------------|--------------|
| Length, km | 20      | 28        | 22        | 45          | 36          | 41          |

Table 3. Tabular values.

| Wire mark | $\hat{Z}_{tabl, \text{OM/kM}}$ | $\hat{Y}_{tabl, \text{mKCM/kM}}$ |
|-----------|--------------------------------|----------------------------------|
| AC-70/11  | 0.428+j0.444                   | -j2.55                           |
| AC-95/16  | 0.306+j0.434                   | -j2.61                           |
| AC-120/19 | 0.249+j0.427                   | -j2.66                           |
In table 4 and table 5 parameters of the source circuit is showed.

**Table 4.** Nodes parameters.

| Node  | P, W | Q, Var | h, µOhm⁻¹ | U, kV   | φ, °  |
|-------|------|--------|------------|--------|-------|
| ST    | 0    | 0      | 0          | 116.8  | -4    |
| SST 1 | 35   | 14     | -165.3     | 112.686| -4.675|
| SST 2 | 24   | 9.6    | 534        | 113.485| -4.3  |
| SST 3 | 1    | 0.4    | 0          | 114.478| -4.207|

**Table 5.** Branches parameters.

| Node       | R, Ohm | X, Ohm | B, µOhm⁻¹ |
|------------|--------|--------|-----------|
| ST - SST 1 | 10.5   | 8      | -102.4    |
| ST - SST 2 | 18.4   | 16     | -100      |
| SST2 - SST 3 | 5    | 7      | -43.75    |
| SST3 - ST  | 12     | 14     | -179.2    |

In table 6 load resistance is showed.

**Table 6.** Load resistance.

| Node      | SST1       | SST2       | SST3       |
|-----------|------------|------------|------------|
| Z_{load}, Ohm | 312.76+j125.1 | 462.6+j185 | 11297.598+j4519 |

The optimal configuration is shown in figure 2. In table 7 and 8 is showed parameters of the optimal scheme.

![Figure 2. Optimal scheme.](image)

**Table 7.** Nodes parameters.

| Node  | U, kV | φ, °  |
|-------|-------|-------|
| ST    | 116.8 | -4    |
| SST 1 | 113.17| -4.675|
| SST 2 | 113.45| -4.567|
| SST 3 | 114.5 | -4.388|

**Table 8.** Branches parameters.

| Node       | R, Ohm | X, Ohm | B, µOhm⁻¹ |
|------------|--------|--------|-----------|
| ST - SST 1 | 10.5   | 8      | -102.4    |
| ST - SST 2 | 18.4   | 16     | -100      |
| SST2 - SST 3 | 5    | 7      | -43.75    |
| SST3 - ST  | 12     | 14     | -179.2    |
| SST1 - SST 2 | 15.4 | 16     | -92       |
| SST1 - SST 3 | 19.26 | 19.98  | -114.8    |

4. Conclusion

As a result of approbation the genetic algorithm, it was required to improve the chromosomes of individuals for three generations. As a result, the optimal configuration plan corresponds to the scheme with maximum connectivity of nodes.
Active power losses of the original network were 1.75 MW, optimal 1.59 MW. Thus, the relative losses decreased by 0.16 MW, the absolute decrease is 9%.

Acknowledgments
We express our gratitude and deep appreciation to RFBR for support under contract № 19-38-90316.

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