Investigation of the Algorithm Optimization of Electric Power Regimes According to Voltage and Reactive Power with the Use of Penalty Functions Method

INVESTIGATION OF THE ALGORITHM OPTIMIZATION OF ELECTRIC POWER REGIMES ACCORDING TO VOLTAGE AND REACTIVE POWER WITH THE USE OF PENALTY FUNCTIONS METHOD

A A Volovikov and A A Yudin

Department of Power Engineering and Automation, Belgorod State Technological University of V.G. Shukhov, Belgorod, 308012, RU

Abstract. The article is devoted to the investigation of the algorithm for optimizing the steady-state regimes of electric power systems and networks for voltage and reactive power based on the application of the penalty function method. The results of the study are illustrated by the example of a 14-node test design scheme. Based on the analysis of the calculation results, conclusions are drawn about the effectiveness of this algorithm for optimizing the modes of closed-loop networks.

At present, when managing the modes of electric power systems and networks, the main attention is paid to ensuring reliable supply of electric energy of required quality to consumers in accordance with the Rules for the installation of electrical installations, the interstate standard GOST 32144-2013 "Electricity. Compatibility of technical means electromagnet. Norms of quality of electric energy in general-purpose power supply systems "and other normative documents. However, an equally important task is to minimize the costs [1] associated with ensuring the functioning of electric power systems and technological processes for the production, conversion, distribution and consumption of electricity [2], which acquires special significance after the adoption in 2009 of the Federal Law # 261- Fedaral Law "On Energy Saving and on Increasing Energy Efficiency and on Amending Certain Legislative Acts of the Russian Federation".

So, for example, in the calculation of network tariffs, the main attention is paid to the distribution of costs of electric grid companies by voltage classes, determining the losses of electric power and power, and distributing them among electric stations and consumers for the formation of prices. The issues under consideration are especially relevant for the energy sector, taking into account the new conditions for its market functioning and the use of modern information technologies [3]. Consequently, the study of algorithms for determining optimal steady-state regimes, that is, such admissible under the technical constraints regimes for which the optimization objective function takes the smallest value, is of great practical and theoretical importance.

The purpose of this paper is to investigate the algorithm for optimizing electric power regimes for voltage and reactive power based on the application of the penalty function method [3].

The optimization of the voltage and reactive power mode is used to determine the voltages at the nodes of the electrical network that are sources of reactive power. Most often, sources of reactive power are used to reduce the loss of active power and maintain the voltage within the required limits [4]:

$$U_{i\,\min} \leq U_i \leq U_{i\,\max}, \qquad (1)$$

where U_i is the *i-th* monitored voltage value;
$U_{i\,min}$, $U_{i\,max}$ – minimum and maximum monitored voltage values.

Allowance for inequality constraints greatly complicates the optimization calculation. With the development of computer technology for solving optimization problems, methods of non-linear programming are widely used. Consider one of these methods, which is implemented in the software and computing complex RastrWin3, designed to solve problems in the calculation, analysis and optimization of the modes of electric power systems and networks [4].

It should also be noted that this software and computer complex allows you to perform optimization not only for voltage and reactive power, but also for the coefficients of transformation of regulated transformers and autotransformers. In this paper, this feature is not considered.

The calculation of the regime in the admissible region corresponds to the determination of the minimum of the objective function:

$$\Psi = \Delta P + \Sigma PF_i = \Sigma \Delta P_{ij} + K_j \Sigma \delta U_i^2, \qquad (2)$$

where ΔP – total losses of active power;

PF_i – penalty functions, which are introduced when the constraints (1) are violated by the voltages in the nodes;

ΔP_{ij} – active power losses in branch i–j;

K_j – penalty coefficient, the value of which is chosen empirically;

δU_i – violation of constraints (1) for stresses in nodes, which is defined as follows

$$\delta U_i = (U_i - U_{i\,max})/U_{i\,max}, \text{ if } U_i > U_{i\,max};$$

$$\delta U_i = 0, \text{ if } U_{i\,min} \leq U_i \leq U_{i\,max};$$

$$\delta U_i = (U_i - U_{i\,min})/U_{i\,min}, \text{ if } U_i < U_{i\,min}.$$

The losses of active power in the circuit branch can be calculated on the basis of the values of the modules U_i, U_j and the angles δ_i, δ_j of the voltage at the beginning and end of the branch i–j, respectively:

$$\Delta P_{ij} = (U_i^2 + U_j^2 + 2U_iU_j\cos(\delta_i - \delta_j))G_{ij},$$

where G_{ij} – active conductivity of the branch i–j.

The minimum of the objective function (2) is determined by changing the voltage modules and the reactive power of the generating units – reactive power sources:

$$Q_{gi\,min} \leq Q_{gi} \leq Q_{gi\,max}; \qquad (3)$$

$$U_{gi\,min} \leq U_{gi} \leq U_{gi\,max}. \qquad (4)$$

The optimal values of the voltages U_i, which are independent variables, are determined as a result of the iterative process.

At each step of the iteration process, the following quantities:

1. The admissible direction of the greatest decrease in the objective function (2):

$$\Delta S = \Delta U_g.$$

2. Direction of change of dependent variables (ΔQ, ΔU, $\Delta \delta$) when the independent variables change in the direction ΔS.

3. From the conditions determined by the inequalities (1), (3), (4), the largest permissible step λ_{max} is calculated in the direction ΔS.

4. The function Ψ values are calculated in the following points: $\Psi(S)$, $\Psi(S+(\lambda_{max}/2)\Delta S)$, $\Psi(S+\lambda_{max}\Delta S)$. Is defined λ_{opt}, which corresponds to the smallest value of the function Ψ on a range $[0; \lambda_{max}]$. If $\lambda_{opt} = 0$, then the step λ_{max} is divided in half and on a new segment is again determined λ_{opt}. The number of repetitions of the step division procedure does not exceed a given number, and if λ_{opt} remains zero, the optimization stops.

5. If the restriction of the step was one of the constraints (that is, $\lambda_{opt} = \lambda_{max}$), the set of independent variables is changed.

6. New values of variables $S' = S + \lambda_{opt}\Delta S$.

7. Power imbalances are determined, and, depending on their magnitude, a new steady state is calculated.

Optimization ends if the loss reduction between adjacent iterations with numbers k and $(k + 1)$ and the value of the penalty component does not exceed the preset values ε_1 and ε_2:

$$|(\Delta P_{(k+1)} - \Delta P_k)/\Delta P_k| \leq \varepsilon_1;$$

$$|((PF_{(k+1)} - PF_k)/PF_k| \leq \varepsilon_2.$$

Consider the application of this algorithm on the modified 14-node IEEE test circuit [5], shown in Fig. 1, whose rated voltages are 220 and 110 kV. In this scheme, node No. 1 is taken as the balancing and

basic one, nodes No. 2, 3, 6, 8 are generating, they are reactive power sources whose parameters can be optimized. The values of the mode parameters before optimization are shown in Fig. 1.

Ranges of reactive power variation of generating units are taken on the basis of available data on the possibilities of regulating reactive power in the nodes of the electric network. In accordance with GOST 32144-2013, positive and negative voltage deviations at the point of transmission of electrical energy should not exceed 10% of the rated or agreed voltage for 100% of the time interval in one week. Thus, the minimum and maximum permissible limits for voltage variation in the circuit under consideration are the values 198 and 242 kV (rated voltage 220 kV), 99 and 121 kV (rated voltage 110 kV).

Optimization of the electric power mode is performed in the RastrWin3 software-computing complex in accordance with the above algorithm. The results of calculating the optimum values of reactive power and voltage in the nodes of the electrical network are presented in Table 1.
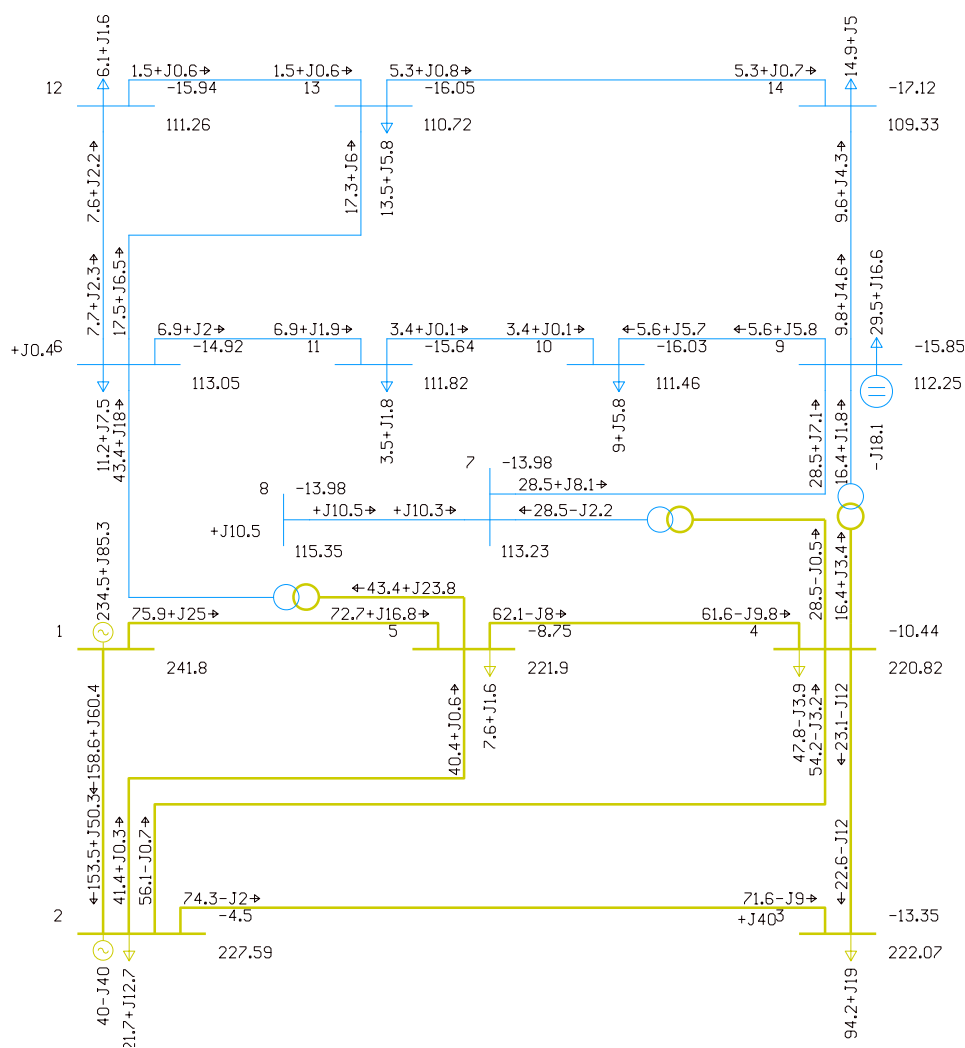

Figure 1. Test 14-node calculation scheme for algorithm analysis optimization in the software complex RastrWin3

The losses of active power in the branches of the scheme under consideration before optimization in the 220 kV network amounted to 14.86 MW, in the 110 kV network – to 0.62 MW. The losses of active power in the branches of the circuit under consideration after optimization in the 220 kV network amounted to 13.14 MW, in the 110 kV network – 0.58 MW. Thus, in general, according to the test scheme, the losses decreased by 11.37% compared to the original version. To calculate the optimum regime, it took two iterations.

Table 1.The results of optimization of the electric network steady-state regime

Node number	U_n,kW	U_{min}, kW	U_{max}, kW	U, kW	Q_{min}, Mv	Q_{max}, Mv	Q_g, Mv
1	220	198	242	241.80	–	–	–9.4
2	220	198	242	238.07	–40.0	50.0	44.8
3	220	198	242	230.49	0.0	40.0	30.0
4	220	198	242	230.88	–	–	–
5	220	198	242	231.47	–	–	–
6	110	99	121	121.00	–6.0	24.0	13.1
7	110	99	121	119.19	–	–	–
8	110	99	121	121.00	–6.0	24.0	9.4
9	110	99	121	118.81	–	–	–
10	110	99	121	118.32	–	–	–
11	110	99	121	119.24	–	–	–
12	110	99	121	119.22	–	–	–
13	110	99	121	118.62	–	–	–
14	110	99	121	116.61	–	–	–

Thus, based on the analysis of the results obtained, it can be concluded that the application of this algorithm provides an acceptable rate of convergence of the iterative calculations. In addition, this method has a high efficiency for optimizing the modes of closed-loop electrical networks.

References
[1]　Dubenko Yu and Dyshkant E 2016 Intelligent system of control and forecasting of energy losses *Bulletin of BSTU named after V G Shukhov* vol 3 pp 131-135
[2]　Bakalin Yu, Mukhin N, Vinoglyadov V 2013 Restraining factors in the organization of energy conservation and issues of obtaining real energy efficiency Bulletin of BSTU V G Shukhov vol 2 pp 185-187
[3]　Filippova T, Sidorkin Yu, Rusina A 2016 Optimization of regimes of power plants and power systems: a textbook (Novosibirsk: Publishing house of the NSTU) p 356
[4]　RastrWin3 - User documentation [Site]: The software complex "RastrWin" 2017 URL: http://www.rastrwin.ru/download/Files/
[5]　Test schemes [Site]: Energy Department of the Institute of Energy and Power Engineering of the Komi Scientific Center of the Urals Branch of the Russian Academy of Sciences 2017 URL: http://energy.komisc.ru/dev/test_cases