ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 12, Issue 5, May 2025

Methods for calculating the derivatives of active power loss in optimizing the state of electric power systems

T.Sh.Gayibov, K.M.Reymov, B.A.Uzakov

Professor (DSc), Department of "Electric Power Stations, Networks and Systems", Tashkent State Technical University, Tashkent, Uzbekistan
Professor (DSc), department of "Power Energy" Karakalpak State University, Nukus, Uzbekistan
Associate Professor (PhD), department of "Power Energy" Karakalpak State University, Nukus, Uzbekistan

ABSTRACT: In this paper, in basis of research the effectiveness of methods and algorithms for calculating the derivatives of losses in the case of optimal planning of short-term modes of power systems, taking into account losses in electrical networks there improving in direction of out coming some problems is carried out. The researches were carried out on the example of a complex power system containing 27 nodes, 11 calculated thermal power plants. Evidence-based proposals for the rational use of various methods have been developed.

KEYWORDS: Electric power system, power network, network factor, losses, derivatives of losses, efficiency.

I.INTRODUCTION

In the world, scientific research is being conducted aimed at developing and improving effective algorithms for planning short-term operating modes of electric power systems, taking into account all influencing limiting factors, to ensure optimal operating modes.

One of the difficult tasks in optimizing short-term states of power systems, taking into account the influence of the electrical network on active power, is taking into account losses in electrical networks. Usually, it is carried out on the basis of calculating the derivatives of losses in the network by the capacities of power plants [1].

[1, 2] an algorithm for calculating the derivatives of losses by the method of numerical differentiation (method of infinitesimal increments) is presented. This method allows for the determination of high-precision values of loss derivatives based on repeated recalculations of the stabilized state of the electrical system. However, the large volume of computational operations performed and, accordingly, the long computational time limit the possibility of using this method for short-term planning and, in particular, for the purposes of operational management of modern complex EPS states. It is recommended for use in calculating other loss derivatives and assessing the effectiveness of simplified optimization methods and algorithms taking them into account.

According to the developments of the All-Russian Research Institute of Electric Power Engineering, these derivatives are calculated using linear formulas [3, 4]. Their coefficients are predetermined based on the calculation of EPS states for characteristic time intervals in characteristic days. This method is effective in conditions of insufficient data for calculating the stabilized states of the electrical network when optimizing the state of the EPS.

Unlike the problem of optimal distribution of the load of the power system between stations without taking into account losses in the electrical network, in this case, along with determining the total losses in the network, it is also necessary to calculate the derivatives of losses by the capacities of all stations participating in the optimization. Accounting for losses in electrical networks leads to significant changes in the distribution of the active load of the power system between stations. To understand the essence of this issue, it is sufficient to consider an energy system that includes thermal power plants (TPPs) participating in optimization. In this case, the mathematical model of the problem is described as follows [3, 5-8]:

- goal function

$$B = \sum_{i=1}^{n} B_i\left(P_i\right) \rightarrow \min \quad (1)$$

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 12, Issue 5, May 2025

- boundary condition

$$\sum_{i=1}^{n} P_i = P_н + \pi \tag{2}$$

Here P_i, B_i - the active capacity of the i-th TPP and the amount of conditional fuel consumed at this capacity; P_n, π - total active load of the power system and total active power losses in its electrical networks.

Solving the formulated optimization problem (1) - (2) requires the use of methods of linear mathematical programming [1-3, 8-11]. Accordingly, for modern large and complex energy systems, their solution is associated with certain difficulties. If we take into account that the objective function is discontinuous, and since it is impossible to directly use such functions in curvilinear programming methods, which are widely used in practice at the present time, it is necessary to represent it with higher-order polynomials, the problem becomes even more complex.

Losses in the electrical network, along with the active power of stations, which are considered optimized parameters, are also a complex function of many other state parameters that change depending on them, in particular, the complex voltages of all nodes. Therefore, when solving this problem, the main and important problem is the determination of the derivatives of losses by the active power of the stations participating in the optimization. Therefore, the question of the rational choice of existing methods in various conditions remains open. In this work, based on the study of existing methods for calculating derivatives of losses, they have been improved and scientifically based recommendations for their rational use have been developed [1-10].

II. CALCULATION METHODS

The classical method for calculating loss derivatives in optimization is the method of small increments from numerical differentiation methods. According to it, the derivative of losses by the power of each station is determined as the total loss increment $\delta\pi$, which arises under the influence of the small increment δPi, given to the power of this station, and as the ratio of these increments [1, 5]:

$$\frac{\delta\pi}{\delta P_i} \approx \frac{\partial\pi}{\partial P_i} = \sigma_i$$

Determining the values of σ_i using the small increment method requires recalculation at each optimization step, equal to the number of stations participating in the optimization of the stabilized state of the electrical network.

A simple method for calculating the derivatives of losses, widely used in practice today, on the basis of which industrial-level programs have been developed, was developed at the All-Russian Research Institute of Electric Power Engineering [1, 3] and provides for the use of the following linear form of the loss derivatives:

$$\sigma_i = \sum_{j\in H} \alpha_{ij} P_j - \sum_{k\in T+\Gamma} \alpha_{ik} P_k + \alpha_{i0} \tag{3}$$

where α_{ij}, α_{ik} - constant coefficients of the linear function; P_j, P_k - nodes with a j -th load and a station participating in the k-th optimization; α_{i0} is the free term of the linear function.

The method, which allows for a more accurate calculation of the loss derivatives in electrical networks compared to the above method, is based on the use of a formula involving the elements of the intrinsic and mutual conductivity matrix Z [1]:

$$\sigma_j = \frac{d\pi}{dP_j} \approx -\frac{2}{U_j^2}\sum_{k=1}^{N} R_{jk}\left(U_j^{'} I_k^{'} + U_j^{"} I_k^{"}\right) + +2\left[\sum_{i=1}^{N}\left(\frac{2U_i^{"} I_i^{"} - P_i}{U_i^2} + g_i\right)\frac{R_{ij}U_j^{'} - X_{ij}U_j^{"}}{U_j^2}\sum_{k=1}^{N} R_{ik} I_k^{'} + \right.$$
$$\left. + \sum_{i=1}^{N}\left(\frac{Q_i - 2U_i^{"} I_i^{'}}{U_i^2} - b\right)\frac{X_{ij}U_j^{'} + R_{ij}U_j^{"}}{U_j^2}\sum_{k=1}^{N} R_{ik} I_k^{"} + 2\sum_{i=1}^{N}\left(\frac{P_i - 2U_i^{"} I_i^{"}}{U_i^2} + g_i\right)\frac{X_{ij}U_j^{'} + R_{ij}U_j^{"}}{U_j^2}\sum_{k=1}^{N} R_{ik} I_k^{"}\right] \tag{4}$$

Another method for calculating loss derivatives when optimizing the states of electric power systems is based on their determination by solving linear algebraic equations.

An increase in the phase angle δ_i of any i-th node voltage by some small value leads to a corresponding change in the total active power loss in the electrical network. This change can be defined as follows:

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 12, Issue 5, May 2025

$$\Delta\pi = \sum_j \frac{\partial \pi}{\partial P_j} \cdot \Delta P_j + \sum_j \frac{\partial \pi}{\partial Q_j} \cdot \Delta Q_j \qquad (5)$$

where $\frac{\partial \pi}{\partial \mathrm{P}_j} = \sigma_{\mathrm{P}_j}$, $\frac{\partial \pi}{\partial Q_j} = \sigma_{Q_j}$ - derivatives of total losses by the active and reactive powers of node *j*;

ΔP_j, ΔQ_j - increase in the active and reactive power of node *j* due to some increase in the phase angle of the *i*-th node voltage by $\Delta\delta_i$.

By dividing both sides of equation (5) by $\Delta\delta_i$ and determining the limit of the resulting equation when the increment of the phase angle approaches zero, we obtain the following equation:

$$\frac{d\pi}{d\delta_i} = \sum_j \sigma_{P_j} \cdot \frac{dP_j}{d\delta_i} + \sum_j \sigma_{Q_j} \cdot \frac{dQ_j}{d\delta_i} \qquad (6)$$

Similarly, from the formula for the change in total losses in the electrical network under the influence of some increase in the voltage modulus by ΔU_i at any node *i*, based on determining the limit when ΔU_i tends to zero, the following relationship can be obtained:

$$\frac{d\pi}{dU_i} = \sum_j \sigma_{P_j} \cdot \frac{dP_j}{dU_i} + \sum_j \sigma_{Q_j} \cdot \frac{dQ_j}{dU_i} \qquad (7)$$

Combining equations (6) and (7) and taking into account that i=1, 2,..., N, we obtain the following system of linear algebraic equations (SLAE), expressed in matrix form, which can be used to determine the loss derivatives [1, 3]:

$$\begin{bmatrix} \frac{\partial P}{\partial \delta} & \frac{\partial Q}{\partial \delta} \\ \frac{\partial P}{\partial U} & \frac{\partial Q}{\partial U} \end{bmatrix} x \begin{bmatrix} \sigma_p \\ \sigma_Q \end{bmatrix} = \begin{bmatrix} \frac{\partial \pi}{\partial \delta} \\ \frac{\partial \pi}{\partial U} \end{bmatrix} \qquad (8)$$

In the system of equations (8), the elements of the coefficient matrix are practically equal to the derivatives of the active and reactive power imbalance functions for the nodes of the electrical network. Therefore, this matrix is a transposed form of the Jacobi matrix, which is used to calculate the stabilized state of the electrical network using the Newton-Raphson method.

To eliminate some shortcomings associated with the method based on solving the above system of linear algebraic equations, an effective algorithm for calculating the derivatives of losses based on its improvement is proposed. It provides for the solution of the resulting system of equations based on decomposition.

Here, the algorithm for calculating the derivatives of losses is improved based on the decomposition of the matrix of the coefficients of the system of linear algebraic equations (8). When using this algorithm, the volume of operations performed is significantly reduced, and the accuracy of calculations is increased.

To calculate the elements of the coefficient matrix in (8), nodal equations written in polar coordinate systems in the form of power balances are used.

In (8), we isolate the equations obtained from the first *N* equations, i.e., written in the form of active power balances for all nodes (except the balancing node), and express the derivatives of losses by the active powers of the nodes:

$$\frac{\partial P}{\partial \delta} \cdot \sigma_P + \frac{\partial Q}{\partial \delta} \cdot \sigma_Q = \frac{\partial \pi}{\partial \delta} \qquad (9)$$

$$\sigma_P = \frac{\partial P^{-1}}{\partial \delta} \cdot \frac{\partial \pi}{\partial \delta} + \frac{\partial P^{-1}}{\partial \delta} \cdot \frac{\partial Q}{\partial \delta} \cdot \sigma_Q$$

(9a)

Considering that the degree of dependence of the reactive power *Q* of the node on the phase angle δ of the complex voltage is weak, we replace the second component in (9a) with a linear vector function:

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 12, Issue 5, May 2025

$$\Delta\sigma_P = \frac{\partial P^{-1}}{\partial\delta}\cdot\frac{\partial Q}{\partial\delta}\cdot\sigma_Q = \rho P + \rho_O \quad (10)$$

where ρ, ρ_0 are the coefficients of the unknown of the linear function and the vectors of the free term.

The values of the derivatives of losses, determined as a result of solving the system of equations (8), are approximate, since when forming it, the partial derivatives of the functions are calculated without taking into account that they are complex functions.

$$\frac{\partial \mathrm{P}}{\partial\delta}\cdot\sigma_P = \frac{\partial\pi}{\partial\delta} \quad (11)$$

$$\Delta\sigma_{P.i} = \alpha_i P_i + \alpha_{0.i} \quad (12)$$

Thus, for calculations according to this algorithm, in the established steady state of the electrical system, the approximate values of the $\sigma_{P.A.}$ derivatives of losses by the active power of the nodes are determined by first solving the system of equations (11). Then, for the nodes at which the stations participating in the optimization are located, the values of these derivatives are corrected taking into account the corrections determined by (12):

$$\sigma_{P.C.} = \sigma_{P.A.} + \Delta\sigma_P \quad (13)$$

III. EXPERIMENTAL PART

The accuracy of the above-mentioned methods and algorithms for calculating the derivatives of losses was determined for the operating states of a complex power system with 27 nodes and 11 design TPPs at characteristic time intervals of the daily control cycle. Table 1 shows the results of calculating loss derivatives for individual station nodes at certain time intervals of the daily control cycle. In this case, the results obtained by the method of small increments can be taken as an exact (standard) result.

Table 1. Results of calculating the derivatives of losses by various methods.

Node Numbers	Station loads	Loss derivatives				
		Small increments method	Linear formula	Based on the Z matrix	Based on the resolution of the SLAE	Based on the decomposition of SLAE
Time interval of the daily control cycle: t=3						
6	560,0	-0,0286	-0,0418	-0,0472	-0,0416	-0,0311
10	400,0	-0,2817	-0,1549	-0,1962	-0,1970	-0,2697
16	460,0	-0,1064	-0,0784	-0,1242	-0,0920	-0,1085
18	433,33	-0,1261	-0,0654	-0,1246	-0,0934	-0,1278
23	80,0	-0,1318	-0,0687	-0,1286	-0,0968	-0,1297
Time interval of the daily control cycle: t=10						
6	747,62	-0,0393	-0,0398	-0,0479	-0,0419	-0,0406
10	594,69	-0,0766	-0,0406	-0,0649	-0,0606	-0,0678
16	677,69	0,0007	-0,0028	-0,0342	-0,0002	-0,0005
18	444,38	-0,1387	-0,0756	-0,1333	-0,919	-0,1358
23	80,0	-0,1418	-0,0773	-0,1354	-0,0928	-0,1393
Time interval of the daily control cycle: t=18						
6	1120.0	-0.0040	-0,0221	-0,0322	-0,0193	-0,0031
10	752,0	0,1116	0,1935	0,0447	0,1569	0,1095
16	712,06	-0,0523	-0,0395	-0,0748	-0,0497	-0,0484
18	447,65	-0,2886	-0,1548	-0,2080	-0,1921	-0,2779
23	80,0	-0,2971	-0,1590	-0,2133	-0,1963	-0,2883

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 12, Issue 5, May 2025

We are convinced that the use of the proposed algorithm, based on comparing the results obtained by various methods of calculating loss derivatives with each other and with the exact results obtained by the method of small increments, has higher accuracy compared to the existing methods and algorithms used in practice today. Also, from the results, we see that the accuracy of the method based on the use of the linear formula is significantly lower in relatively heavy modes, and the accuracy of the methods based on the use of the formula using the elements of the Z matrix and the complete solution of the system of linear algebraic equations is approximately the same.

IV. CONCLUSION

1. Although the use of the linear formula allows for easy and fast determination of loss derivatives, it has the lowest accuracy indicator. In this case, the error increases as the operating state of the electrical system deteriorates. Therefore, its use is effective only for the purposes of optimal operational management;
2. The methods based on solving formulas and systems of linear algebraic equations using Z matrix elements have approximately the same degree of accuracy. In this case, the use of the formula is associated with certain difficulties in calculations. In particular, it is necessary to frequently recalculate the elements of the Z matrix. Also, this formula is characterized by its relative complexity;
3. The proposed method, based on the decomposition of a system of linear algebraic equations, requires relatively fewer calculations and has higher accuracy compared to the previous method. Therefore, it is recommended to use this method in optimization algorithms based on the calculation of loss derivatives of the states of energy systems.

REFERENCES

[1] Fazylov Kh.F., Nasyrov T.Kh. Steady regimes of electric power systems and their optimization. - T .: “Moliya”, 1999.
[2] Fazylov H.F., Yuldashev H.Yu. Optimization of Electric Power System Regimes. - Tashkent: Fan, 1987.
[3] Automation of dispatch control in the electric power industry // Ed. ed. Yu.N. Rudenko and V.A. Semenov. -M.: MEI Publishing House, 2000.
[4] V.M.Gornshteyn, B.P.Miroshnichenko, A.V.Ponomarev et al.; Edited by V.M.Gornstein. Methods for optimizing energy system modes / - M.: Energy, 1981.
[5] Gayibov T.Sh. Methods and algorithms for optimizing the modes of electric power systems. - T .: Ed. Tashkent State Technical University, 2014,
[6] J.C. Carpentier: Optimal Power Flows: Uses, Methods and Developments. In: IFAC Proceedings Volumes. 18(7), pp. 11-21. https://doi.org/10.1016/S1474-6670(17)60410-5. (1985).
[7] Tulkin Gayibov, Sherxon Latipov, Bakhodir Uzakov. Power System Mode optimization by piecewise-linear approximation of energy characteristics of Power Plants. E3S WoC 139, 01086 (2019). doi.org/10.1051/e3sconf/201913901086.
[8] Tulkin Gayibov, Behzod Pulatov. Taking into account the constraints in power system mode optimization by genetic algorithm. E3S Web of Conferences 264, 04045 (2021). https://doi.org/10.1051/e3sconf/202126404045.
[9] Hardiansyah, Junaidi, Yohannes. An Efficient Simulated Annealing Algorithm for Economic Load Dispatch Problems. TELKOMNIKA, Vol.11, No.1, March 2013, pp.37-46. http://dx.doi.org/10.12928/telkomnika.v11i1.880.
[10] El Hachmi Talbi, Lhoussine Abaali, Rachid Skouri, Mustapha El Moudden. Solution of Economic and Environmental Power Dispatch Problem of an Electrical Power System using BFGS-AL Algorithm, Procedia Computer Science, Volume 170, 2020, pp. 857-862, https://doi.org/10.1016/j.procs.2020.03.144.
[11] Ismi Rosyiana Fitri, Jung-Su Kim, Economic Dispatch Problem using Load Shedding: Centralized Solution, IFAC-PapersOnLine, Volume 52, Issue 4, 2019, pp. 40-44. https://doi.org/10.1016/j.ifacol.2019.08.152.