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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

DEVELOPMENT OF METHODS MODELING OF ESTABLISHED MODES OF POWER TRANSMISSION LINES TAKING INTO ACCOUNT LOADİNG AND METEOROLOGICAL FACTORS

Specialty: 3340.01 – Electrotechnical systems and complexes

Field of science: Technical sciences

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INTRODUCTION

Relevance and development of the topic. The relevance of the work and the degree of its elaboration. In modern times, the increase in the demand for electricity and the noticeable variability of climatic conditions of the environment are observed with the growth of interest in reporting the loads of overhead power transmission lines (OHL) with permissible load currents. Thus, the maximum uninterrupted, safe and economically viable use of the transmission capacity of power transmission lines is one of the main requirements given to their operating mode. The main condition for the satisfaction of such demand is the availability of accurate information about the OHL and the transfer of information to operational management tools in real time.

It should be noted that the process of transmission, distribution and demand of electricity is a process characterized by uncertainties. That is, this process by a multiple of the number of its parameters, which must be taken into account when calculating the OHL operating mode and throughput:

- line wiring brand and voltage;
- quality indicators of electricity;
- features and operating conditions of the territory through which the track of the lines passes;
- line wiring and ambient temperature;
- transmitted load or load currents;
- resistance of line wiring;
- dependence of the temperature of the line wiring on active resistance;
- the force of influence of solar radiation on the wire;
- the condition of the surface of the wire;
- density, direction and angle of incidence of the sun's rays;
- speed and direction of the wind;
- errors of measuring systems, etc. it is characterized.

At the same time, it should be noted that the software tools available for modeling the settled load modes of OHL cannot take into account the set of specified parameters as a whole. In this case, it is of great importance to carry out continuous control of the temperature of the line wiring in various modes and weather conditions, to have software developed on the basis of a special algorithm for its assessment. Also, the temperature of the line wires can significantly exceed the ambient temperature due to the impact of the load currents passing through it and the sun's rays, resulting in increased losses, lengthening of the line wires, shortening the distance between the Earth's surface and the line wires, natural obstacles, engineering structures and wires passing over each other, as a result of inductive communication, additional currents arising between certain overvoltages can lead to increased switching resistance and breakage of the wire at the connection points of the wires, which may result in a violation of the continuity requirement. For this very reason, it is of great importance to consider the fact that the temperature of the line wires exceeds the permissible limits as the main factor limiting the throughput or load currents of the line.

The indicated cases include the relevance of the issue of developing an improved algorithm and software tools that can eliminate the shortcomings of existing models for increasing the accuracy of calculating active power and energy losses and automatic recording of the temperature of the wiring.

One of the directions of increasing the calculation accuracy of variable electric power losses in OHL is called the determination of active resistance by taking into account the Working current flowing through the line wires, the ambient temperature, the wind speed and the heat generated by the sun's Rays.

In order to increase the accuracy of determining the active resistance of the line wires of electrical networks, it is necessary to take into account the temperature of the wires, which can affect the value of this resistance.

Given that the track of the OHL is not rectilinear, and the wind speed and direction do not remain unchanged, then it may not seem possible to determine the section of the line with the worst heat transfer conditions.

If, during the reporting determination of the temperature of the wires and the current discharge value, the uncontrollable parameters of the environment are taken equal to their values in the most severe operating conditions, then it can be concluded that the transmission capacity of the OHL is significantly used.

The basis of the modern theory and practice of calculating the temperature regimes of power transmission lines and the limiting current loads of overhead lines, the current regulatory documents were laid in the 20-30s of the 20th century by Burgsdorf V.V., Ravdonik V.S., McAdams V.G., Frick K. V., Shurig O.R. and others.

Many of their theoretical provisions have been developed and are being improved by a number of authors who have developed practical methods for determining the parameters of overhead lines. These methods are described in the works of P.I. Bartolomeya, Berdina A.S., Vorotnitskiy V.E., Gerasimenko A.A., Girshina S.S., Zhelezko Yu.S., Zharkovo Yu.I., Zarudskiy G.K., Zinner L.E., Levchenko I.I., Lordkipanidze V.D., Merzlyakova A.S., Nazarova I.A., Nikiforova E.P., Nikitina G., Petrova T.E., Satsuk E.I., Syromyatnikova S.Yu., Timashova L.V., Faibisovich V.A., Figurnova E.P., Cheremisina N.M., Cherkashina V.V., Daniel J. Tilavski, Dee Shi, Korba P., Christian M., Larsson M ., Lovrenchich V., Polak M., Peulik S., Rodriger A., Köliner, Xiaoming Bian, Inger R.L., Zamora Kardenas A., Zima M. and of many other scientists. Modern advanced methods make it possible to increase the accuracy of determining the temperature of overhead lines, taking into account natural factors that were not previously taken into account.

One of the main problems of the electric power system is the issue of saving energy resources, their efficient use and reducing electricity losses. This, in turn, shows the importance of analyzing losses arising in the electric power system, determining ways to reduce them and developing a new algorithm and software that allows increasing accuracy by taking into account numerous factors in calculating losses.

Object and subject of research. The object of the study is electrical networks and electrical transmission lines. The subject of the study is the dependence of the resistance of power transmission lines on the temperature and atmospheric factors of the wiring.

The purpose and objectives of the study. The purpose of the dissertation work is to develop an improved algorithm and software that can eliminate the shortcomings of existing models in calculating the settled mode of OHL, taking into account overloads and meteorological factors.

In order to achieve the set goal, the main directions of the research carried out in the dissertation work are as follows:

1. The modern state of the methods for calculating the temperature regime of the wiring of OHL;

2. Development of a methodology for taking into account regime and atmospheric factors in the calculation of temperature and active resistances of wires of OHL;

3. Modeling the calculation of active power losses of OHL taking into account regime and meteorological factors;

4. Monitoring of the load throughput of OHL based on the temperature of the line wiring.

Research methods. In solving the problems posed in the dissertation, the basics of electrotechnics; numerical methods of mathematical modeling; methods of successive approximation; matrix methods of analysis of electrical circuits; theoretical and practical bases of transmission and distribution of electrical energy were used.

The main provisions put on defense. The following provisions were put up for defense in the dissertation:

1. Reporting methodology that can take into account the parameters of overhead power transmission lines and regime and atmospheric factors affecting the increase in the temperature of the line wiring of the environment;

2. Mathematical models and block scheme for estimating the permissible temperature arising during the passage of natural obstacles of the OHL under consideration over engineering structures and other objects;

3. Algorithm for more accurate modeling of parameters and temperature of OHL, taking into account the intensity and radiation density of solar radiation at equivalent heights above sea level of the area where the line is laid;

4. Results of modeling in Delphi and Azerbaijan Scientific-Research and Designed- Prospecting İnstitute of Energetics software packages;

5. Block scheme and program of modeling the temperature and active resistance of the wires of OHL, depending on load currents and atmospheric factors;

6. Methodology and program for reporting the specific active resistance of the hevx wiring, taking into account the air temperature, line working current, wind speed, radiation, density, direction and angle of incidence of the sun's rays;

7. Errors of existing methods depending on the level of solar radiation;

8. Comparative analysis of the results of the report of the temperature of the line wiring with the results of the IEEE and CIGRE standards and other reporting methods;

9. Loss monitoring system in OHL and the results obtained;

10. The effectiveness of monitoring the throughput of overhead lines based on the temperature of the line wiring.

Scientific novelty of the study. The main scientific innovations of the dissertation work are as follows:

1. The method of calculating the temperature of the wiring by taking into account the parameters of the overhead power transmission lines, the cost of current, atmospheric factors: air temperature, intensity of solar radiation, wind speed and direction and obtaining a multivariate dependence has been developed.

2. A mathematical model and a flowchart based on iterative refinement have been proposed for the determination of the temperature of the wire. This mathematical model allows you to directly determine the temperature of the wire depending on its parameters and load current, air temperature, solar radiation.

3. The proposed methodology was compared with IEEE, CIGRE standards and other methods in test samples.

4. The method and algorithm for determining the temperature of the wire by area, taking into account geographical and atmospheric factors, along the territory through which the Air Line passes, has been proposed.

5. Multifactor nonlinear regression models have been built to estimate power losses taking into account atmospheric factors.

Theoretical and practical significance of the study. Under modern operating conditions, the availability of software for monitoring the temperature of the line wires along the track of the OHL, taking into account the regime and meteorological factors, reducing losses, increasing throughput and taking appropriate measures to prevent the line from overloading, is of great importance both theoretically, economically and practically.

As a result of theoretical reports conducted in the direction of assessment of the effect of load current, ambient temperature, solar radiation and wind speed on the active resistance of the wires of the OHL, it was determined that the relative error may be 26% or more if the dependence of the active resistance on the temperature of the wires is not taken into

Theoretically, the three-degree approximation function of the dependence of current on the temperature of the wire, wind speed and air temperature has sufficient accuracy for practice.

Approbation of work. The main provisions and results of the dissertation were reported and discussed at the following conferences:

1. Fedorov Readings. XLVII International Scientific and Practical Conference with elements of a scientific school. MPEI,

November 15-17, 2017.

2. International Scientific Conference "Topical Issues of Applied Physics and Energy" (May 24-25, 2018), Sumgait, SSU.
3. Information systems and technologies, achievements and prospects. International scientific conference. Sumgait, SDU, November 15-16, 2018.
4. Fedorov Readings, XLVIII International Scientific and Practical Conference with elements of a scientific school. MPEI, November 14-16, 2018.
5. Topical issues of personnel training in energy specialties. Republican scientific conference. Sumgait, SDU, May 20-31, 2019
6. 15th International Conference on Technical and Physical Problems of Electrical Engineering İCTPE-2019 October 14-15, 2019 Istanbul, Turkey.
7. Fedorov Readings 2019, XLIX international scientific and practical conference with elements of a scientific school. Moscow, November 20-22.
8. Achievements and prospects of information systems and technologies. II International Scientific Conference. Sumgait SDU, 09-10 July 2020.
9. International Scientific Conference, 2020.

Implementation of work results. The software, developed on the basis of the proposed methods and algorithms, taking into account the dependence of the resistance of power lines on the wire temperature and atmospheric factors, was used for research and calculation of technical losses at Azerenerji OJSC.

The results of the dissertation were used in the reports on research work carried out for OJSC "Azerenerji".

The name of the organization where the work was done. The dissertation work was performed at Sumgayit State University. The research and developments were carried out on the basis of plans approved by Azerenerji OJSC and included in the reports of the Energy System Modes Department for 2012-2021.

The total volume of the dissertation with a sign indicating the volume of the structural sections of the dissertation separately. The dissertation consists of an introduction, 4 chapters, main results and a list of used literature. The volume of the dissertation is approximately distributed amonq the charters as follows:

- Total character count - 167813 symbols
- Introduction - 23904 symbols
- First charter - 65392 symbols
- Second chapter - 20138 symbols
- Chapter three - 23791 symbols
- Chapter four - 32139 symbols
- Conclusion - 2449 symbols

DİSSERTATİON CONTENT

The introduction reflects the relevance and degree of elaboration of the topic of the dissertation, the goals and objectives of the study, research methods, the main provisions put forward for defense, the scientific novelty of the study, the theoretical and practical significance of the study, a brief summary of the chapters.

In the first chapter, a brief overview of the current state of the existing works on the calculation of the temperature regime of the wires[1] of the air EVX, the permissible load currents of the line wires, static and dynamic load capacity, differential equation of the temperature of the wire, reports on various standards, theoretical information on the settled and switching modes of the It has been established that:

- Modern reporting programs of power system modes do not include thermal balance equations of overhead lines;

[1] Г.Александров. Режимы работы воздушных линий электропередачи / Г. Александров– Санкт-Петербург: - Второе издание Центра подготовки кадров энергетики, - 2006 г. - с. 139.

- The active resistance of the line wires does not correspond to their temperature regime;

- When determining technological losses on electrical networks, the temperature of the wire, which affects the price of its active resistance, is not taken into account;

- Interactions and dependencies between the regime and meteorological factors of the line during the process of transmission, distribution and demand of electricity are not taken into account in the calculation of temperature and active resistance.

The algorithm for calculating the temperature that can be released on the wire is given in Figure 1.

This chapter also discusses the existing standards for accounting for atmospheric factors for calculating the temperature of power transmission lines - the IEEE standard, the CİGRE standard, the difference between the IEEE and CİGRE standards, the standards used in Russia and other CIS countries, the application of these standards in steady, transient and emergency modes.

For example, the CİGRE method for high wind speeds is based on the following algorithm:

$$P_J + P_M + P_S + P_i = P_C + P_r + P_W \tag{1}$$

where P_J - is the heat of the load current (Joule's heat), P_M - is the magnetic heat, P_S - is the heat from solar radiation, P_i - is the heat associated with the corona phenomenon; P_C - is the amount of heat released during convection; P_r - radiation losses; P_W - losses from evaporation.

The specific active resistance of overhead wires is found from the following expression

$$R = R_{20} \cdot \left[1 + \alpha \cdot \left(t_{wire} - 20\right)\right] \tag{2}$$

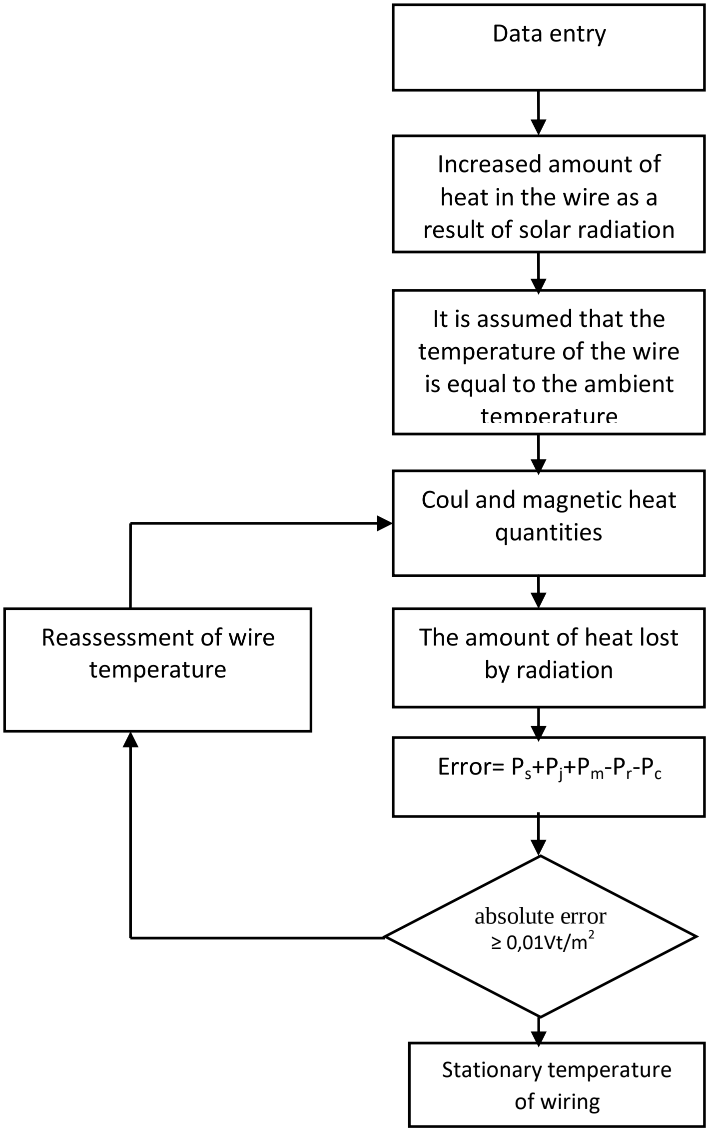


Fig. 1. Block scheme for calculating the temperature of the wiring

where R_{20}–20°C resistance of the wire at temperature, Om/кm; α=0,004003–temperature coefficient of resistance, 1/degree; t_{wire} - temperature of the wire, °C.

The temperature of the wire depends on the elektric current flowing through it, the ambient temperature, and the wind speed.

The temperature of the wire can be calculated using the heat balance equation:

$$0{,}95 \cdot R_{20} \cdot \left[1 + \alpha \cdot \left(t_{wire} - 20\right)\right] \cdot I^2 - Q_{rad} = Q_r + Q_к \qquad (3)$$

where I – current flowing through the wire, Q_R, Q_k – are power losses during heat trasfer by radiation and convection, Wt/m.

From the Stefan-Bolsmann law, the power losses by radiation are found from the following expression:

$$Q_r = \varepsilon C_0 \left(273 + t_{wire}\right)^4 S \qquad (4)$$

where ε –for oxidized aluminium, the degree of blackness of the surface of fhe wire equal to 0,13 relative units; C_0–the radiation coefficient must be the absolute value of the object, $5{,}67 \cdot 10^{-8}$ Wt/m^2; S-is the surface area of the wire, m^2.

Power losses during convection heating are determined by the following expression:

$$Q_K = \varphi_k \left[\left(t_{wire} - t_{rad}\right) - t_{air}\right] S \qquad (5)$$

where $\varphi_к$ – coefficient of heat transfer by convection, Wt/(m^2·°C); t_{rad} – heating temperature through solar radiation,°C, t_{air} –is the air temperature.

The coefficient of heat transfer by convection is determined from the following expression:

$$\varphi_K = 0{,}13057 \cdot \left(\frac{k_v v d}{a}\right)^{0.71719} \frac{\lambda_h}{d} \qquad (6)$$

burada $\kappa_v = 0,5$ – coefficient that takes into account the angle formed by the angle of propagation of the wind by the airline axis; v– wind speed, m/sec.; *d*– wire diameter, m; a=18,8·10^{-6}m²/sek– temperature conduction coefficient of air; λ_h=0,0244Wt/(m·°C)- it is the heat conduction of air. (1-5) from the solution of the system of equations, we get the following expression for the current:

$$I = \sqrt{\frac{\varepsilon C_0 \left(273 + t_w\right)^4 \pi d + \quad _k \left[\left(t_w - t_{rad}\right) - \mathrm{t}_h\right]\pi d}{0{,}95 \cdot R_{20} \cdot \left[1 + \alpha \cdot \left(t_w - 20\right)\right]}} \qquad (7)$$

The dependence of the temperature of the wiring on the load current, air temperature and wind speed cannot be clearly obtained from equation (7). To solve this equation according to the temperature of the wiring and obtain analytical dependencies on the load current, air temperature, wind speed, the following algorithm is used.

1. Obtaining in the form of a table the dependence of the current on the temperature of the wire, wind speed and air temperature in specific values of th, trad, v according to the formula (7) for a given wire. 2. Approximation of the obtained dependencies with a third-degree polynomial in the temperature range of -40°C ÷ +40°C:

$$t_m = a_0 + a_1 I + a_2 I^2 + a_3 I^3 \qquad (8)$$

In connection with the fact that the heat transfer coefficient depends on the temperature of the wire, the formula for the temperature of uninsulated wires (8) and

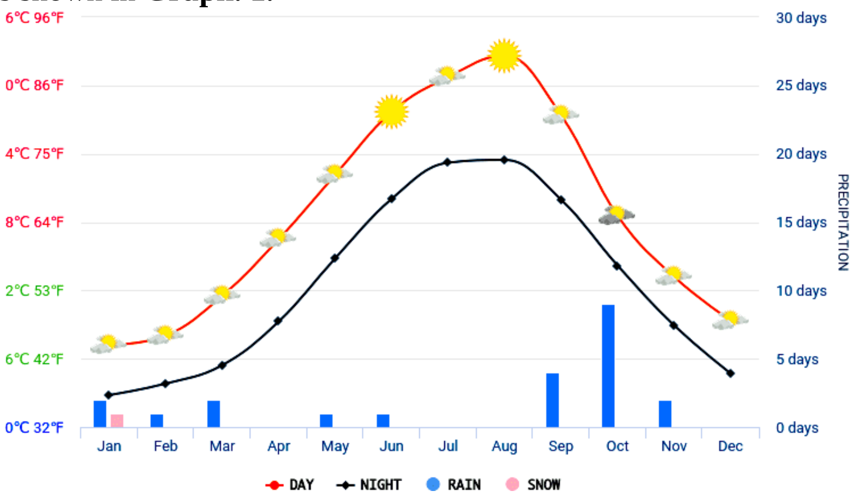
$$t_w^{[k+1]} = \frac{P_s + \alpha_k (t_w^{[k]}[(t_w - t_{rad})]\pi d - \alpha_ş (t_w^{[k]} + \Delta P_{20}(1 - 20 \cdot \alpha)}{(\alpha_k (t_w^{[k]})) \cdot \pi d - \alpha \Delta P_{20}(1 - 20 \cdot \alpha)} \qquad (9)$$

it can be calculated by the method of successive approximations based on the equation.
where k - is the iteration number; ΔP_{20} - active power losses at a temperature of 20°C.

An algorithm and a program for calculating the specific active resistance of overhead lines, taking into account the air temperature, operating current, wind speed and solar radiation, have been developed. A quantitative assessment of the influence of the load current, ambient temperature, solar radiation and wind speed on the active resistance of the overhead line wires has been carried out.

It is shown that monitoring the technical condition of overhead lines, wire current, temperature and intensity of solar radiation, wind speed allows increasing the transmission capacity of overhead lines. Modern technologies to improve the efficiency of overhead lines based on monitoring their condition make it possible to increase the efficiency and reliability of power transmission.

Chapter I also considered information on climate change in Azerbaijan by month. Climate change in Azerbaijan during the year is shown in **Graph. 1.**



Graph. 1. Climate change in Azerbaijan by months

The main results of this chapter are reflected in the author's papers [5-7, 12].

The second chapter considers the issue of developing a methodology for taking into account regime and atmospheric factors in calculating the temperature, active resistance of the wiring of OHL. It was noted that the results in the reports of the temperature and active resistance of the line wires are obtained with errors as a result of non-use of thermal balance equations of the line wires in the existing software, not taking into account the interaction and dependence between regime and atmospheric factors, not noting the instability of the relief and, violation of safety rules when passing over natural obstacles and engineering structures is manifested by a decrease in distances between intersecting lines. In order to eliminate these situations, thermal balance equations were developed at different values of wind speed and two algorithms of hsablation of temperature and active resistance were considered taking them into account.

I algorithm. In normal mode, the heating temperature of the wire is equal to the sum of the ambient temperature, i.e. air temperature and the temperature increment of the wire from to the air temperature[2]

$$t_w^{(k+1)} = t_a + \Delta t^{(k)}.$$

II algorithm. The temperature of the wire is equal to the ambient temperature (air), the sum of the heating of the wire -$\Delta t^{(k)}$ as a result of the solar heating of the wire and, in addition, the load current flowing from the wire:

$$t_{wire}^{(k+1)} = t_{air} + t_R + \Delta t^{(k)},$$

[2] Герасименко, Алексей Алексеевич. Статистическое моделирование электрических нагрузок в задаче определения интегральных характеристик систем распределения электрической энергии. - Красноярск: монография / А. А. Герасименко, И. В. Шульгин. – Омск: Сиб. федер. ун-т, Политехн. ин-т. - 2014. - 207 с.

The application of the heat balance equation in calculating the temperature and active resistance of the overhead line wire, taking into account atmospheric factors is considered. Taking into account the change in the mechanical stresses of the power line wire and its intersection with other objects, the permissible heating temperature was estimated, it was shown that the disadvantage of the technique used in practice is the determination of the wire temperature by selection.

It is noted that due to the nonlinearity of the system of general equations and to take into account the relationship, it is necessary to split the solving into subsequently stages and clarify it iteratively ion.

Calculations were carried out using the example of a 110 kV power transmission line, and it was found that, in comparison with the proposed method, the known method has a systematic error of more than -13,5%.

Figure 2 shows a block diagram of the program for assessing the permissible temperature of the power transmission line.

In the second chapter, the calculation of the permissible long-term current loading and powers for overhead lines with a rated voltage of more than 110 kV at an allowable wire temperature of +70°C and an air temperature of 25°C is carried out.

For wires of the AC95/16 brand at a wind speed of 3,0 m/s, the permissible load for overhead lines increases from 256 A to 453 A compared to a wind speed of 3,0 m/s.

Permissible power values were:

$$P_{p0,5} = \sqrt{3} \cdot 1{,}05 \cdot U_n \cdot I_p = \sqrt{3} \cdot 1{,}05 \cdot 110 \cdot 256 \cdot 10^{-3} = 51{,}15 \text{ MVt}$$

$$P_{p3} = \sqrt{3} \cdot 1{,}05 \cdot U_n \cdot I_p = \sqrt{3} \cdot 1{,}05 \cdot 110 \cdot 453 \cdot 10^{-3} = 90{,}52 \text{ MVt}$$

those increased by (90,52-51,15)·100/51,15 = 76,97%.

Thus, by correctly calculating the capacity of the overhead line based on monitoring wind speed, controlling and increasing power, it

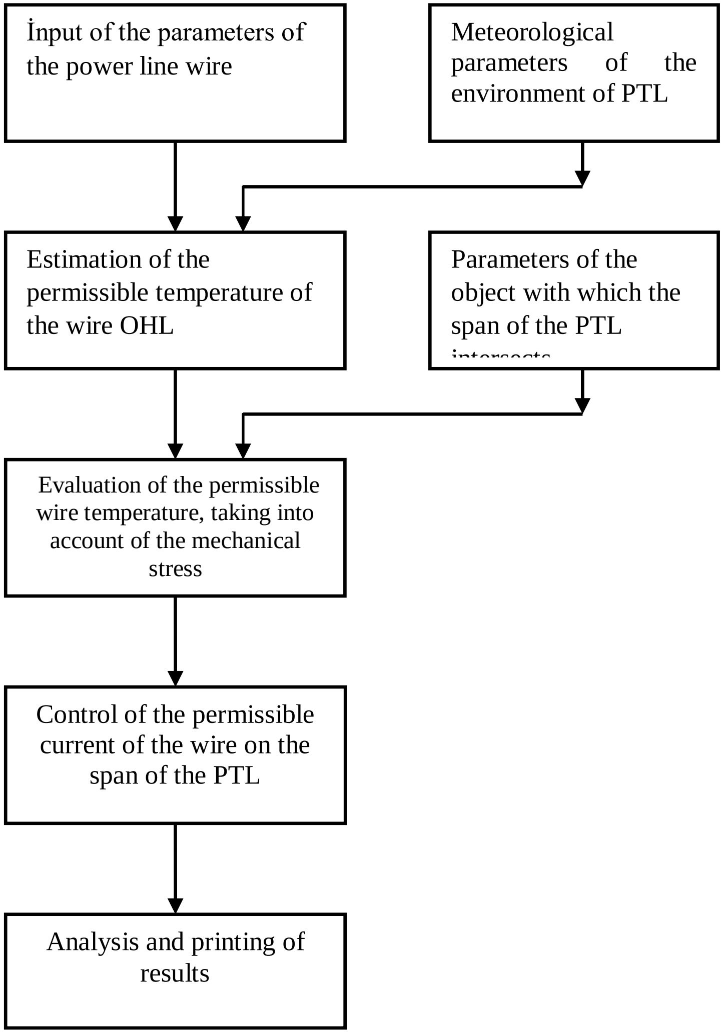


Fig. 2. Block diagram of the program for assessing the permissible temperature of power lines

is possible to improve the efficiency of electricity transmission and increase the throughput of the electrical network.

Long-term permissible load current for wires of overhead lines of AC95/16 brand at permissible temperature +70°C and air temperature 40°C, wind speed v = 0.5 m/s and solar radiation T_{rad} = 15,8°C decreases from 219,5 A down to 171 A, i.e. by 219,5-171 = 48,5 A.

That is (171-219,5)·100/171 = 28,36%, i.e. it decreases.

The permissible values of the long-term admissible power at the level of solar radiation T_{rad} = 15.8°C were:

$$P_{p15} = \sqrt{3} \cdot 1{,}05 \cdot U_n \cdot I_p = \sqrt{3} \cdot 1{,}05 \cdot 110 \cdot 171 \cdot 10^{-3} = 34{,}17 \text{ MVt}$$

Therefore, for the proper calculation of the load capacity of the overhead line based on monitoring solar radiation and its control, in order to comply with the dimensions of the overhead line, it is necessary to reduce its power.

The main results of this chapter are reflected in the author's papers [8, 9, 14].

In the third chapter, the problem of modeling the temperature and power losses of line wires based on the consideration of regime and atmospheric factors is considered, existing programs are analyzed. In connection with the increasing demand for electricity and the noticeable change in climatic conditions in modern times, interest in calculating the permissible mechanical and current loads of overhead lines is also growing. It should be noted that the maximum use of the transmission capacity of the line can be obtained only and only in the presence of sufficiently accurate information about its condition. It can also be determined by increasing the calculation accuracy of electric power losses of overhead lines, taking into account the active resistance of the wires, the Working current of the line, the ambient temperature, the wind speed and the heat generated by the sun's Rays.

RateKit calculates the overhead line current (or maximum achievable temperature value) for the weather conditions that can be used. The user can use one of two calculation methods: the IEEE 738-2012 method or the method based on the latest CIGRE 207 technical brochure[3].

Evaluation of the thermal regime of overhead lines is implemented in a software package developed on the basis of the Azerbaican Research and Project Design Energy Institute methodology. The software package is based on the technique used in the CIS countries with various regime changes and atmospheric factors (**Fig. 3**).

The calculations were performed for wire samples 429-AL1/56-ST1A. The obtained temperature values corresponding to the CIGRE, IEEE and FEM methods are shown in the **table 1.**

Table 1.

Comparison of wiring temperature with different reporting methods

Calculation methods	Reporting methods			
	The effect of solar radiation is not taken into account		The effect of solar radiation is taken into account	
	T_{wire}, °C	Π_{i} %	T_{wire}, °C	Π_{I} %
CİGRE	-	-	55,7	0
İEEE	-	-	55,3	4,3
FEM	-	-	54	3,1
Az.SR and DP Eİ	48	2	52	6,5

Based on the calculations performed to assess the influence of the load current, ambient temperature, solar radiation and wind speed on the active resistance of the overhead line, it was found that the

[3] Staszewski, L., Rebizant, W. The differences between IEEE and CIGRE heat balance concepts for line ampacity considerations // Modern Electric Power Systems, - Wroclaw: IEEE, - 20-22 Sept., -2010, - pp. 1-4.

relative errors in calculating power losses in wires without taking into account the dependence of resistance on temperature can be 26% or more, which is unacceptable.

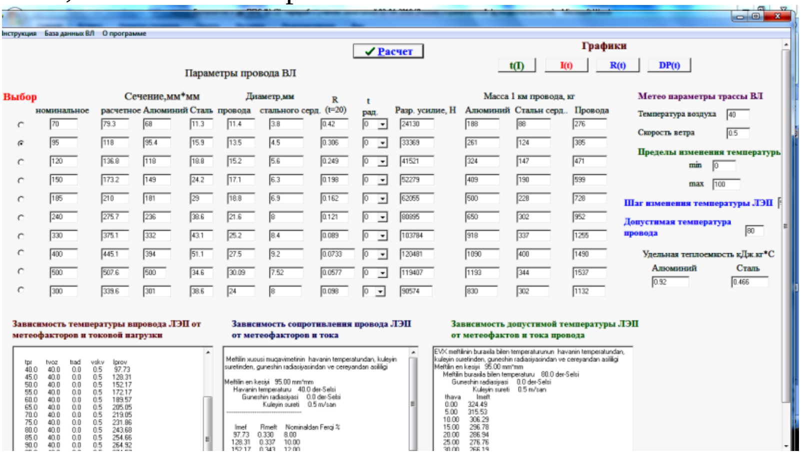
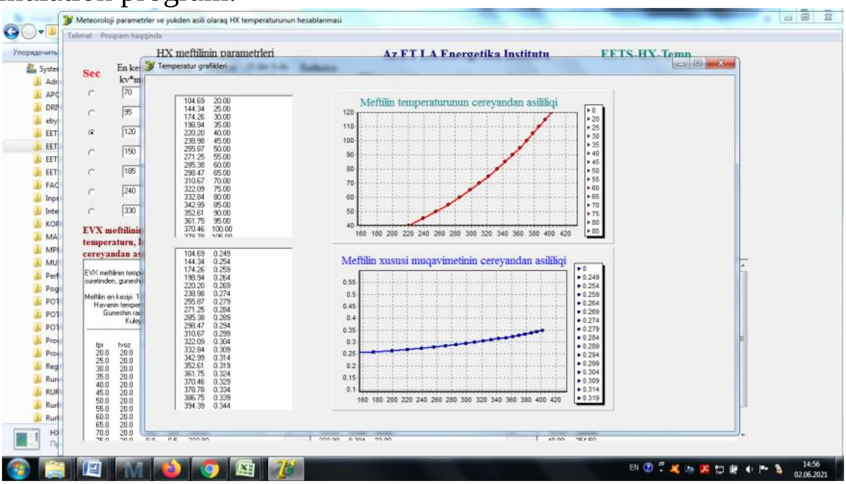


Fig. 3. Wire temperature simulation program

Graph.2 shows the screen forms of the wire temperature simulation program.



Graph.2. Dependence of temperature and wire resistance on current

Representation of a graph of piecewise nonlinear approximation by dividing it into two parts - $t_a \leq 0$ and $t_a > 0$ and the use of a second-order polynomial for approximation has some advantage and practically acceptable accuracy compared to the results of using polynomials of higher order.

For example, for t_a = –40÷0°C,

$$I_{n(-40 \div 0)} = -0,164x^2 + 2,3118x + 490,58$$

And for t_a = 0÷90°C,

$$I_{n\ (0 \div 90)} = -\ 0,0149x^2 + 4,1767x + 498,45.$$

A comparison with a polynomial of the third degree at standard deviation of 4,35% shows that the non-linear piecewise approximation of the second degree polynomial by dividing it into two parts is more accurate: the standard deviation of the first part is 3%, and the second is 0,21%.

To improve the accuracy of calculating active power and energy losses, automatic registration of the wire temperature is necessary.

The Azerbaijan Research and Project Design Energy Institute has developed an algorithm which implemented in the form of a program for simulating wire temperature, taking into account the load current of overhead lines and the influence of atmospheric factors (Fig.4).

The program has found practical application in modeling the technical losses of electricity in the EPS of Azerbaijan and at monitoring 110 kV overhead lines.

It is shown that the accuracy of approximation of the dependence of the current on the wire temperature, wind speed and air temperature by the polynomial of the third degree is sufficient for practical purposes.

The main results of this chapter are reflected in the works [13, 15, 16] of the author.

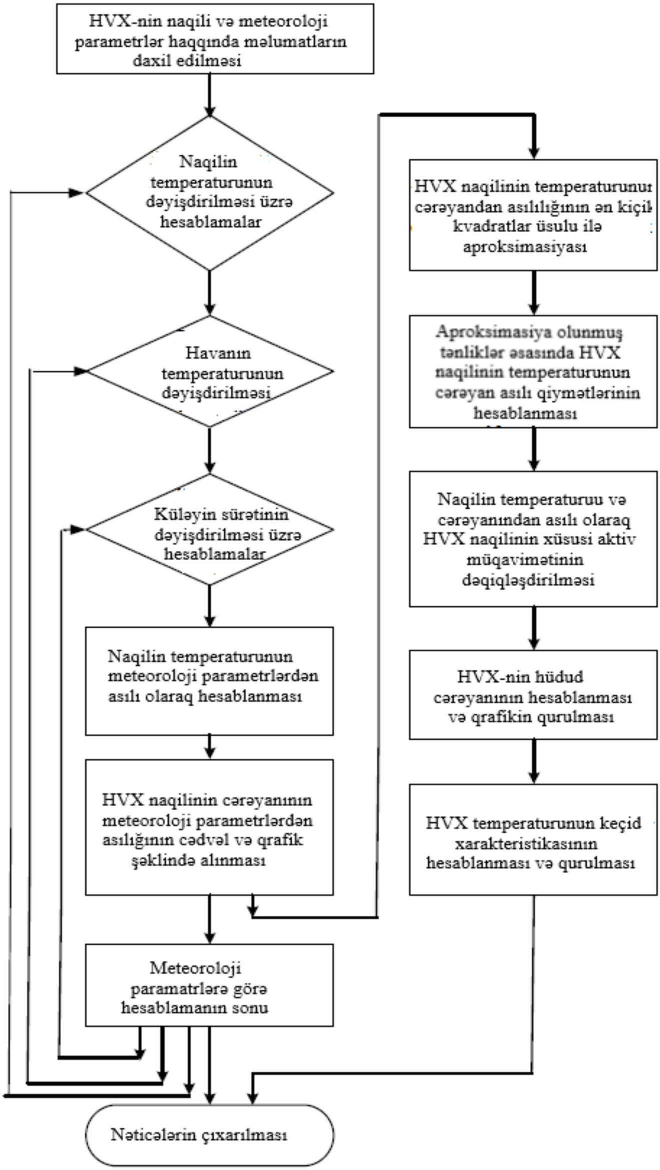


Fig. 4. Block-scheme of modeling the temperature and active resistance of the OHL wire depending on the current and atmospheric factors

In the fourth chapter considers the issue of checking the effectiveness of monitoring the load capacity of the OHL using the algorithm and software developed according to the proposed method based on the temperature of the line wires. For this purpose, the 2th Absheron line with a length of 250 km and a voltage of 500 kV was taken as the object of research.

The use of control devices in the summer months at high air temperature and solar radiation, wire temperature control and determination of permissible load currents for specific climatic conditions, in order not to limit or significantly reduce the scope of consumer restrictions in case of high current loading of overhead power lines, allows more complete use the load capacity of overhead lines. There are two main ways to provide this opportunity: direct and indirect (calculated).

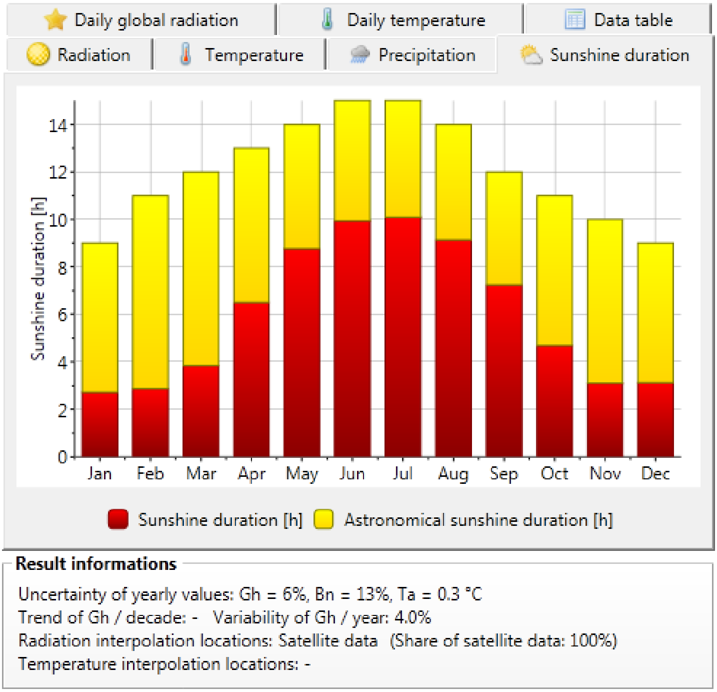
In power lines, the following types of losses are distinguished: inevitable losses due to the ohmic resistance of the wire; losses due to electromagnetic radiation; corona discharge losses in wires and insulators; losses due to resonant phenomena in the wire with load incompatibility; current leakage due to lack of insulation, etc.[4]

Meteonorm program to monitor the weather was used. To work in the program, you must enter the coordinates of the point, the desired location of solar radiation. For the power transmission line in the zone of the Baku airport, Bina is accepted – 40,5°N/50,1°E, 1m.

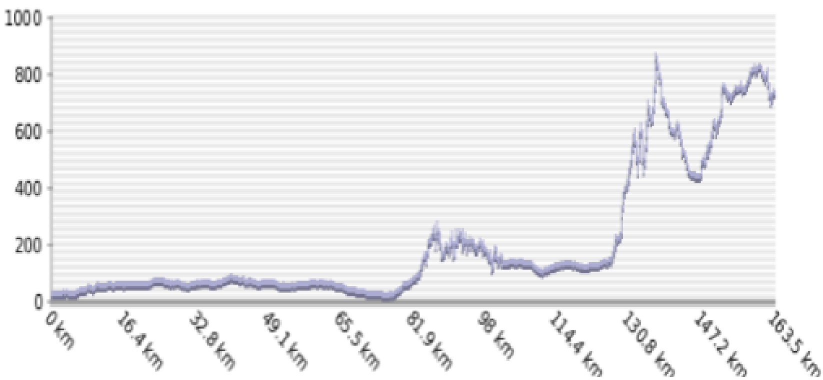
The average solar radiation per year for the Bina airport zone in Baku is shown in graf. 3.

The height of the power transmission lines at the distance to the Absheron substation relative to sea level is given in graf.4.

[4] Balametov, Ə.B., Xəlilov, E.D. Enerji sisteminin elektrik şəbəkələrində elektrik enerjisi itkilərinin hesablanması, təhlili və normalaşdırılması. - Bakı: - “Elm”, - 2015. – 234 s.

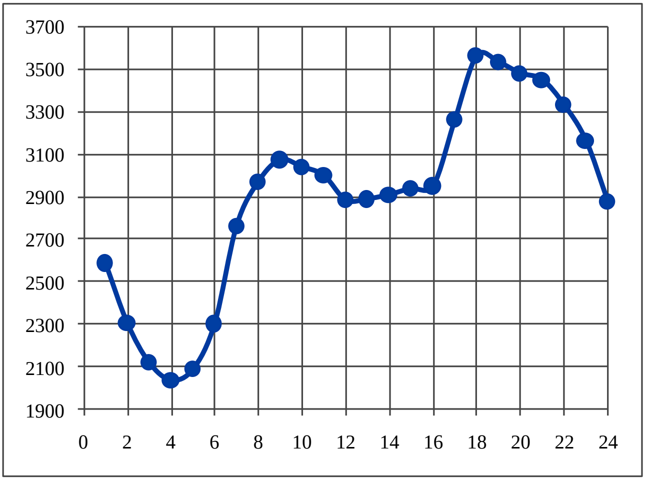


Graf. 3. Solar radiation for Bina airport zone of Baku



Graf. 4. The height of power transmission lines at sea level at the distance to Absheron substation

On the day of control measurement on December 17, 2008, The Daily Load graph obtained from the SCADA system of the EES of Azerbaijan is presented in graph. 5.



Graph.5. Load graphic of active power of 500 kV Absheron overhead line

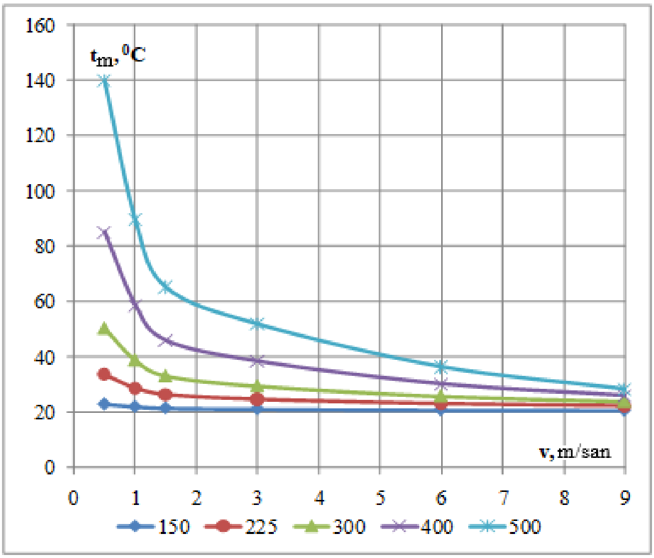
Table 2 shows the dependence of the current in the overhead line on the additional temperature caused by the temperature of the wire, solar radiation and wind speed.

The results of monitoring in extreme weather conditions and the load capacity of the power transmission line are given, the system for monitoring the wire of the power transmission line is presented, the dependence of the temperature of the wire on the speed and strength of the wind (graph.6), the dependence of the permissible load current of the AC-185 wire on the wind speed (graph.7), the graph of the dependence of the permissible current of the AC240/39 wire at temperature air at -40°C, 0°C and +40°C, and wind speed ν = 0,5 m/s (graph.8).

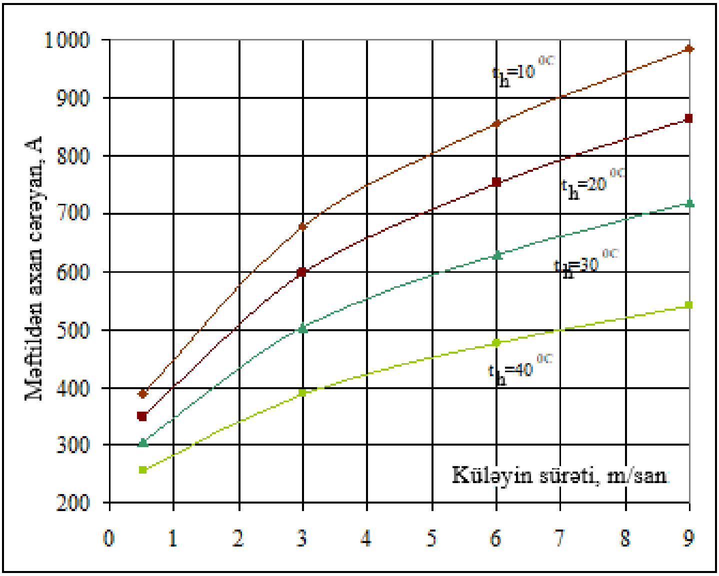
Table 2.

Dependence of the current in the overhead line on the additional temperature caused by the temperature of the wire, solar radiation and wind speed

Temperature of wire, °C	Temperature of solar radiation, °C	Wind speed, m/sec	Current of wire, A
Air temperature, 20°C			
80	0	0,5	675,95
80	0	1,0	833,97
80	16	0,5	598,41
80	16	1,0	730,12
Air temperature, 35°C			
80	0	0,5	603,55
80	0	1,0	737,04
80	16	0,5	515,24
80	16	1,0	617,09



Graph.6. Dependence of wire temperature on wind speed and current

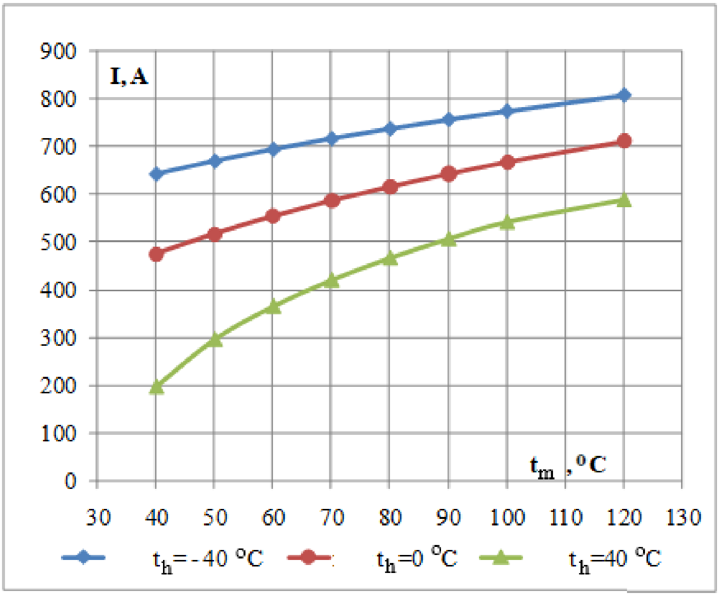


Graph. 7. Dependence of the discharge load current of the AC185/24 wire on the wind speed

A system for monitoring power losses based on SCADA measurements has been implemented on the power transmission line.

On the example of a transmission line, the results of modeling (P_2, Q_2, U_2, $\Delta P_{\sum}$) of the mode parameters based on measurements at the beginning (P_1, Q_1, U_1) and at the end (P_2, Q_2, U_2) of the overhead line, the possibility of estimating power losses (ΔP_{load}, ΔP_{kor}) is shown. On fig. 3 shows the hourly load on the vertical axis in OHL.

In this chapter, a multifunctional regression model of wire temperature is obtained using a full factorial experiment. The problem of constructing regression models by the method of parametric simulation for obtaining multifunctional analytical dependencies is considered.



Graph. 8. Graphs of the discharge current of the AC 240/39 wire

For this purpose, an experiment plan for obtaining a full-factor model by processing the results of simulation based on the developed software composed, the problem of obtaining complete second-order regression models on two-factor samples based on statistical processing of the results by applying regression modeling algorithms was solved, and the adequacy of the obtained model checked.

The advantage of polynomial regression models is simplicity and clarity. The coefficients of multifunctional regression models directly indicate the degree of quantitative influence of each of the parameters on the process under study.

The fact that it is simple and clear is the main advantage of polynomial-type regression models. The coefficients of multifunctional regression models show the degree of direct quantitative influence of each of the parameters on the process under study.

As an example, regression models were obtained for the wire AC330/43. The specific active resistance of the wire is R_{20}=0,0869 Om/km.

The calculation of the wire temperature performed based on the results of simulation using software for the given ambient temperature for the wire and the operating current values of the wire.

Factors - independent variables are presented in a normalized form:

$$x_{in} = \frac{x_i - x_{i0}}{\Delta x_i}$$

Variations of air temperature and wire current factors are shown in **table 3**.

Table 3.

Limits of variation of factors air temperature and current in the wire

Level	Factor	
	T_{air}, °S	I_{wire}, A
Main variation level of factor	20	450
High level	40	700
Low level	0	200

The planning matrix for a two-factor experiment is shown in **table 4**.

Table 4.

Two-factor experiment planning matrix

Plan of coded factor levels in relative units		Plan of factor levels in named units		Calculated wire temperatures
T_{airK}	I_{wireK}	T_{air}, ^{0}C	I_{wire}, A	T_{wire}, °C
1	1	40	700	107
-1	1	0	700	65
1	-1	40	200	40
-1	-1	0	200	0
-1	0	20	450	20
1	0	40	450	58
0	-1	20	200	20
0	1	20	700	85
0	0	20	40	40

In order to calculate the regression coefficients by the method of a full-factor experiment, an Excel program was compiled. The values of the coefficients of regression dependencies are shown in **table 5**.

Table 5.

Values of coefficients of regression dependencies

№	For complete quadratic model	
	Coefficient	Value
1	B_0	39,333
2	K_{TairK}	20
3	KI_{wireK}	32,833
4	K_{12}	0,5
5	K^2_{TairK}	0
6	K^2I_{wireK}	13,5

The display form of the program for calculating the temperature of the wire by means of a regression model is shown in Figure 5.

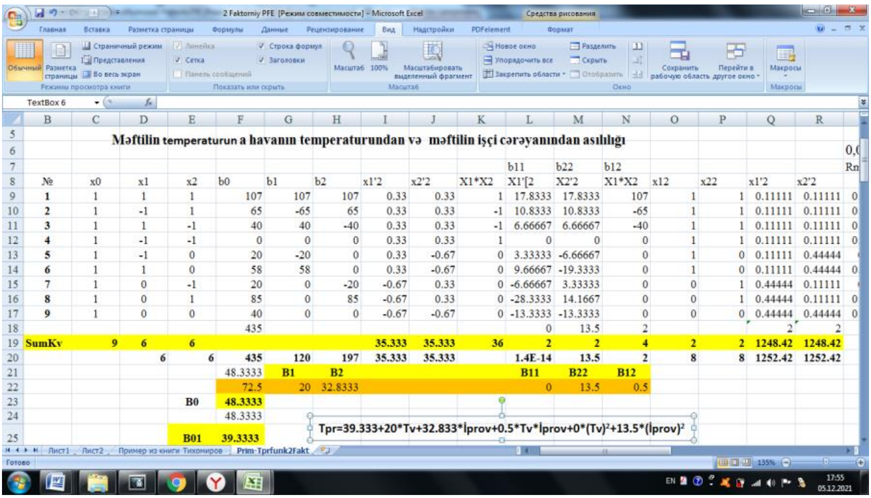


Fig.3. Screen form of the program for calculating the temperature of the wire through the regression model

The regression model is described by the following mathematical equation:

$$T_{wire}=39{,}333+20\cdot T_{airK}+32.833\cdot I_{wireK}+0{,}5\cdot T_{wireK}\cdot I_{wireK}+$$
$$+0\cdot(T_{airK})^2+13{,}5\cdot(I_{wireK})^2$$

The coefficient of the air temperature factor is equal to zero, which indicates that the coefficient is not significant. The linearity of the temperature dependence of the active resistance indicates the adequacy of the regression model.

The objective function for the values in named units of the factors is obtained by substituting the encoded values

$$T_{airK}=\frac{T_{air}-20}{20} \qquad I_{wireK}=\frac{I_{wireK}-450}{250}$$

in

$$T_{wire}=39{,}333+20\cdot\left(\frac{T_{air}-20}{20}\right)+32{,}833\cdot\left(\frac{I_{wireK}-450}{250}\right)+$$
$$+0{,}5\cdot\left(\frac{T_{wire}-20}{20}\right)\cdot I_{wireK}+0\cdot\left(\frac{T_{air}-20}{20}\right)^2+13{,}5\cdot\left(\frac{I_{wireK}-450}{250}\right)^2$$

The results of complete and incomplete regression models are shown in the **table 6.**

An incomplete regression model leads to an error of more than 10%.

The following regression equation is obtained for the dependence of the active resistance of the wire on the air temperature and the working current of the wire:

$$R_{wire}=0{,}09362+0{,}006952\cdot T_{airK}+0{,}011413\cdot I_{wireK}+$$
$$+0{,}000174\cdot T_{airK}\cdot I_{wireK}+0\cdot(T_{airK})^2+0{,}004693\cdot(I_{wireK})^2$$

Table 6.

Results of complete and incomplete regression models

№	Factor coded levels plan		Results of imitation modeling	Results of regression models	
	T_{airK} r.u.	$T_{air\ K}$ r.u.		incomplete	complete
1	1	1	107	92,667	106,167
2	1	-1	65	51,667	65,167
3	1	1	40	25,999	39,499
4	1	-1	0	-13,001	0,499
5	1	-1	20	19,333	19,333
6	1	1	58	59,333	59,333
7	1	0	20	6,499	19,999
8	1	0	85	72,167	85,667
9	1	0	40	39,333	39,333

The calculation of power losses on a 500 kV overhead line with a length of 250 km was carried out based on the equation in hyperbolic functions:

$$\Delta P_H = \left[0{,}9556\cdot\left(\frac{P_2^2+Q_2^2}{U_2^2}\right)+5{,}5573\cdot10^{-7}\cdot U_2^2+9{,}01\cdot10^{-6}\cdot P_2-12{,}5227\cdot10^{-4}\cdot Q_2\right]\cdot \mathrm{r}_{0t}\cdot \mathrm{L}$$

Regression dependences of active power losses of overhead lines on air temperature and operating current of the wire on the following form are obtained:

$$\Delta P_{wire}=18935{,}9+1730{,}76\cdot T_{airK}+25144{,}8\cdot I_{wireK}+$$
$$+1649{,}36\cdot T_{airK}\cdot I_{wireK}+33{,}312\cdot(T_{airK})^2+9662{,}7\cdot(I_{wireK})^2$$

Relative errors in calculating the specific active resistance for wire AC-330/43 are computed taking into account the air temperature relative to the specific active resistance at a temperature of 20°C.

The relative error in the air temperature range from 0°C to +40°C at an allowable wire temperature of +107°C is 34%.

The main results of this chapter are reflected in the works [1-4, 10, 11] of the author.

THE MAIN RESULTS OF THE DISSERTATION WORK

1. An algorithm and a program for calculating the specific active resistance of overhead lines wires have been developed, by taking into account air temperature, operating current, wind speed and solar radiation. A quantitative assessment of the influence of the load current, ambient temperature, solar radiation and wind speed on the active resistance of the wires of overhead lines has been carried out.
2. Permissible continuous load currents and power for wires of overhead lines with a rated voltage of more than 110 kV at an allowable temperature of +70°C and an air temperature of 25°C have been calculated.
3. For AC95/16 wires at a wind speed of 3.0 m/s, the permissible load on the overhead line wire increases from 256A up to 453 A compared to 3,0 m/s. On the basis of wind speed monitoring, by proper calculation and management of the overhead line carrying capacity and increasing its capacity, it is possible to improve the transmission efficiency of the electric network.On the basis of solar radiation monitoring, to proper calculation and management of the throughput of the overhead line, to compliance with the overall dimensions of the overhead line, a decrease in its power is required.
4. Relative errors in the calculation of power losses in wires without taking into account the temperature dependence of the resistance can be 26% or more.
5. Monitoring of the technical condition of overhead lines, current strength and temperature of wires and intensity of solar radiation, wind speed allows you to increase the load capacity of overhead lines. Modern technologies for improving the

efficiency of overhead lines based on monitoring their condition can improve the efficiency and reliability of electricity transmission. It has been established that, taking into account regime, atmospheric factors and solar radiation, the load capacity of overhead lines can be increased by more than 20%.

6. The use of the heat balance equation for calculating the temperature and active resistance of the OHL wire is considered, taking into account atmospheric and regime factors.
7. The method for calculating the wire temperature and power losses, by taking into account atmospheric factors and temperature, is realized as a program in the Delphi programming system.
8. Regression dependences related with load current, air temperature and wind speed have been developed. With the help of regression models, the temperature and active resistance of the power line wire were simulated depending on the current and atmospheric factors.
9. Full-factor regression models dependence on the working current of the wire, atmospheric factors are proposed to be approximated by a multifunctional analytical polynomial.

THE MAIN RESULTS OF THE DISSERTATION ARE REFLECTED IN THE FOLLOWING PUBLISHED SCIENTIFIC ARTICLES:

1. Agaxanova K.A. Analysis parameters of power transmission line considering influence of solar radiation and temperature by sections of the route //ISTRE-2019 Conference proceedings. The 15th International Conference on Technical and Physical Problems of Electrical Engineering, - Istanbul, Turkey: - 14-15 October, - 2019, - s. 194-198.
2. Ağaxanova K.A. Hava xəttinin yük buraxma qabiliyyətinin məftillərin temperaturuna əsasən monitorinqi // Sumqayıt: Elmi xəbərlər jurnalı, - 2021. №2, - s. 89-96.
3. Balametov A.B., Agahanova K.A., Balametov E.A. Analysis of OHL parameters taking into account the influence of solar radiation and temperature on the sectors of the route // - Tabriz: International Journal on "Technical and Physical Problems of Engineering" (IJTPE), - June 2021, Issue 47, Volume 13, Number 2, - pp. 118-123.
4. Balametov Ə.B. İsayeva T.M. Ağaxanova K.A. SCADA ölçmələri əsasında elektrik veriliş xəttində güc itkilərinin monitorinqi sistemi // İnformasiya sistemləri və texnologiyalar, nailiyyətlər və perspektivlər Beynəlxalq elmi konfransı, - Sumqayıt: - SDU, - 15-16 noyabr, - 2018, - s. 46-48.
5. Balametov Ə.B., Bayramov M.P., Ağaxanova K.A. Elektrik verilişi xətti məftilinin buraxıla bilən yükünün hesabatı metodikası // - Sumqayıt: "Elmi xəbərlər" jurnalı, - 2018, Cild 18, №1, - s. 80-86.
6. Balametov Ə.B., İslamov İ.Z., Ağaxanova K.A. Elektrik enerjisi itkilərinin qiymətləndirilməsi üçün CİGRE və İEEE standartlarının tətbiqi // - Sumqayıt: "Elmi xəbərlər" jurnalı, - 2018, - Cild 18, №4, - s. 89-94.

7. Balametov Ə.B., Səlimova A.K., Ağaxanova K.A. Hava xətti naqilinin istilik hesablanması nümunəsində temperatur artımının müqayisəli təhlili // Energetika ixtisasları üzrə kadr hazırlığının aktual məsələləri respublika elmi konfransının materialları, - Sumqayıt: SDU, - 20-31 may, - 2019, - s. 180-183.
8. Balametov Ə.B., Səlimova A.K., Ağaxanova K.A., Abdullayeva G.K. Aktiv müqavimətlərin temperatur asılılığını nəzərə alaraq paylayıcı elektrik şəbəkədə güc itkilərinin hesablanması//İnformasiya sistemləri və texnologiyalar nailiyyətlər və perspektivlər II Beynəlxalq Elmi Konfransın materialları, - Sumqayıt: SDU, - 09-10 iyul, - 2020, - s. 88-90.
9. Агаханова К.А. Анализ параметров воздушной линии с учетом атмосферных факторов и солнечного излучения по участкам трассы // - Сумгаит: Журнал «Научные новости», - 2021. Том 21, №2, - s. 89-96.
10. Баламетов А.Б., Агаханова К.А. Анализ параметров воздушной линии с учетом влияния солнечного излучения и температуры по участкам трассы // Федоровские чтения XXIX Международная научно-практическая конференция с элементами научной школы, - Москва: МЭИ - 20-22 ноября, - 2019 г., - с. 100-103.
11. Баламетов А.Б., Агаханова К.А. Анализ температурного режима электропередачи с учетом атмосферных факторов по трассе линии // Труды международной научной конференции, - Сумгаит: СГУ, - 2020, №7, - с. 237-242.
12. Баламетов А.Б., Агаханова К.А. Применение совместной электрической и тепловой модели воздушной линии для расчета режимов // Федоровские чтения XLVIII Международная научно-практическая конференция с элементами научной школы, - Москва: МЭИ - 14-16 ноября, - 2018 г., - с. 138-140.

13. Баламетов А.Б., Байрамов М.П., Исламов И.З., Агаханова К.А. Анализ результатов моделирования температуры проводов воздушных линий с учетом влияния солнечной радиации // Международная научная конференция Актуальные вопросы прикладной физики и энергетики, - Сумгаит: СГУ, - 24-25 мая, - 2018, - с. 250-252.
14. Баламетов А.Б., Салимова А.К., Агаханова К.А. Сравнение методов оценки потерь электроэнергии с учетом температуры провода// Федоровские чтения XLVII Международная научно-практическая конференция с элементами научной школы. Москва: МЭИ, - 15-17 ноября 2017 г., - с. 135-137.
15. Баламетов А.Б., Халилов Э.Д., Байрамов М.П., Агаханова К.А. Программа моделирования температуры провода и потерь мощности на основе учета режимных и атмосферных факторов. Программные продукты и системы/Software & Systems 2 (31) 2018, с. 396-402.
16. Баламетов А.Б. Оперативное моделирование температуры провода для максимального использования пропускной способности воздушных линии/А.Б. Баламетов, Э.Д. Халилов, М.П. Байрамов [и др.] // Журнал «Оперативное управление в электроэнергетике: подготовка персонала и поддержание его квалификации», - Москва: - 2019. №1 (76), с. 16-24.

Applicant's Personal Contribution in Published Works

The works [1,2,9] were carried out by the author independently.

In the works [3,4,5,7,8,10,11,12,13,16] the experiments, the analysis of the results, the formulation of the provisions was carried out by the author. The remaining parts of the works were performed by their authors in the same volume.

The defense of the thesis will be held at the meeting of the ED 2.04 Dissertation Council operating under the Azerbaijan Technical University on 17.01.2025.

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