International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

June 2021 | Issue 47 | Volume 13 | Number 2 | Pages 118-123

ANALYSIS OF OHL PARAMETERS TAKING INTO ACCOUNT THE INFLUENCE OF SOLAR RADIATION AND TEMPERATURE ON THE SECTORS OF THE ROUTE

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Abstract- An algorithm for more accurate modeling of the wire temperature and power transmission line (PTL) parameters taking into account solar radiation by dividing into equivalent sectors by altitude and radiation intensity is proposed. To take into account the influence of the real state of solar radiation, weather conditions and their influence on its parameters, the PTL is divided into sections according to the altitude, the intensity of heat of solar radiation and its direction, wind speed and direction. A block diagram of a program of modeling is proposed. The calculation results are demonstrated on the example of a 500 kV PTL with a length of 250 km.

Keywords: Power Transmission Line, Air Temperature, Solar Radiation Intensity, Atmospheric Transparency, Average Temperature, Resistance, Power Losses.

1. INTRODUCTION

The power transmission line (PTL) is constantly impacted by weather conditions. Temperature, precipitation, atmospheric pressure, humidity, as well as wind speed and direction are important parameters, the measuring of which is necessary for monitoring the weather conditions for PTL.

Knowing the current weather situation along the power transmission line allows for reducing power outages. Sensors and monitoring systems for weather conditions should be located along the PTLs. Energy companies require reliable weather data to effectively manage the operation of electrical networks. For monitoring, both complete weather stations operating in autonomous mode and simply a set of remote sensors mounted on supports can be used.

Reliable and uninterrupted power supply to consumers is possible only with the introduction of effective measures for monitoring weather conditions along power transmission lines.

Overhead transmission lines (OHL) in the autumn-winter period to prevent ice accidents and in the summer period for a more complete use of the load capacity of overhead line.

The use of monitoring equipment in the summer at high air temperatures and solar radiation can make it possible to more fully use the load capacity of overhead transmission line and avoid or significantly reduce the scope of consumer restrictions at high current loads on the line due to monitoring of the wire temperature and determining the limiting current loads for specific climatic conditions. Two main ways are possible: direct and indirect (calculated).

In the absence of the wire temperature data, it can be calculated using the OHL monitoring program. In addition, the program allows for calculating the current load values according to the condition of the mechanical strength of the wire and non-disturbance of the permissible dimensions of OHL under various weather conditions, including taking into account the solar radiation. The program allows for calculating the change in the temperature of wire and sags in the 5th dynamics and determining the permissible time of operation of OHL when the overloading of the wires occurs.

Monitoring systems for overhead electrical networks of PTLs provide additional functions allowing for improving the efficiency of power transmission and reducing losses. Monitoring not only ensures an increase in the reliability of electricity transport, but also helps to reduce the costs for the maintenance of power transmission lines due to faster and more accurate data when localizing emergency segments, as well as prediction of problem situations on the route. The use of promising monitoring systems for overhead electrical networks has recently become especially topical in the section of 220-330-500 kV PTL of the Azerbaijan EPS, since, firstly, the cost of damage during major accidents has increased significantly, and secondly, due to the decrease of the reliability of power systems due to heavy wear and tear of both the equipment used and wire lines.

In June-August, due to hot weather and high current load on the section of 220-330-500 kV OHL of the Azerbaijan EPS, it is required to introduce restrictions on loads. Measurements of the actual values of current loads, wire and air temperatures and dimensions of OHLs in several areas were performed.

1.1. Improvement of Efficiency of Power Transmission through Power Transmission Lines

When transporting EE along PTLs, the permissible current loads have been determined. In this case, the limiting current values also determine the sagging of the wires above the permissible value. There is usually a resource for the transmission of large capacities without disturbing the normal operating conditions. In practice, PTL has the ability to transfer additional power of 15-30%. The presence of a monitoring system makes it possible to use this additional resource (Figure 1).

For this, it is necessary to control the current level and the temperature of the wires and, in accordance with the real state of the line, adjust the level of the transmitted power. At present, various monitoring systems for PTLare widely used all over the world.

An excess of the temperature of wires above the ambient temperature can be significant due to the simultaneous effect of flowing currents and solar radiation. At that, the sagging of wires and their active resistance increase, causing an increase in power losses and electric power in the distant power lines and networks. Thereby, the economic indicators of operating modes noticeably demerit rate [1].

As a result of increased heating, the distances, normed by safety conditions, from the wires to the ground surface, as well as to natural obstacles and engineering structures crossed by lines, may be disturbed. Therefore, the heating of wires is considered as a factor limiting the transmitted power or the current load of the wires.

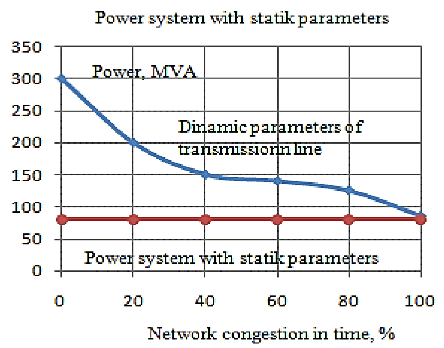


Figure 1. Improvement of the efficiency of power transmission through power transmission lines

Since the OHL route is not straight and the wind speed and direction are not constant, it is impossible to determine the OHL section with the worst heat transfer conditions. If at calculated determination of the wire temperature and the permissible current value the uncontrolled environmental parameters should be taken according to their worst values, this leads to a significant underutilization of the carrying capacity of overhead line.

The power of solar radiation absorbed by the wire obviously depends on the state of the wire surface, on the solar radiation flux intensity (clear or cloudy sky, winter or summer, time of day) and on the cosine of the angle between the direction of the sun's rays and of the axis of wire. Since the OHL route is long and not straight, it is not possible to determine the section of the OHL most strongly heated by the sun.

The climate of Azerbaijan is significantly influenced by the geographical location of the country, the relief and the Caspian Sea. Here semi-desert and arid steppe, subtropical, mild and cold climate are observed. According to V.V. Keppen, 8 climatic zones of 11 are identified here. Kura-Araz lowland and Absheron are characterized by a dry subtropical climate. Humid subtropical climate is observed only in the south of the Talysh mountains, it is characteristic for the foothills and Lankaran lowland. The mild subtropical climate, being observed mainly on the slopes of Creator and Lesser Caucasus covered mainly with forests, is characterized with mild-hot dry, mild-hot humid and mild cold climate. The cold climate is observed in the high mountain ranges, the peaks of the Greater and Lesser Caucasus, in the belt of alpine and subalpine meadows. The average annual temperature in the lowlands is 15 °C, while in high mountain areas it reaches 0 °C and below. In July, the temperature reaches 25-27 °C in the lowland areas and 5 °C in the mountainous areas. The absolute maximum temperature is 43 °C, and the absolute minimum is -30 °C. The intensity of solar radiation on the ground surface in the Republic of Azerbaijan is 800 ÷ 1000 kW*h W/m^2 for a cloudless clean atmosphere for the Absheron Peninsula and the Caspian coastal strip. Here the number of sunny hours during a year is 2500 hours. For the Nakhchivan Autonomous Republic, these figures are 1100 ÷ 1200 kWh/m^2 and 2500 hours, respectively.

1.2. Solar Radiation Intensity on the Ground Surface in Different Weather Conditions W/m^2

The data are: clear sky - 1200; cloudy sky - 800; the sun is like a white disk - 300; overcast winter day - 100.

According to an international agreement in 1981 and on the recommendation of the Commission of the European Community and the International Electrotechnical Commission at the UN, it is recommended to use the solar energy value - 1367 W/m^2 as a single standard for measuring the value of solar energy in calculations [2-3].

Direct solar radiation for the territory of Nakhchivan AR at summer solstice time: S_m = 1163 W/m^2. Direct solar radiation for winter solstice: S_{pz} = 522 W/m^2. Diffusion solar radiation for the summer solstice: S_{dl} = 51 W/m^2, for the winter solstice: S_{ppz} = 45 W/m^2.

Then the total receipt of sun rays on the territory of the Nakhchivan AR (2) at summer time solstices: S = 1214 W/m^2; for the winter solstice: S = 567 W/m^2. The level of sun rays on the Nakhchivan Autonomous Republic is quite high and amounts to 2900÷3000 hours per year [4].

The duration of the sun shine in the Nakhchivan Autonomous Republic is: in March, 290-300 hours, in April 300-310 hours, in May 310-320 hours, in June 460 hours, in July 470 hours, in August 470 hours, in September 320-330 hours and in October 340 hours. Maximum solar radiation falls on the summer months.

In conditions of complex, mountainous relief, such as the territory of Nakhchivan Autonomous Republic, the intensity of the sun's rays increases by 7-14 W/m^2 every 100 m above sea level [4-6].

2. HEAT BALANCE OF WIRES

The heating of the wire in relation to the ambient air temperature in a steady thermal mode is determined by the balance of powers, heating and cooling the wire. The heat balance equation for steady-state thermal conditions is written as follows [1]:

$$\left[I^2 R_{20}\left[1+a\left(t_w-20\right)\right]+W_c=pd_w\left(a_\kappa+a_r\right)\left(t_w-t_a\right)\right] \quad (1)$$

where, I is line current, A; Ohm/m; t_a is air temperature, °C; α_k, a_r are heat emission coefficient of wire at convective and radiant heat exchange, W/(m_2°C); W_c is heat flux of solar radiation absorbed by 1 m of wire per unit of time, and W; d_w is wire diameter, m.

From Equation (2) for current [5, 6] can be obtained

$$I=\sqrt{\frac{\varepsilon C_0\left(273+t_w\right)^4\pi d_w+\sigma_k\left[\left(t_w-t_{rad}\right)-t_h\right]\pi d_w}{0.95\times R_{20}\times\left[1+0.004\times\left(t_w-20\right)\right]}\sigma} \quad (2)$$

Heat emission coefficient by convection is determined by the formula [3]

$$\sigma_k=0.13057\times\left(\frac{k_v v d_w}{a}\right)^{0.71719}\frac{\lambda_a}{d_w} \quad (3)$$

where k_v is coefficient taking into account the influence of the angle of wind direction to the axis of the overhead line, equal to 0.5; v is wind speed, m/s; α is air thermal diffusivity, equal to 18.8×10^{-6} m^2/s; λ_a is air thermal conductivity, equal to 0.0244 W/(m°C).

Due to the dependence of the heat transfer coefficient on the wire temperature, the calculation of the temperature of bare wires can be obtained from formula (6) and solved by the method of successive approximations based on the equation

$$t_w^{[k+1]}=\frac{\pi d_w\left[\alpha_k\left(t_w^{[k]}\right)\right]-\alpha_1\left(t_w^{[k]}\right)-I^2R_{20}\left(20\alpha-1\right)+W_C}{\pi d_w\alpha_k\left(t_w^{[k]}\right)-I^2\alpha} \quad (4)$$

where, k is iteration number. Formula (4) allows for calculating the wire temperature at known current and different weather conditions.

From the heat balance equations of wire (2) follows that the minimum allowable value of temperature t_p consists of three components

$$t_p=t_I+t_a+t_{rad} \quad (5)$$

where, t_I is component of wire heating by load current due to energy losses in the active resistance of wire.

The temperature t_{rad} depends on solar radiation intensity, height and density of clouds. The sun's radiation intensity varies during the year. According to the state of the sun in September from 14:30 to 15:30 at blue sky and no wind, the following equation was obtained for the AC wires in [3]:

$$t_{rad}=K_\tau\times K_\tau'\times K_{rad}\times d^{0.44152} \quad (6)$$

where, K_{rad} = 92.0375 °C/m. For the period from 20 to 24 and from 24 to 7 o'clock t_{rad} = 0 is taken.

Measurements made for wires of different grades to take into account the solar radiation in June for the time from 11 to 13 o'clock (maximum heating) during calculation the following coefficients are entered to the formula (6), at blue sky K_τ=1.15, K_τ'=1 and at gray sky and visible sun K_τ'=0.5.

3. EFFECTS OF SOLAR RADIATION

The heat emission coefficient by radiation is characterized by a considerable uncertainty, which depends both on the state of the wire surface and on the wire temperature in certain sections of the OHL.

The intensity of solar radiation absorbed by the wire:

$$W_s'=\alpha.k_n.W_r.\sin\delta \quad (7)$$

where, α = 0.6 is wire absorption coefficient; k_n is coefficient taking into account the influence of altitude; and δ is active tilt angle of sun rays, defined by the expression:

$$\delta=\arccos(\cos h_c.\cos(180-\psi))$$

where, h_c is angular height of the sun; and ψ is geographic angle of power line (its orientation relative to the meridian) with a range of change of 0÷180°.

4. SIMULATION

The algorithm for more accurate modeling of the wire temperature, taking into account the real state of weather conditions on the OHL route by sectors, is shown in Figure 2. The algorithm consists of: dividing the overhead line into sections with altitude-averaging in meters; the length of the relevant sections in km; hourly load (a current) of OHL per day; setting of weather conditions for the OHL sectors; determination of the wind intensity angle; setting of the wind speed and its direction angle for the OHL sectors; modeling of the of solar radiation intensity by sectors; modeling of the intensity of solar radiation absorbed on the OHL sectors [7-12].

In order to assess the overheating of wires from the solar radiation, it is necessary to find out the solar radiation intensity at the site of the construction of PTL. For this, we will use the Meteonorm program. To work in the program, it is necessary to set the coordinates of the point at which it is required to find solar radiation. For PTL for the Bina Airport zone of Baku City, we will take coordinates - 40.5°N/50.1°E, 1m.

For example, the 2nd Absheron PTL 500 kV with length of 250 km is considered, the route of which runs across mountainous terrain having different heights, weather conditions and solar radiation intensity and wind speed respectively. The parameters of the PTL are shown in Figures 3-7. The height of the sections of power transmission lines above sea level of the 500 kV OHL section of 2nd Absheron from the Absheron - Shamakhi - Agsu substation and the distances of the sections are shown in Figure 6.

The load chart at the end of the power transmission line on control measurements days on December 17, 2008 is shown in Figure 7. The results of the calculation on program, for the wire AC 330/43 depending on the air temperature, the intensity of solar radiation and the wind speed at air temperature of 25 °C are given in Table 1.

For the section of the power transmission line of Shamakhi 500 kV, the 2nd Absheron line with a height above sea level of 800 m. The air temperature in Shamakhi differs on average by 5-8 °C relative to the temperature of Absheron substation.

	Gh kWh/m²	Dh kWh/m²	Bh kWh/m²	Ta °C	Td °C	FF m/s
January	54	27	74	4.7	2.7	4.9
February	65	40	54	5.2	3.3	5.4
March	112	64	83	7.8	5.7	5.9
April	140	79	95	11.7	8.8	5.2
May	179	104	107	17.7	13.4	4.9
June	193	98	132	22.9	16.3	5.7
July	189	100	124	26.2	19.7	5.4
Abgust	161	91	104	26.8	20.4	4.7
September	122	67	90	22.6	17.8	4.7
October	90	52	76	17.2	14.6	4.6
November	61	32	74	11.5	9.3	4.9
Deccember	53	29	67	66	4.9	5.1
Year	1417	783	1080	1.1	11.4	5.1

Result information
Uncertainty of yearly values: Gh=6%, Bn=13, Ta=0.3°C
Trend of Gh/decade: - Variability of Gh/year:4.0%
Radiation interpolation locations: Satellite data (Share of satellite data: 100%)
Temperature interpolation locations: -

Figure 3. The average total solar radiation for each month for Bine Airport zone in Baku

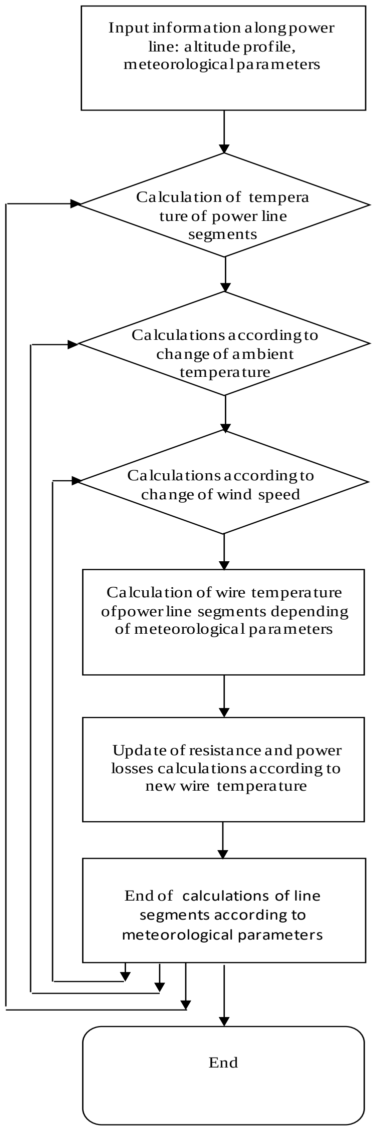
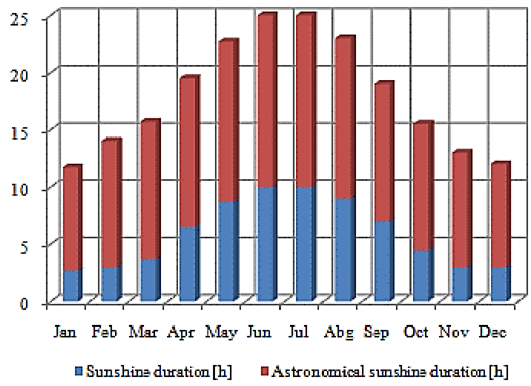
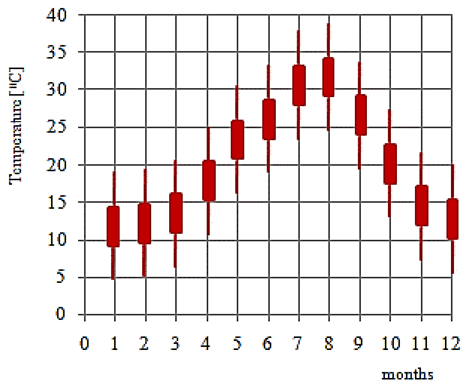


Figure 2. Block diagram of temperature modeling taking into account the state of weather conditions along the OHL route



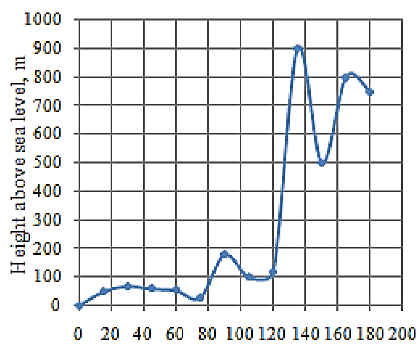
Result information
Uncertainty of yearly values: Gh=6%, Bn=13, Ta=0.3°C
Trend of Gh/decade: - Variability of Gh/year: 4.0%
Radiation interpolation locations: Satellite data (Share of satellite data: 100%)
Temperature interpolation locations: -

Figure 4. Average solar radiations by months during a year for Bine Airport area, Baku, Azerbaijan



Result information
Uncertainty of yearly values: Gh=6%, Bn=13, Ta=0.3°C
Trend of Gh/decade: - Variability of Gh/year: 4.0%
Radiation interpolation locations: Satellite data (Share of satellite data: 100%)
Temperature interpolation locations: -

Figure 5. Minimum and maximum air temperatures



Amplitude profile [m] - created by www.topocoding.com

Figure 6. Altitude of sections of PTL and distance from Absheron substation

The results of the calculation according to the program, depending on the air temperature, the solar radiation intensity and the wind speed at air temperature of 25 °C for the AC 330/43 wire, are shown in Table 1.

For the section of the 500 kV Shamakhi PTL - 2nd Absheron- at an altitude of 800 m. The air temperature in Shamakhi differs on average by 5-8 °C relative to the temperature of the Absheron substation. Solar radiation in Shamakhi differs from the Absheron substation due to the degree of transparency (clouds in the highlands) W_{cr} = 800 kW/m^2. The calculation results for the Shamakhi section at T_V = 200 °C, T_{rad} = 160 °C and H = 800 are given in Table 2.

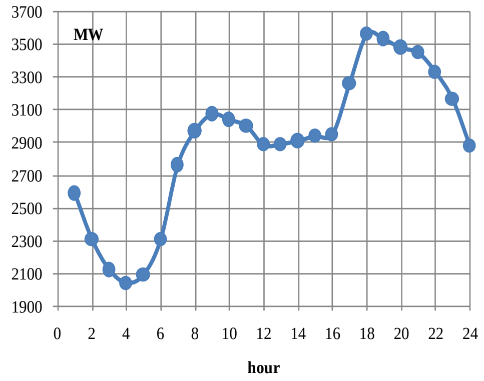


Figure 7. Active power flow through 500 kV OHL

Table 1. Dependence of wire's current from the wire temperature, additional temperature caused by solar radiation and wind speed

Wire temperature, °C	Temperature of solar radiation, °C	Windspeed, m/sec	Current in wire, A
Ambient temperature, 25 °C			
80	0	0.5	652.7
80	0	2.0	1002.2
80	20.4	0.5	547.8
80	20.4	2.0	814.8
Ambient temperature, 40 °C			
80	0	0.5	577.40
80	0	2.0	868.32
80	20.4	0.5	455.43
80	20.4	2.0	643.04

Table 2. Dependence of wire's current from wire's temperature, additional temperature caused by solar radiation and wind speed

Wire temperature, °C	Temperature of solar radiation °C	Wind speed, m/sec	Current in wire, A
Ambient 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
Ambient 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

5. CONCLUSIONS

1. An increase in the temperature of power transmission lines leads to an increase in their resistances, which leads to an increase in resistance, power losses and electric power. Power losses are directly related to commerce. Therefore, in accurate calculations it is necessary to pay attention to the overheating of the wires from solar radiation.

2. In modern conditions of operation of electrical networks, it is important to have the software for the monitoring of the wire temperature taking into account weather conditions, to realize the possibility of increasing carrying capacity of line and performing unloading measures to prevent overloading of lines.

3. An algorithm and a program for calculating the specific active resistance of wires of OHL taking into account the air temperature, operating current, wind speed and solar radiation have been developed. The algorithm and the program have been tested on the example of different grades of wires AS 330/43. The results of the calculation of the dependence of the specific active resistance on the air temperature, operating current and solar radiation, limit current loads are given. It has been established that when calculating the power losses for wires without taking into account the temperature dependence of the resistance, the relative errors can reach 26%. Therefore, in operation conditions of PTLs, it is necessary to take into account the wire temperature by sections to improve the accuracy of modeling of the losses of active power and energy.

4. Usually there is a resource for the transmission of large powers without disturbing the normal operating conditions of PTL. The monitoring system allows for using this additional resource. In practice, the PTL has the ability to transfer additional power of 15-30%.

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