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MODELLING OF ACTIVE POWER LOSSES IN AIRLINES CONSIDERING REGIME AND ATMOSPHERIC FACTORS

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Abstract- Temperature of airlines wires is defined by loading current and refrigerating conditions in environment. In extreme cases within a year the wire temperature can changed between +70 °C (at the big loadings) and -50 °C (at small loadings). Accordingly actual resistance of wires (hence, power losses in them) can increase in comparison with settlement size by 20% and decrease approximately for 30%. The algorithm and the program of calculation specific active resistance of wires of airlines taking into account temperature of air, a working current, speed of a wind and solar radiation are developed. Influence of wire temperature on an error of electric power losses calculation is estimated.

Keywords: Monitoring of Airlines, Wire Temperature, Active Resistance, Wire Current, Weather Conditions.

I. INTRODUCTION

Electric power losses (EE) are an important indicator of the efficiency of electrical networks. Electric power losses in a power system can be classified into two categories: current depending losses and voltage depending losses (iron losses of transformers, dielectric losses and losses due to corona).

Different deterministic and probabilistic-statistical methods are now used which allow an exact account of electric power losses. Active power losses depend substantially on the circuit and weather factors. In this regard, increase of the accuracy of power losses calculations required [1-5].

It is known, that a primary need of the power systems Control Center operators are reliable information. On the other hand, not all the measurements are available in the Control Center of power system.

To control the EHV power lines necessary for the rapid identification of electrical parameters of the line. These parameters vary due to the real-mode operation and weather conditions. When measuring the active power losses and the allocation of losses in the components of the operational management of EHV overhead lines it is important to increase the accuracy of simulation.

With development of technology increases the accuracy of the PMU estimate the parameters of the transmission line. Increasing the accuracy of the estimate increases the accuracy of the impedance isolation components of active power losses

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Modern hardware and software make it possible to carry out field tests on existing air lines (AL) and accumulate data on the heating wires and quickly identify the electrical parameters of the AL.

II. THERMAL BALANCE OF AN AIRLINE

It is known that the overhead line temperature depends on the conductor material properties, conductor current, conductor diameter and surface conditions, ambient weather conditions, such us wind, sun, air.

To monitor the temperature, we can use two basic ways: direct and calculated. In the first case, the wire temperature is measured by special sensors at the control points of the power line. Information about the wire temperature can be transmitted using a GSM connection. This is the most accurate way to determine the wire temperature. If no sensor wire temperature can be calculated under certain conditions a wire cooling (air temperature, wind speed and direction).

Heat balance equation for the steady thermal regime is [6-8]:

$$I^2 R_{Tc} + q_s = q_c + q_r \quad (1)$$

where, I is conductor current, R_{Tc} is resistance at a temperature T_c, q_c and q_r are heat loss due to convection and radiation, and q_s is solar heat gain.

Conductor resistance-temperature dependence can be determined as [1]:

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

where R_{20} is resistivity of the conductor at 20 °C, Ohm/km, α = 0.004 C^{-1} is temperature coefficient for steel-aluminum wires 1/deg, and t_{cond} is conductor temperature in °C.

The objective of research - to develop an algorithm and evaluate the impact of the load current, conductor temperature, solar radiation on the resistance of wires, depending on the ambient temperature, wind speed and solar radiation, as well as to determine the calculation error variable energy losses. Heat balancing equation of conductor can be represented by [1-4]:

$$0.95R_{20}\left[1+\alpha\left(t_{cond}-20\right)\right]I^2=Q_s+Q_c \quad (3)$$

Power loss during heat transfer by radiation is determined by the Stefan Boltzmann law [2]

$$Q_{rad}=\varepsilon C_0\left(273+t_{cond}\right)^4 S_{cond} \quad (4)$$

where ε is the emissivity of the wire surface for aluminum oxidation equal to 0.13 pu, C_0 coefficient of blackbody radiation, equal to 5.67×10^{-8} W/m^2, S-wire surface area m^2. Convection heat losses are:

$$Q_c=\varphi_k\left[\left(t_{cond}-t_{rad}\right)-t_{amb}\right]S \quad (5)$$

where, φ_k is convection heat transfer coefficient, W/(m^2°C); t_{rad} is heating temperature by solar radiation, °C, and t_{amb} is air temperature.

Convection heat transfer coefficient can be determined by formula [3]

$$\varphi_k=0.13057\left(\frac{k_v v d}{a}\right)^{0.71719}\frac{\lambda_a}{d} \quad (6)$$

where, k_v=0.5 is coefficient taking into account the effect of wind angle to the axis of the air line; v is wind speed, m/s; d is wire diameter, m; a is coefficient of the air thermal conductivity, equal to 18.8×10^{-6} m^2/s; λ_a is thermal conductivity of air, equal to 0.0244 W/(m°C).

From the Equations (3) to (6), we have for the current

$$I=\sqrt{\frac{\varepsilon C_0\left(273+t_{cond}\right)^4\pi d+\varphi_c\left[\left(t_{cond}-t_{rad}\right)-t_b\right]\pi d}{0.95R_{20}\left[1+0.004\cdot\left(t_{cond}-20\right)\right]}} \quad (7)$$

where ε is degree of blackness of a wire surface for the oxidized aluminum, equal 0.13 pu, C_0 is factor of radiation of absolutely blackbody, equal 5.67×10^{-8} Vt/m^2; S is area of a radiating surface of wires in m^2; j_κ is heat transfer factor, Vt/(m^2°C); and t_{rad} is temperature of heating by solar radiation, °C.

Accounting for the Effects of Solar Radiation

During the day, the solar radiation temperature is taken into account. Wire temperature t_{rad} depends on the intensity of solar radiation received by a wire, the height and density of the clouds.

The intensity of solar radiation changes in the day and throughout the year. Daily temperature fluctuations associated with changes in the value of the incoming solar radiation and outgoing during the day (Figure 1). From midnight to sunrise in the absence of the heat flux outgoing long wave radiation provides a reduction in temperature. Minimum it comes an hour after sunrise, marking the equality of the outgoing and incoming radiation. Subsequently *I-R* becomes positive, *T* and *R* are also increased, but the afternoon *I* starts to decrease, but remains greater than *R* only for approximately the next three hours. At this time again the equality incoming and outgoing radiation and *T* reaches its maximum.

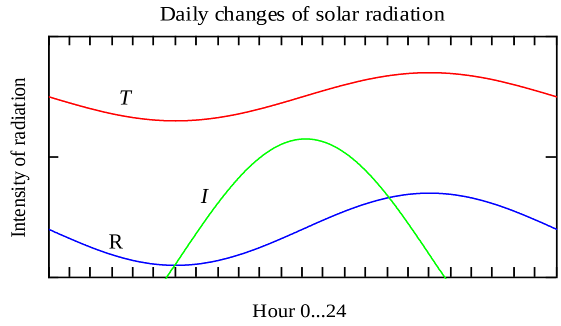

Figure 1. The entering short-wave radiation (*I*), leaving long-wave radiation (*R*) and temperature (*T*) near to a surface of the Earth within days

Similarly, we can consider seasonal variations in temperature near the surface of the Earth. In this case, using daily averages of incoming radiation, its variation over time can be represented as a sine wave, which has a maximum at the summer solstice and the minimum - at the winter solstice. Maximum and minimum temperatures are usually reached in about a month after the respective solstice.

As the sun in September, 14:30 hour to 15:30 hour at the blue sky and no wind in [3], the dependence of the AC wire heating temperature from solar radiation on the approximated by the equation

$$t_{rad}=K_\tau K_t' K_{rad} d^{0.44152} \quad (8)$$

where, K_{rad} = 92.0375 °C/m$^{0.44152}$; d is wire diameter, m.

Table 1 shows the values of t_{rad} wire of AC grade in the summer and the spring-autumn season (from 7 to 20 hours) at the blue sky, calculated according to the Equation (10) (according to [3]).

Table 1. A component of temperature from solar radiation for steel-aluminum wires

S	April-August	March-October
50	13.6	12
70	14.7	13
95	15.8	14
120	16.7	14.5
150	17.6	15
180	18.5	16
240	19.5	17
300	20.4	18
500	22.5	19.5

Between 20 to 24 hours and from 24 to 7 hours t_{rad} = 0 is received. In the USA, overhead line wire current-temperature depending defined by the standard IEEE [7].

III. MODELLING AND PROGRAMMING

Preparation of the wires temperature dependence from the load current, temperature and wind velocity explicitly in Equation (7) fails. Therefore, to obtain analytical relationships for the wires temperature of the load current, air temperature and wind speed the following algorithm is used:

1. Getting the wires temperature, wind speed and air temperature for a given wire by Equation (7) for specific values t_{amb}, t_{rad}, v in tabular form.

2. Obtaining the approximation coefficients

$$t_{cond} = a_0 + a_1 I + a_2 I^2 + a_3 I^3 \quad (9)$$

Cubic approximation of the temperature dependence of the conductor current, wind speed and air temperature has sufficient accuracy for practice.

For operational accounting impact of regime and the weather conditions on the wire temperature used wire temperature characteristics obtained by influencing factors. A modified algorithm for modeling the overhead line conductors temperature (1-9) with the actual values of the current air temperature and wind speed, implemented in the software package of calculation of losses EE power systems [9-11].

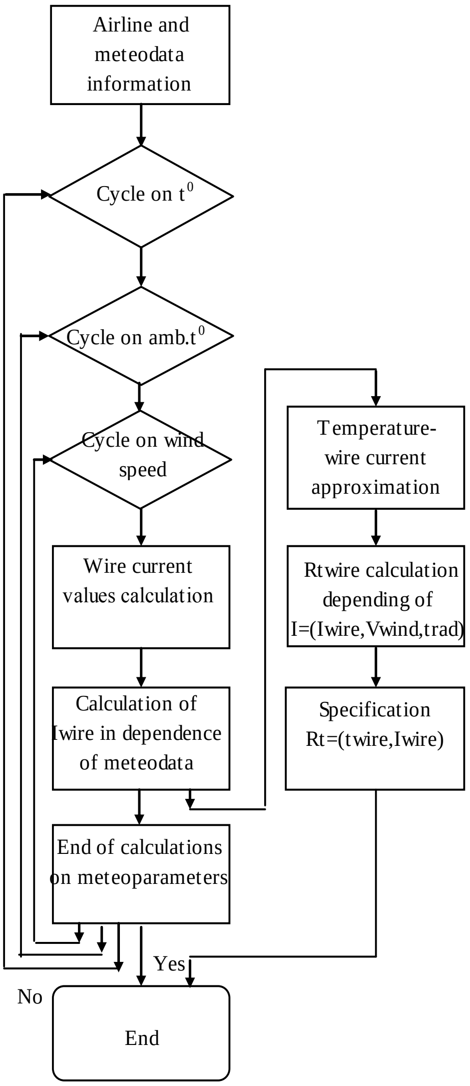

Figure 2. The chart of developed software

The software is developed for modeling of wire temperature depending on type of a wire and weather conditions (Figure 2). Screen sheet of the software is shown on Figures 3 and 4. The program allows displaying results of modeling in tabular and graphic forms.

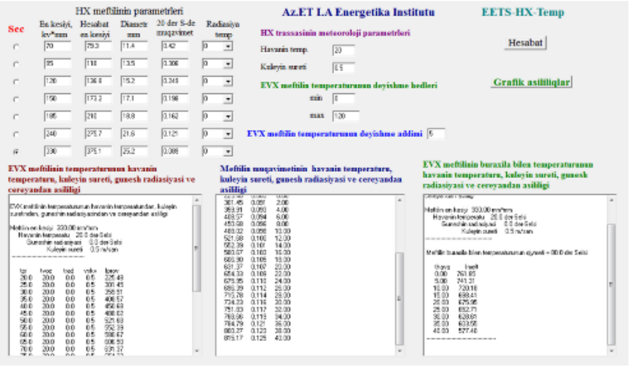

Figure 3. Results of modeling in tabular form

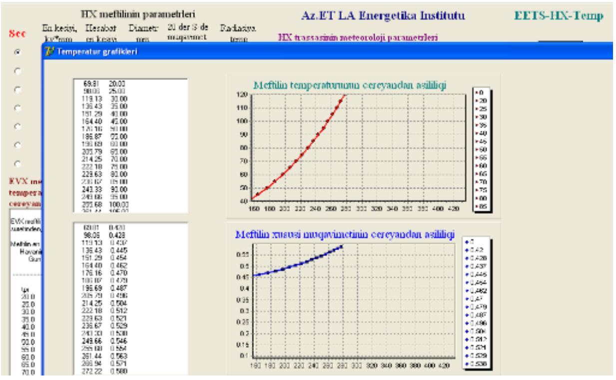

Figure 4. Results of modeling in graphic form

IV. SIMULATION RESULTS

As an example, it was used by the HV EHV 500 kV (conductor AC 330/43). Wire diameter, d = 25.2 mm, specific resistance line 0.089 Ohm/km.

For the application of the method requires the input of the four direct measurements of wind, temperature, and flow of the load current conductor. They were studied possible variations of the conductor temperature by changing single parameter in the base scenario determined by the following conditions:

North-east wind speed: v = 0.5;1,0; 1,5; 3,0; 4.5;6 in 9 m/s; ambient temperature, t_{amb} = -20; 0; 10; 20 in 40 °C; radiation temperature, t_{rad} = 20.4 °C; and conductor current: 500 A.

Table 2 ahows coefficients of cubic dependence on depending of current, wind speed and ambient temperature for calculation wire temperature (for wire AC 150/24, on v = 0.5 m/s and t_{rad} = 0 °C), obtained by developed software.

Table 2. Coefficients of cubic dependence on depending of current, wind speed and ambient temperature

No	Ambient temperature, °C	Coefficients of cubic dependence (7)			
		a_0	$a_1\times10^{-2}$	$a_2\times10^{-5}$	$a_3\times10^{-7}$
1	-40	-45.9663	3.920	-4.29437	9.05847
2	-30	-36.33343	3.896	-3.92358	9.06552
3	-20	-26.73832	3.880	-3.5683	9.06892
4	-10	-17.18252	3.869	-3.22571	9.06725
5	0	-7.66751	3.861	-2.89327	9.05924
6	10	1.80527	3.857	-2.56872	9.04374
7	20	11.23442	3.854	-2.25001	9.01969
8	30	20.61866	3.852	-1.93525	8.98681
9	40	29.95683	3.848	-1.62266	8.94226

Table 3 presents coefficients of cubic dependence on depending of current, wind speed and ambient temperature for calculation wire temperature (for wire AC 150/24, on v = 0.5 m/s and t_{rad}= 0 °C), obtained by developed software.

Table 4 presented Dependence of wire temperature from load current and ambient temperature at v_{wind} = 0.5 m/sec and t_{rad} = 0 °C for AC 150.

Table 3. Load current dependence from wire and ambient temperature at v_{wind} = 0.5 m/sec and t_{rad} = 0 °C for AC 150

No	Wire temperature [°C]	Load current [A] on ambient temperature [°C]				
		0	10	20	30	40
1	0	112.71				
2	10	203.00	118.57			
3	20	260.07	203.89	124.53		
4	30	303.70	259.18	205.22	130.59	
5	40	339.46	301.82	258.78	206.96	136.74
6	50	369.87	336.95	300.43	258.82	209.09
7	60	396.38	366.94	334.93	299.52	259.31
8	70	419.89	393.18	364.51	333.39	299.05
9	80	441.02	416.51	390.46	362.55	332.30
10	90	460.22	437.54	413.61	388.22	361.04

Table 4. Dependence of wire temperature from load current and ambient temperature at v_{wind} = 0.5 m/sec and t_{rad} = 0 °C for AC 150

No	Calculated current [A]	Wire temperature [°C] at ambient temperature [°C]				
		0	10	20	30	40
1	150	3.72	13.24	22.72	32.15	41.53
2	170	6.02	15.61	25.16	34.66	44.10
3	190	8.56	18.25	27.88	37.47	46.98
4	210	11.39	21.19	30.93	40.61	50.22
5	230	14.54	24.47	34.34	44.14	53.86
6	250	18.07	28.15	38.16	48.09	57.92
7	270	22.03	32.27	42.43	52.49	62.46
8	290	26.46	36.88	47.19	57.40	67.49
9	310	31.42	42.01	52.49	62.84	73.07
10	330	36.94	47.72	58.36	68.86	79.23
11	350	43.09	54.05	64.85	75.51	86.00

Figure 5 shows the wire temperature dependence of the conductor current at different air temperatures t_{amb} = -20; 0; 20 and 40 °C at a wind speed v = 0.5 m/s; t_{rad} = 0 °C.

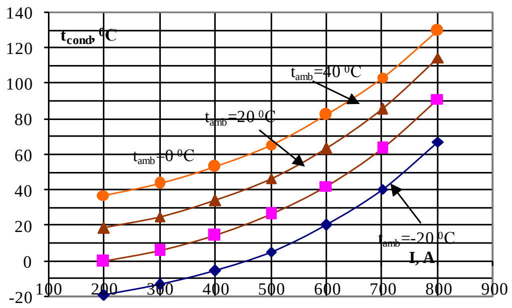

Figure 5. Dependences of temperature of a wire from a current at different air temperatures

Figure 6 shows the change in temperature of the conductor of current when the solar radiation temperature t_{rad} = 17.6 °C.

The simulation results of AC 330/43 conductor temperature dependence from the load current at air temperature t_{amb} = 20 °C, t_{rad} = 0 °C for values of wind speed v = 0.5; 1; 1.5; 3.0; 4.5; 6 and 9 m/s and the wire load current in the range from 0 to 900 A shown in Figure 7.

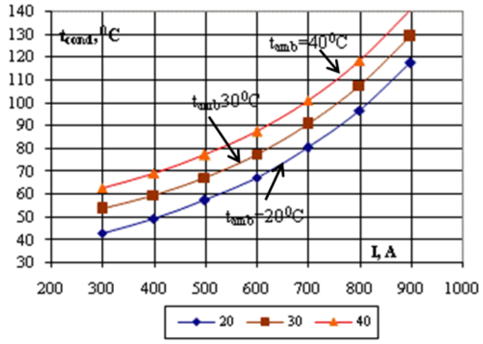

Figure 6. Dependence of temperature of a wire from a current at t_{air} = 20 °C, V_{wind} = 0.5 km/s, T_{rad} = 20.4 °C

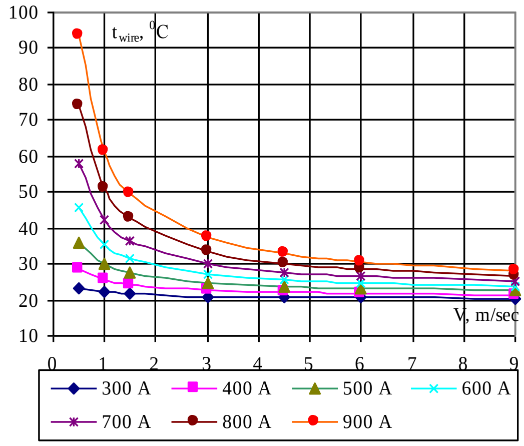

Figure 7. Dependences of wire temperature on a loading current at various wind speed values

Results of modeling of wire current, ambient temperature, wind speed influence on wire temperature show that ambient temperature and a loading current essentially influences to wire temperature.

It is known that ambient temperature changes in a range [-40, 40] °C. Therefore the wire temperature changes largely depending on size of a loading current. The analysis of temperature changes depending on operational modes and weather conditions show that at an admissible range of wire temperature change can have values from -40 °C to 70 °C. It leads accordingly from 24% to 20% change of specific wire active resistance of AL according to (2).

For the comparative analysis calculations of influence of regime and atmospheric conditions on accuracy of active losses, the modeling of the ultrahigh voltage transmission line are carried out. Such problem arises at measurement of mode parameters on the ends of a line and allocation of loading and crown losses.

Modeling and comparison of active power losses for a line 500 kV with wires 3×AC-330/43 and splitting step 40 cm, (r_0 = 0.029 Ohm/km, x_0 = 0.299 Ohm/km, b_0 = 3.74 cm/km, ΔP_{crown0} = 4 kW/km, L = 250.25 km) is spent.

Initial data for modeling are: U_2 = 484.74 KV, P_2 = 700 MW, Q_2 = 100 MWAr, t_{amb} = 20 °C and $R_{t20°C}$ = 7.2657 Ohm. Settlement value of loading losses was equal $\Delta P_{l20°C}$ = 14.957 MW. Corona power losses at good weather are equal ΔP_{crown} = 0.925 MW.

Let's specify wire active resistance at wire temperature 70 °C: $R_{t70°C}$ = 8.7188 Ohm. In this case active loading losses equal $\Delta P_{n70°C}$ =17.948 MW.

Thus, loading losses are specified on size $\Delta P_{l70°C}$ - $\Delta P_{l20°C}$ =17.948-14.957 = 2.99 MW.

Thus, for adequate modeling in problems of estimation and identification of power line electric parameters monitoring of wire temperature taking into account regime and atmospheric factors is very necessary

V. CONCLUSION

1. For adequate modeling in problems of estimation and identification of power line electric parameters monitoring of wire temperature taking into account regime and atmospheric factors is very necessary
2. The modified algorithm and the software for calculation of wires specific active resistance and their characteristics taking into account of air temperature, a conductor current, wind speed and solar radiation are developed.
3. Dependences of wire temperature of on ambient temperature, working current, wind speed are received.
4. The analysis of influence of a loading current and weather conditions on active loading losses of power line changes in limits from -24% to 20% from a condition at wire temperature 20 °C.

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