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Simulations of the Allowable Load Current of the Overhead Lines in the Latvian Power Network

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Abstract: This paper considers the influence of changes of the transmission lines of permissible load current depending on conductor and ambient temperatures, climate conditions. The theoretical background of the allowable conductor temperature as well as load current determination principles are proposed. On one hand, the principles are based on mechanical limitations; on the other hand, they are based on thermal limitations. The simulation tasks were based on specific data information of three existing overhead lines of Latvian power system as well as the planned 330 kV overhead line. Moreover, the special thermovision device was used for precious determination of conductor temperature of the existing transmission lines. The simulation results of the obtained data are reviewed in the paper.

Key words: Allowable conductor temperature, permissible load current, climate conditions, overhead line.

1. Introduction

Due to historical reasons, the Baltic countries have been operated in parallel with the Russian and Belarusian networks. Being a former of the Soviet Union, the Baltic States have networks with strong physical connections and system stability. The Baltic States form the so-called BRELL (Belarus-Russia-Estonia-Latvia-Lithuania) ring [1]. The restoration of national independence of the Baltic region countries and sweeping economic changes have led to considerable changes in the structure of the power system and significant changes in the power flows over the transmission grid, for example, because of the closure of Ignalina Nuclear Power Plant [2] as well as the number of economically inefficient plants running on heavy fuel oil and sharp application of the wind power stations [3].

The expansion of the electrical connections among countries will be required, especially if the capacity of the new nuclear power plants (NPP Visaginas, Kaliningrad, Belarus) are to be 3,000 MW and more [4]. The output and export of electric power of the new nuclear power stations to the Nordic countries will also require the expansion of the internal power grid of the Baltic region (Fig. 1) [5] between Latvia and Lithuania (Ignalina-Liksna, an existing 330 kV overhead line) and between Estonia and Latvia (Sindi-Riga TEC-2, the 330 kV transmission line under construction).

Due to increasing the capacity of existing network of the Baltic region in normal mode, it becomes necessary to uprate the existing network. There are different possible solutions for increasing the transmission capacity and making the maximum use of existing transmission systems, for example, reconstruction of the overhead line for a higher voltage, replacing the existing wires by ones with a larger cross-section [6], using the HTLS (high temperature-low sag) conductors

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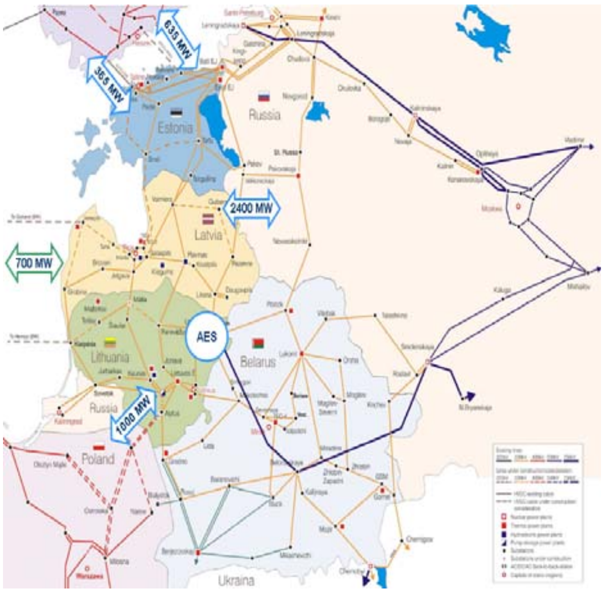

Fig. 1 Electrical connections of the Baltic power systems.

[7, 8], installation of series and shunt compensations [9, 10], construction of new supply substations, and using control devices for the power network.

The sources [11-13] review the methodology for calculating conductor temperature depending on the seasonal climate conditions such as air temperature, wind speed and direction, solar radiation and the load current in detail. The allowable temperature is assumed to be known. Based on this, the permissible load current is calculated. This study additionally takes the dependence of the permissible conductor temperature on the concrete weather conditions and the mechanical characteristics of the power transmission line into consideration. The consideration of such dependence ensures an additional increase in the allowable load current [14].

The proposed calculation method improves the accuracy of determining the load current for an existing overhead line or designing of a particular overhead line. Using it can help to find the borders of the maximum transmission line current without exceeding the conductor thermal and sag line limits.

2. The Existing Transmission Lines of the Latvian Power Network

The allowable load current calculation is based on the "Kurzeme Ring" planned 330 kV overhead line (Fig. 2) and existing 330 kV lines: RTEC-1—RTEC-2; RTEC-2—SALASPILS; SALASPILS—JELGAVA.

The reconstruction of the existing 110 kV transmission network loop in the Western part of Latvia, the KR ("Kurzeme Ring"), has the purpose of increasing the transmission capacity and voltage level to 330 kV, because of low power supply reliability due to bottlenecks in the Kurzeme network, the strong dependence of the Baltic region power network on limited power suppliers and isolation from the European power market and the limited possibilities for the development of generating capacities in Latvia (the use of renewable power) [15].

3. Permissible Conductor Temperature Determination Principles

The permissible temperature determination principles take into account various conditions, for example, the physical characteristics of the examined conductor like diameter, weight, strength, thermal elongation (Table 1), and mechanical limitations like conductor sag, ground clearance and clearance to crossed objects. All these factors are taken into account in the presented calculation method of the allowable conductor temperature, which shows the influence of the main parameters on conductor temperature.

The next expressions that provided Eqs. (1)-(8) allow to find conductor temperature depending on the type of tower (tension or intermediate support) and its mutual arrangement (equivalent or sloping span) [16].

The conductor temperature determination based on the condition of retaining the distance (H_{norm}-$H_{allow\ g}$):

(1) Tension tower and equivalent span:

(a) Distance between wire and ground at mid-span:

$$t_{allow} = t_c + \frac{\Delta H}{\alpha}\left[\frac{\gamma_1 l^2}{8Ef(f+\Delta H)} + \frac{8}{3}\cdot\frac{2f+\Delta H}{l^2}\right] \quad (1)$$

(b) Distance between wire and crossed objects at any point of span:

$$t_{allow} = t_c + \frac{\Delta H_X l^2}{4\alpha x(l-x)}\left[\frac{2\gamma_1 x^2 (l-x)^2}{El^2 f_X (f_X+\Delta H_X)} + \frac{2}{3}\times\frac{2f_X+\Delta H_X}{x(l-x)}\right] \quad (2)$$

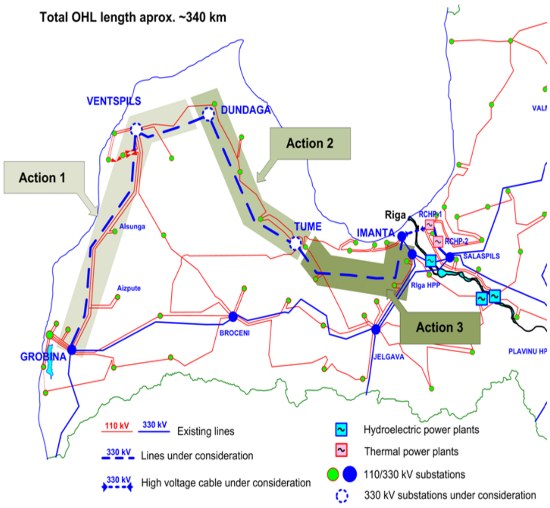

Fig. 2 A simplified diagram of the "Kurzeme Ring" [15].

Table 1 The technical characteristics of the conductor.

Conductor	AC-400/51
Diameter, mm	27.5
Area, mm²	445.1
Weight, kg/m	1.49
Strength, GPa	77.0
Thermal elongation 10-6/°C	19.8
Electrical DC resistance @20 °C, Ω/km	0.075
Solar absorption coefficient	0.8
Temperature coefficient of resistance per °C	0.004

(2) Intermediate support and equivalent span:

(a) Distance between wire and ground at mid-span:

$$t_{allow}=t_c+\frac{\Delta Hl_e^{\,2}}{\alpha l^2}\left[\frac{\gamma_1 l^4}{8Efl_e^{\,2}(f+\Delta H)}+\frac{8}{3}\cdot\frac{2f+\Delta H}{l^2}\right] \quad (3)$$

(b) Distance between wire and crossed objects at any point of span:

$$t_{allow}=t_c+\frac{\Delta H_X l_e^{\,2}}{4\alpha x(l-x)}\left[\frac{2\gamma_1 x^2(l-x)^2}{El_e^{\,2}f_X(f_X+\Delta H_X)}+\frac{2}{3}\times\frac{2f_X+\Delta H_X}{x(l-x)}\right] \quad (4)$$

(3) Tension tower and sloping span:

(a) Distance between wire and ground:

$$t_{allow}=t_c+\frac{\Delta H}{\alpha}\left[\frac{\gamma_1 l^4}{8Ef\left[f(l^2-4a^2)+l^2\Delta H\right]}+\frac{8}{3}\times\frac{2(l^2-4a^2)f+l^2\Delta H}{(l^2-4a^2)^2}\cos\psi\right] \quad (5)$$

The given expressions have such parameters as conductor temperature (t_c), length of span (l), modulus of elasticity (E), measured mid-span sag (f), specific conductor tension (γ_1), sag at cross point of conductor temperature t_c (f_x), distance from the crossed object to the nearest support (x) and the equivalent span (l_e), and it also include the following conventional signs:

(a) ΔH—the difference between the measured and predetermined dimensions, distance, respecting the permissible reduction of $\Delta H_{allow\,g}$:

$$\Delta H=H-(H_{norm}-\Delta H_{allow\,g}) \quad (6)$$

(b) H—the vertical distance between the wire and the ground in the middle of the span, which is measured at the temperature t_c, m;

(c) H_{norm}—a predetermined distance between the conductor and the ground, m;

(d) $\Delta H_{allow\,g}$—the permissible reduction in the distance between the wires and the ground, m:

- overhead line 110-150 kV: $\Delta H_{allow\,g}=0.5$ m;
- overhead line 220-330 kV: $\Delta H_{allow\,g}=1.0$ m;

(e) ΔH_x—the difference between the measured and predetermined dimensions, distance, respecting the permissible reduction of $\Delta H_{allow\,o}$:

$$\Delta H_x=H_x-(H_{norm}-\Delta H_{allow\,o}) \quad (7)$$

(f) H_x—the vertical distance between the wire and the crossed object, which is measured at the temperature t_c, m;

(g) $\Delta H_{allow\,o}$—the permissible reduction in the distance between the wires and the crossed objects, m:

- overhead line 110-500kV: $\Delta H_{allow\,o}=1.0$ m;

(h) H_{norm}—the predetermined distance between the wires and the crossed object, m [17];

(i) a—distance in the sloping span of conductor sag to the lowest point of the mid-span, m;

(j) ψ—wire pivot points of the imaginary line connecting the inclination angle to the horizon.

As you see, one of the most important parameters of the determination of load current is the conductor temperature. The conductor temperature of the three existing 330 kV lines RTEC-1-RTEC-2 (LN-501), RTEC-2-SALASPILS (LN-321), SALASPILS-JELGAVA (LN-303) was measured by using the special thermovision equipment named FLIR

ThermaCAM P65 [18]. The conductor temperature was measured for line LN-501 of span limited by supports №53 and №54; line LN-321 of span limited by supports №17 and №18; line LN-303 of span limited by supports №59 and №60. The temperature measurements were done for each phase of examined line. The obtained data are presented in Table 2. These practical results were used for the load current calculation.

4. Allowable Load Current Determination Principles

A simplified estimate of the allowable load current takes into consideration certain meteorological conditions and the vertical distances between wire and ground or between the wires and the crossed object and it is calculated by the following formula:

$$I = \sqrt{\frac{(\lambda_s+\lambda_c)\cdot\Delta t}{R_t}} \qquad (8)$$

where λ_s is the coefficient of heat radiating through the exchange, λ_c is the coefficient of heat exchange through convection, Δt is temperature rise, R_t is the resistance of the conductor at temperature t and I is the current rating of the temperature rise (Δt).

5. Simulation Results of the Load Current Based on the “Kurzeme Ring” Planned Overhead Line

To enable exact load current estimation, a special program was used for systematic calculation of the planned line, which is intended for estimation of the conductors of lightning protection wires and the corresponding installation tables [19].

The presented simulation is based on four modes of systematic conductor calculation, which are:

(1) Maximum temperature mode;
(2) Storm without wind mode;
(3) Average operation mode;
(4) Storm with wind mode.

The obtained data are shown in graphic form (Fig. 3). Fig. 3 shows the permissible load current values in various modes, for example, the allowable load current values of mode No. 3 is the maximum calculated, the next one is mode No. 2, which equals to mode No. 4, and then it is mode No. 1—the maximum temperature mode. This clearly presents that mode No. 1 has a thermal limitation, the ambient temperature, by which the permissible load current is limited, and its output data are less than others represented curves.

Table 2 Received output data of the overhead lines.

The received data of operation mode	LN-501	LN-321	LN-303
Voltage, kV	351	352	352
Load current, A	230	429	438
Active power of load, MW	109	214	258
Reactive power of load, MVar	88	150	70
Maximum temperature of phase 1 (AR01), °C	36.5	30.3	20.0
Maximum temperature of phase 2 (AR01), °C	36.2	34.3	24.2
Maximum temperature of phase 3 (AR01), °C	38.3	31.1	29.3
Ambient temperature, °C	36.0	30.0	19.0

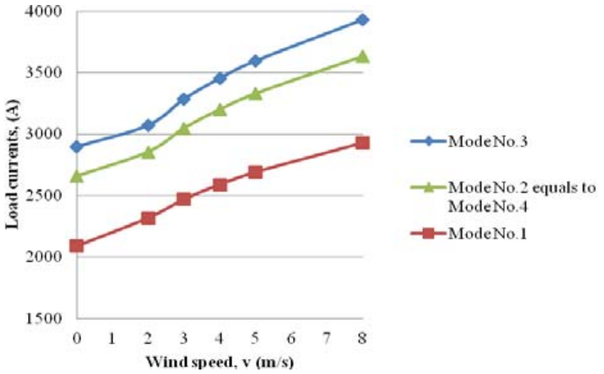

Fig. 3 The load current depending on various modes of systematic calculation of the conductor of a particular 330 kV overhead line.

6. Simulation Results of the Load Current Based on the Existing Overhead Lines

The presented theoretical background of the load current calculation of overhead power line was used for modeling the load current for existing lines according to concrete technical information.

Firstly, the allowable conductor temperature was determined by using Eq. (1); secondly, the conductor temperature was adopted 38.3 ºC according to the results of measurements. These conditions of estimation are the base for the simulation of load current for existing 330 kV line RTEC-1-RTEC-2 (Fig. 4).

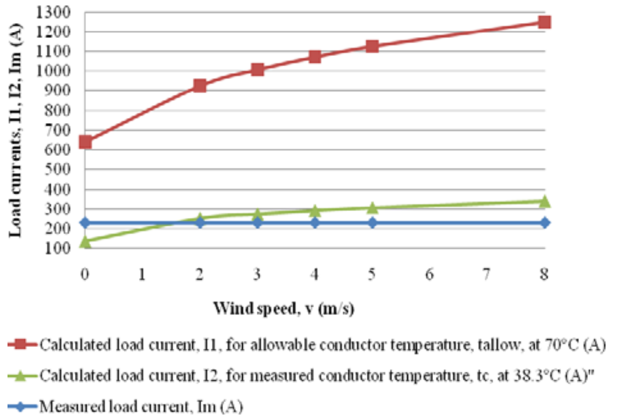

Fig. 4 Load current values (I1, I2) of RTEC-1-RTEC-2 line, depending on wind speed, measured conductor temperature and an ambient temperature 36 ºC.

Fig. 4 shows that the calculated values of the load current, which were based on the actual conductor temperature of 38.3 ºC, have tendency for rise by the wind speed increasing. Thus, using the allowable conductor temperature for determination of current rating, it can be seen that the calculated load current (I1) for the allowable conductor temperature 70 °C is up to 3.5 times more than the calculated load current (I2) which was based on the measured conductor temperature for a wind speed of 0 m/s, but it is more than the measured load current (Im) at a wind speed of 2, 3, 4, until 8 m/s.

Simulation of the load current for existing 330 kV line RTEC-2-SALASPILS (Fig. 5) was based on such main conditions: the allowable conductor temperature was determined by using Eq. (3); the conductor temperature was adopted 34.3 ºC. In this case, the measured load current (Im) exceeds the calculated load current (I2) based on a measured conductor temperature at a wind speed of 0, 2, 3, until 7 m/s, then it has tendency for rise.

Concerning the simulation of the existing line SALASPILS-JELGAVA (Fig. 6), in this case, the calculated load current (I1) for the allowable conductor temperature 70 °C is up to 2.5 times more than the calculated load current (I2) based on the measured conductor temperature of 29.3 ºC for a wind speed of 0 m/s, but it is more than the measured load current (Im) at a wind speed of 2, 3, 4, until 8 m/s.

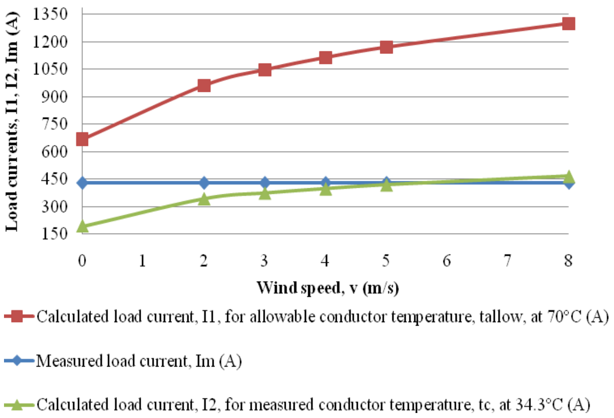

Fig. 5 Load current values (I1, I2) of RTEC-2-SALASPILS line, depending on wind speed, measured conductor temperature and an ambient temperature 30 ºC.

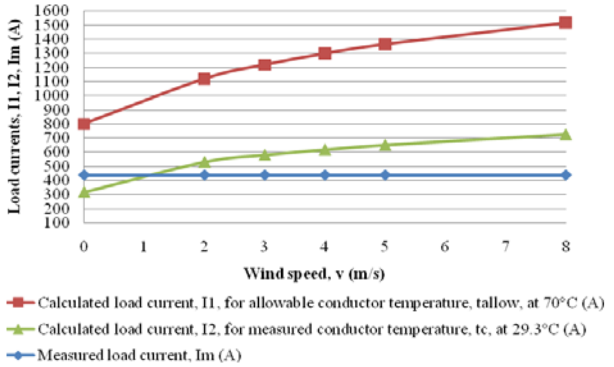

Fig. 6 Load current values (I1, I2) of LN-303, depending on wind speed, measured conductor temperature and an ambient temperature 19 ºC.

7. Conclusions

The use of the described approach of load current calculation allows to improve the accuracy of determination of the current rating for the existing or designing of transmission lines based on an ambient temperature, wind speed, wind direction, solar radiation. Thus, the capacity of transmission lines is greatly increased by the exact allowable conductor temperature determination.

The application of the described approach that takes into account mechanical and thermal limitation for estimation of load current provides new opportunities for integration of the smart grid. Simulations confirm efficiency of the presented theoretical background of the load current determination and it allows an increase of the load current of existing transmission lines with less costs.

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