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POMIAR WPŁYWU WARUNKÓW OTOCZENIA NA OBCIĄŻALNOŚĆ PRĄDOWĄ PRZEWODU 143-AL1 / 25-ST1A

Streszczenie: Ponieważ zużycie energii elektrycznej rośnie z każdym rokiem, ważne jest, aby wiedzieć, czy nadal można korzystać z istniejących napowietrznych linii energetycznych, czy też konieczne jest ich rozszerzenie lub wymiana. Obciążalność prądowa lub natężenie prądu jest definiowana jako maksymalna ilość energii elektrycznej, która może przepłynąć przez przewodnik bez jego uszkodzenia. Zależy to od właściwości elektrycznych i mechanicznych przewodnika, ich zdolności do rozprowadzania generowanego ciepła oraz od warunków atmosferycznych otoczenia. Ten artykuł dotyczy potwierdzenia maksymalnego dopuszczalnego prądu, który wynika z maksymalnej temperatury roboczej, dostarczonej przez producenta przewodu. W tym celu przeprowadzono pomiary oparte na standardowej broszurze 207 CIGRE. Wyniki pomiarów porównano z obliczeniami. Udowodniono, że standardowa broszura CIGRE 207 ma wystarczającą dokładność do zastosowania w praktyce.

Słowa kluczowe: obciążalność prądowa, napowietrzna linia energetyczna, warunki otoczenia, natężenie prądu

MEASUREMENT OF THE INFLUENCE OF AMBIENT CONDITIONS ON THE CURRENT CARRYING CAPACITY OF THE 143-AL1 / 25-ST1A CONDUCTOR

Summary: Since the consumption of electricity is rising every year, it is important to know if it's still possible to use existing overhead power lines or if it's necessary to extend or replace them. Current carrying capacity or ampacity, is defined as maximum amount of electricity that can flow through conductor without damaging it. It depends on the electrical and mechanical properties of the conductor, their ability to spread generated heat and on the ambient weather

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conditions. This article is dealing with confirmation of maximal allowable current that is resulting maximal operating temperature provided by manufacturer of the conductor. For that purpose, the measurements based on standard CIGRE brochure 207, were carried out. The measured results were compared with calculation. It was proven that standard CIGRE brochure 207 has sufficient accuracy for the use in practice.

Keywords: current carrying capacity, overhead power line, ambient conditions, ampacity

1. Introduction

Power system consists of electric power components, which are used for generation, transformation and transmission of electricity. For transmission of electricity, we differentiate the transmission and distribution power lines. A transmission lines are representing at ultra-high voltage system, which provide a transmission of power from sources to the three local areas of distribution system. Also cross-border power lines belong to the transmission system of power lines [1] [2].

Current capacity of every power lines depends on their constructions and used types of the conductor. Manufacturer of the conductors specified maximal allowable temperature for the operation of the power line. With maximal allowable temperature is related a current that can flow through the conductor and leads to achieve maximum operating temperature [3]. A maximal current value that flow through the conductors by not excited allowable temperature is marked as capacity of power lines or ampacity of power lines [3].

Capacity of the power lines depends on the electrical, mechanical and thermal properties of the conductor insulation and ambient conditions [3].

Every construction of electricity facilities is subject to the standard. This standard described methods for construction these facilities and to determination of maximum allowable conditions, that are non-destructive for their operation.

During a preparing of project to construction of power lines it is necessary to determine a capacity of power lines. For determining a capacity of power lines exist a standard EN 50341 where are defined ambient conditions, that have main influence on the value of maximal current.

2. Defining research problems

a) Current capacity

Current capacity of the power lines is defined as nominal value of electrical current that can be transmitted through a power line without destroying conductor. For this state deals steady state equation, which depends on determinants that represents the produced and consumed heat (1) [5] [6].

$$P_Z + P_S = P_k + P_r \tag{1}$$

where:

P_Z is heating the conductor due to current flow,

P_S is heating the conductor due to solar radiation,

P_k is cooling the conductor due to forced convection,

P_r is cooling the conductor due to natural convection.

By substitution of (1), we obtained a following expression for determining current capacity [5] [6]:

$$I = \sqrt{\frac{P_r + P_k - P_S}{R_{ac}}} \tag{2}$$

where: R_{ac} is the ac resistance of the conductor at 20 °C in Ω.

For the design of power lines is currently applicable standard EN 50341 where are defined ambient conditions for calculation of maximum allowable current value. This standard recommended maximum operating temperature 70°C of conductor [7].
Ambient conditions for calculation of maximum allowable current value of conductor according to the standard are:

- the ambient temperature is 35 °C,
- wind speed is 0.5 m.s-1 at 45° angle of impact,
- solar irradiance is 1000 W.m-2,
- absorption coefficient is 0.5,
- emissivity coefficient of 0.5 [7].

It is necessary to say that conditions given by a standard are the worst case of ambient conditions, which is rarely found. For determining current capacity standard CIGRE Technical Brochure 207 describes equations for calculation based on the climatic conditions and temperature of conductor. [8]

Based on this hypothesis, we compare temperature of conductor during a heating by nominal current value and calculated temperature for examined conductor.

b) Construction of ultra-high power lines

In practical terms, for the line of 400 kV voltage level are used trunked conductors where one phase consists of three conductors each and electrically connected at a distance, thereby enhanced radius of the conductor of one phase [9].
As conductors of transmission lines are used aluminum cables with steel core. Their advantage is greater mechanical strength, which allows its use for large distance. Among their other advantages include greater flexibility, more uniform structure. When wires material mistake can degrade the whole wire, but with aluminium-conductor steel-reinforced ropes (ACSR), tearing of one wire not damage the whole conductor [9].
A rope 143-AL1/25-ST1A was chosen for research with following parameters:

Table 1. Parameters of 143-AL1/25-ST1A ACSR

Conductor type		143-AL1/25-ST1A
Cross section (mm^2)	AL	143,4
	ST	24,71
	Overall	168,11
Number of wires	AL	10+16
	ST	1+6
Diameter of wires (mm)	AL	2,65
	ST	2,12
Rope diameter (mm)	Inner section	6,36
	Overall	16,96

Table 2. Electromechanical specifications of 143-AL1/25-ST1A ACSR

Nominal weight (kg.km^{-1})	589,3
Nominal strength (kN)	53,29
Maximum DC resistance at 20 °C (Ω.km^{-1})	0,1969
Final modulus of elasticity (MPa)	74 200
Coefficient of thermal expansion (10^{-5} K^{-1})	1,87
Current load capacity (A)	395,6

3. Measuring of the ambient temperature influence on ampacity of 143-AL1/25-ST1A conductor

To determine the influence of ambient temperature on ampacity of conductors was carried out measurement in laboratory.

From the point of view of ensuring credibility of measurements were individual measurements repeated 10 times. Measured temperature was arithmetically averaged. The ambient conditions were as follows:

- Ambient temperature T_a = 27°C,
- Wind speed v = 0,2 m.s^{-1}, windlessness
- Intensity of solar radiation I_s = 0 W.m^{-2}.

In the process of verification of the mathematical model, measurements were made on the basis of the proposed experimental set-up and technological procedure for the measurement of overhead power lines.

On Figure 1 is shown time course of measured temperature of 143-AL1/25-ST1A conductor in a step load of nominal current. As shown in the Figure 1, temperature of conductor was measured in advance, i.e. before switching on the measuring circuit.

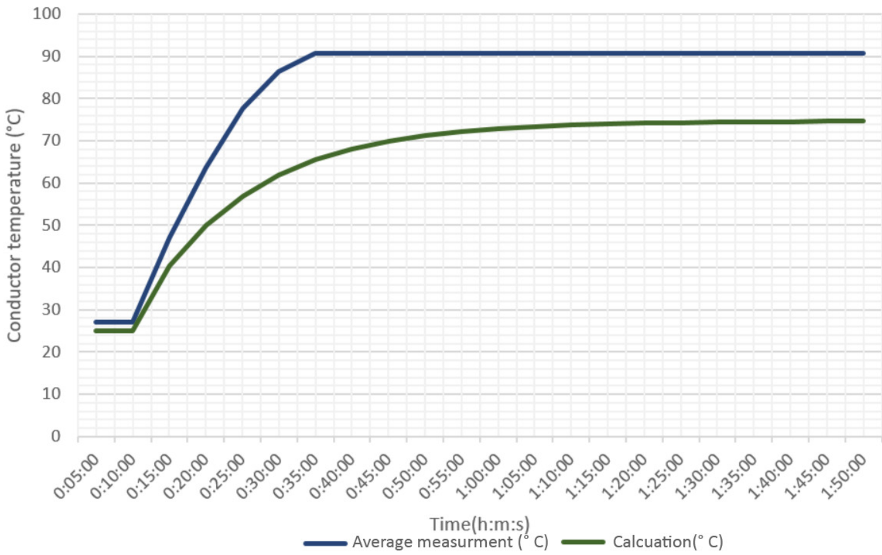

Figure 1. Graphical comparison for 143-AL1/25-ST1A conductor

After the measuring circuit was switched on, a slightly higher current than the rated current, 400A, was passed.

There was a steep increase in the driver's temperature between the start of the measurement (00:10:00) and 00:25:00. From a conductor temperature of 25-27 ° C at 10 repeated measurements, the temperature rose to 72 to 82 ° C. In the case of averaged driver temperature, this was an increase in temperature from 27 ° C to 77.6 °C. As of previous measurements, a dampened rise in driver temperature has been observed since 00:25:00. For individual measurements, the temperature rise of the driver was 00:25:00 for individual measurements from 72 to 82 ° C to 00:35:00 to 85 to 94 ° C. For the mean temperature values, an increase from 77.6 ° C to 90.8 °C was recorded.

At Figure 1 is possible to observe, that in case of sub-measurements 1 – 10, was temperature increase different, however characteristic of partial temperature increases were almost identical.

This state was caused by the inconsistency of the surrounding conditions. In the laboratory was recorded 1.4 ˚C difference in temperature. The temperature of the conductor is also influenced by its surface treatment. In the manufacture process of these ropes they are treated against oxidation in air to maintain their mechanical properties. To verify the proposed mathematical model for the determination of the static and dynamic part, a calculation was made for determining the temperature of the conductor in the dynamic and static parts. From a solution point of view, the determined steady-state conductor temperature was then compared to the average conductor temperature obtained on the basis of the repeat measurement.

The following ambient conditions were used to determine the static temperature:

- Ambient temperature Ta = 27˚C,
- Room temperature was between 25 – 27 ˚C, however in calculation is necessary taken in to account higher one.

- Intensity of solar radiation lS = 0 W.m-2,
- Wind speed, windlessness v = 0,2 m.s$^{-1.}$
  - Beaufort's wind force scale defines windlessness at a speed interval 0,0 until 0,2 m.s^{-1}. Given that it was not possible to achieve 0.0 m.s^{-1} in the laboratory; higher wind value is considered.
    Nominal current I = 400 A.

By gradual adjustment of the conductor temperature by the iteration method, the determined conductor temperature was Ts = 74.6 ° C. The factors involved in heating and cooling the conductor was equal to:

- Warming due to current flow P_J = 39,28 W.m^{-1},
- Warming due to solar irradiation P_S = 0 W.m^{-1},
- Cooling due to forced convection P_C = 29,46 W.m^{-1},
- Cooling due to natural convection P_r = 9,84 W.m^{-1},
- Difference ΔP is equal to -0,01 W.m^{-1}.

The dynamic value of the conductor temperature is the conductor temperature that changes over time after the conductor current change or when the ambient conditions suddenly change. To calculate the conductor temperature at a jump load by the nominal current value, it starts from the static conductor temperature obtained by the calculation in the previous subchapter. It is equal to θm = 74.7 ˚C. This temperature represents the steady-state conductor temperature after a step change in current or ambient conditions. The biggest difference was in the first points of measurement, when the difference was up to 39,35%. With increasing time of measurement and calculation, the difference between the measured temperature and the calculated temperature decreased to value around 20%. The CIGRE Technical Brochure 207 standard defines a temperature difference up to 20% for smaller wind speeds of 0.5 m.s^{-1}. Measurement uncertainty also has a significant impact. When comparing the driver's static temperature values, this difference is up to 20% by standard. Due to the low wind speed, the convection is mixed, which is not taken into account by the conductor temperature calculation standard. The graphical representation of the comparison is shown on Figure 1.

4. Conclusion

Ambient conditions have most influence on the actual value of current capacity. If it is possible to accurately determine the ambient conditions in real time, current capacity can be determined under these terms and adapted on operation of power system or power lines. Increasing current capacity of existing power lines is one of the way how to operate power system in the short term. On the other side, is necessary to build, expand with new power lines which is however time-consuming and economically demanding.

For the static part, i.e. steady-state conductor temperature at rated electric current was found to be 25,69 % difference for 143-AL1/25-ST1A. In point of view of such a high difference in measurement and calculation temperatures, the CIGRE 207 standard defines a situation where the air flow rate is less than 0.5 m.s^{-1}. In this case difference is up to 20%. In our case, considering the combined measurement uncertainty, this result is excessively accurate.

In the dynamic part, i.e. after switching the measuring circuit, when the nominal current flowed through the conductor, the difference was significantly higher at 39,35% for the 143-AL1 / 25-ST1A rope.
These differences in temperature are beyond the explanation in CIGRE 207. The problem with these parts of the results and its verification is that the CIGRE 207 methodology does not specify a sufficiently accurate calculation option for a state where the wind speed is below 0.5 m.s^{-1} in the dynamic part of the load.
The missing parameter is the effect of mixed convection.

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