Design of a measurement assembly and methodology for determining the conductor's current load

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Abstract.

The constant increase in the number of electricity sources requires increasing transmission capabilities of transmission lines, whether transmission or distribution networks. Member States of the European Union are committed to reducing greenhouse gas emissions and also to making renewable energy 20% of final energy consumption. This leads, on the one hand, to limiting the combustion of fossil fuels, but also to limiting the production of nuclear power plants. In 2011, Germany announced the closure of its nuclear power plants by 2022 at the latest, which, due to the energy infrastructure of Germany, causes problems in the management of power systems in neighboring countries. The second problem is the unpredictable or severely limited prediction of electricity generation from renewable sources. While the location and construction of some of the new power sources is relatively simple, the construction of new power lines is, on the other hand, more demanding in terms of time or money. As a result, we are continually looking for new ways to increase the transmission capabilities of existing lines, taking into account the lowest investment costs and minimizing losses. It is possible to determine the driver's current carrying capacity based on ambient conditions: Using simulation programs and modeling drivers and environmental conditions, measuring on the selected line, Measurement on a measuring set in laboratory conditions. This article deals with the design of a meter assembly and methodology for determining driver current load. In the paper, the measurement assembly and the measurement procedure are described together with the evaluation of the current load measurement for the 24-AL1 / 4-ST1A wire.

Keywords

Power system, Power lines, Maximum current, Overhead lines, Climatic conditions,

1. Introduction

Power system is a set of interconnected facilities used for the generation, transformation and transmission of electricity. Transmission of electricity is provided at the level of the transmission system and level of the distribution system. Within the transmission systems are mostly used twisted ACSR ropes, which, depending on the voltage level can be arranged in a bunch or individually.

Each ACSR rope has determined the maximum allowable current that it can flow without any damage. Maximum allowable current depends on the following parameters:

Electrical and mechanical properties of the conductor material

- Thermal insulation properties of the material in conductor
- The thermal capacity and conductivity of the guide body and its ability to transfer heat to the surroundings
- Environmental conditions

For the purposes of this article, we will examine the impact of solar radiation on the maximum current value.

For the design of power lines, applies standard EN 50341, which for the calculation of the maximum current value determined the following environmental conditions.

- The current conductor is the highest loaded
- The ambient temperature is 35 °C
- Wind speed is 0.5 m / s at 45 ° angle of impact
- Global temperature solar radiation is 1000W/m2
- Absorption coefficient is 0.5
- Emissivity coefficient is 0.5

2. The steady state temperature of the electrical conductor

The maximum permissible current value of the conductors is not constant but varies over time, depending on the ambient conditions.

The maximum permissible current value is defined as the current value that can flow an electrical conductor without damaging or disrupting its function. Disrupting its function is due to exceeding the maximum permissible operating temperature.

The thermal equilibrium of conductor is determined by the following equation, wherein the left part of the formula is formed by factors, which heat the conductor and the right side of the equation is made by factors which cool the conductor.

$$P_Z + P_S + P_C = C_v \cdot \frac{d\Theta}{dt} + P_k + P_r + P_w \qquad (1)$$

Where:

P_J (W/m) - heat losses in the conductor

P_M (W/m) - magnetic heating of magnetic field variations AC

P_S (W/m) - solar radiation

P_i (W/m) - heating from the corona

P_C (W/m) - cooling by heat convection – by radiation

P_r (W/m) - radiant cooling

P_W (W/m) - cooling from water evaporation

From the above expression (1) can be expressed equations for calculating current, while respecting environmental conditions.

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

In the calculations heating due to the corona neglected. The heating of conductor due to the corona (P_C) occurs mainly during the rain and wind, which is cooling conductor highest. It is also possible to neglect cooled by evaporation of water (P_w).

3. Design of experimental set for the verify mathematical model for determination of current capacity of conductor

The basic hypothesis for this work is the verification of the proposed mathematical model, which was determined on the basis of empirical equations to determine the current carrying capacity of drivers based on the influence of ambient conditions according to the CIGRE standard.

The main element for exploration will be the driver that will run the I-th current value. This current, due to Joula's losses, causes the driver to heat up while neglecting ambient conditions. On the basis of theoretical knowledge, when the influence of ambient conditions on the temperature of the conductor is influenced, the ambient temperature, which also enters the temperature contribution due to Joule's losses, and the intensity of the solar radiation influence. On the other hand, when the driver cools down, the temperature drop due to forced air flow and the temperature drop due to natural convection are affected.

Another essential element for the measuring assembly is a transformer, which allows continuous current regulation up to the current I-value along with the current flow measurement. The measurement will also include thermal probes for measuring conductor temperature on the surface.

On the basis of the theoretical analysis for the measuring assembly, a measuring opinion was compiled. The block diagram of the measurement assembly is shown in the following figure.

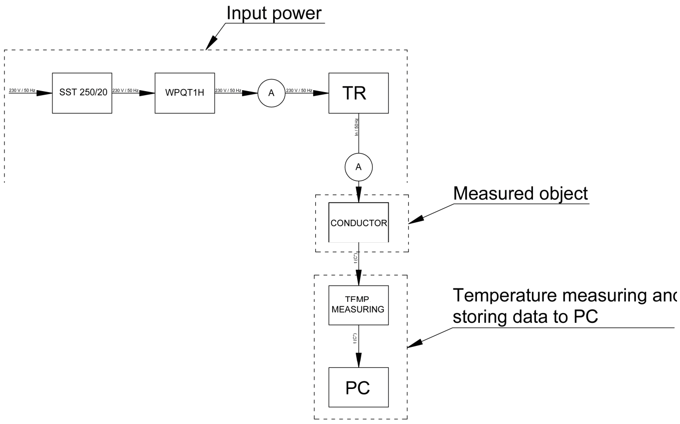

Fig. 1 Block diagram of equipment for determining ampacity

There is a three-phase power supply SST 250/20 with input voltage regulation 0 - 250V and current regulation with range 0 - 20A at the input of the measuring system. The SST250 / 20 power supply is a high current transformer. At the output of the large current transformer, the current is regulated in the range of 0 - 1000A label. WPQT1H is connected in the wiring between the SST250 / 20 drive and the large current transformer. The device primarily serves as a test device for electromechanical protection. In the measuring system, its protective functions are used to prevent damage to the large current transformer.

On the secondary side of the large current transformer, the examined AlFe rope is connected together with temperature probes for temperature measurement. Based on the driver's temperature, the maximum permissible driver temperature can be determined.

A flowchart measurement procedure is shown in Fig. 2. After initializing the ampacity measurement, the temperature and humidity measurement in the room and the driver temperature are started simultaneously. Subsequently, the I-th nominal current value is set by the voltage source depending on the purpose of the measurement. To terminate the measurement, the condition of the driver's temperature is set, ie. has no upward or downward tendency.

4. Determination of the influence of ambient conditions on current carrying capacity of conductors by measurement

An experiment was performed based on the proposed experimental setup and flowchart to measure the influence of ambient temperature on drivers current load. Due to the technical and safety constraints of the laboratory, experiments were carried out on ACSR ropes used in HV grids.From the point of view of ensuring the credibility of the measurement results, individual measurements were made with a 10-fold repeat.

The surrounding conditions were as follows:

- Ambient temperature Ta = 27°C
- Wind speed v = 0 $m.s^{-1}$,
- Sunlight intensity Is = 0 $W.m^{-2}$.

The measured temperature was arithmetically averaged.

Parameters of examined ACSR conductor are in table 1.

Results from individual measurements are at Fig. 3

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

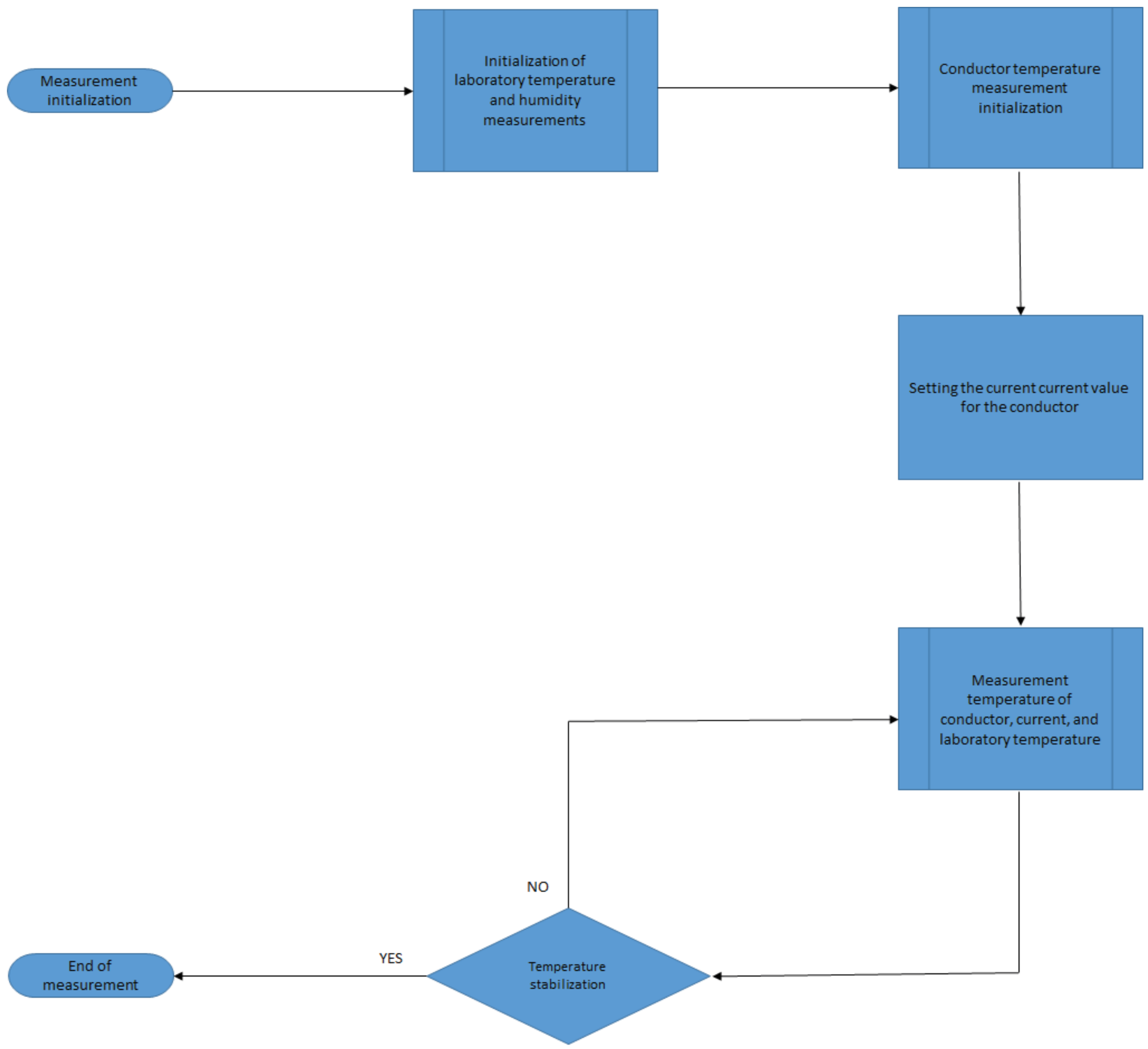

Fig. 2 Flowchart for power ampacity research

Examined conductor		24-AL1/4-ST1A
Crossection (mm^2)	AL	23,64
	ST	3,94
	Overall	27,58
Number of wire	AL	6
	ST	1
Diameter of wire (mm)	AL	2,24
	ST	2,24
Diameter of conductor (mm)	Core	2,24
	Overall	6,72
DC resistance (Ω/km)		1,1823

Tab. 1 Parameters of conductor 24-AL1/4-ST1A

As can be seen from the accompanying figure, the conductor temperature was measured in advance, i. before switching on the measuring circuit. The measurement time for unloaded AlFe lane was 10 minutes. The measuring circuit was closed at 10 minutes. The set current value was almost nominal, equal to 125A.

There was a sharp rise in driver temperature between 00:10:00 and 00:20:00. From a conductor temperature of 25-27 ° C at 10 repeat measurements, the temperature increased to 73 to 85 ° C. For averaged driver temperature, this was a temperature rise from 26.2 ° C to 80.5 ° C.

A dampened increase in driver temperature was recorded from 00:20:00. In the case of individual measurements, the temperature rise of the conductor at 00:20:00 for individual measurements ranged from 77 ° C to 85 ° C to 00:50:00 to 77 ° C to 90 ° C. For average temperature values, an increase from 80.5 ° C to 85 ° C was recorded.

FIG. It can be seen that in the case of partial measurements 1-10 the temperature increase was different, but the characteristics of the individual temperature increases were almost identical. This condition was caused by the volatility of the surrounding conditions. In the laboratory, an ambient temperature increase of 1.3 ° C was recorded using a temperature measuring thermometer. Also, the temperature of the driver is influenced by AlFe rope treatment. In the manufacture 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 driver in the dynamic and static parts. From the 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 measurements.

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 driver are:

- Heating $P_J = 22.88$ $W.m^{-1}$
- Warming due to solar radiation PS = 0 $W.m^{-1}$
- Airflow cooling $P_C = 19.01$ $W.m^{-1}$
- Radiant cooling $P_r = 3.88$ $W.m^{-1}$
- The difference ΔP is equal to -0.01 $W.m^{-1}$.

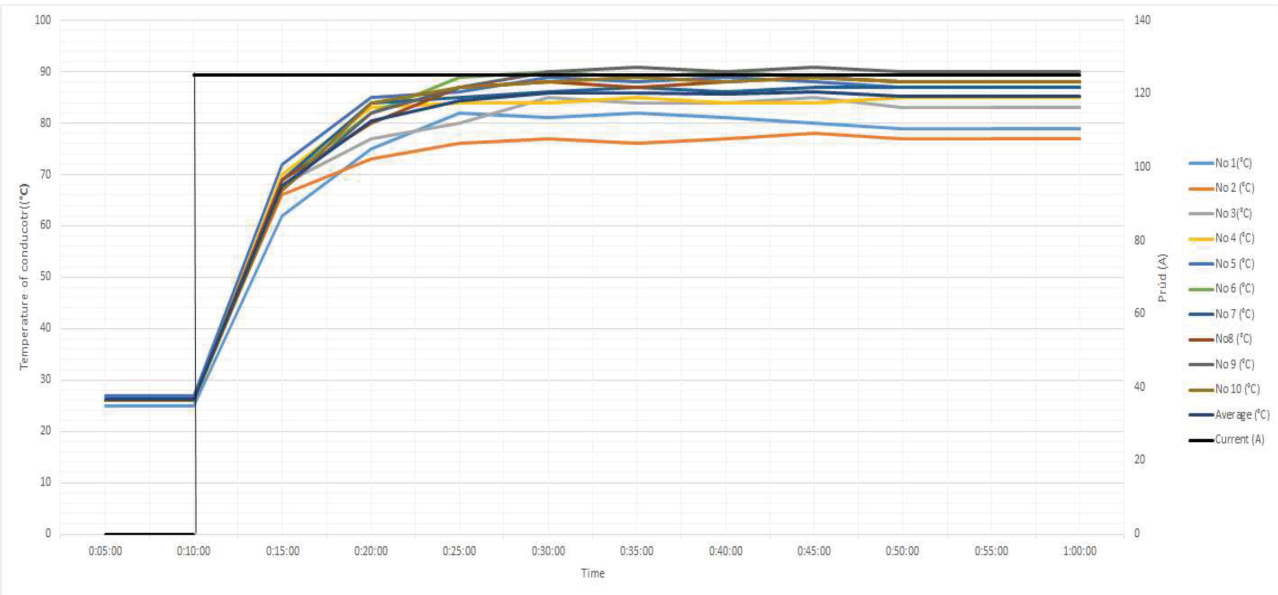

Fig. 3 Conducting the temperature of the 24-AL1 / 4-ST1A wire at a jump load of the rated current

As shown in the enclosed table, when comparing the average conductor temperature obtained from 10 measurements and the calculated conductor temperature, there is a significant difference between these temperatures. The biggest difference was in the first points of measurement, when the difference was up to 67.19%. With increasing measurement time and calculation, the difference between the measured temperature and the calculated temperature decreased to 14.21%. The CIGRE 207 standard defines a temperature difference of up to 20% for smaller wind speeds of 0.5 m / s. 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 driver's temperature calculation standard. The graphical representation of the comparison is shown in the following figure.

Average temperature (˚C)	Calculated temperature (˚C)	Difference (˚C)	Difference (%)
26,2	35,5	9,3	26,13
67,9	42,4	25,5	60,04
80,5	48,1	32,4	67,19
84,3	52,9	31,4	59,5
85,8	56,7	29,1	51,27
85,8	59,9	25,9	43,24
85,7	62,5	23,2	37,09
86	64,7	21,3	32,99
85,2	66,4	18,8	28,25
85,2	67,9	17,3	25,51
85,2	69,1	16,1	23,34
85,2	70,1	15,1	21,61
85,2	70,9	14,3	20,22
85,2	71,5	13,7	19,11
85,2	72,1	13,1	18,21
85,2	72,5	12,7	17,47
85,2	72,9	12,3	16,88
85,2	73,2	12	16,4
85,2	73,4	11,8	16
85,2	73,7	11,5	15,68
85,2	73,8	11,4	15,41
85,2	74	11,2	15,2
85,2	74,1	11,1	15,02
85,2	74,2	11	14,88
85,2	74,2	11	14,76
85,2	74,3	10,9	14,66
85,2	74,4	10,8	14,58
85,2	74,4	10,8	14,51
85,2	74,4	10,8	14,46
85,2	74,5	10,7	14,41
85,2	74,5	10,7	14,38
85,2	74,5	10,7	14,35
85,2	74,5	10,7	14,32
85,2	74,6	10,6	14,21

Tab. 2 Comparison of measurement and calculation results for 24-AL1 / 4-ST1A

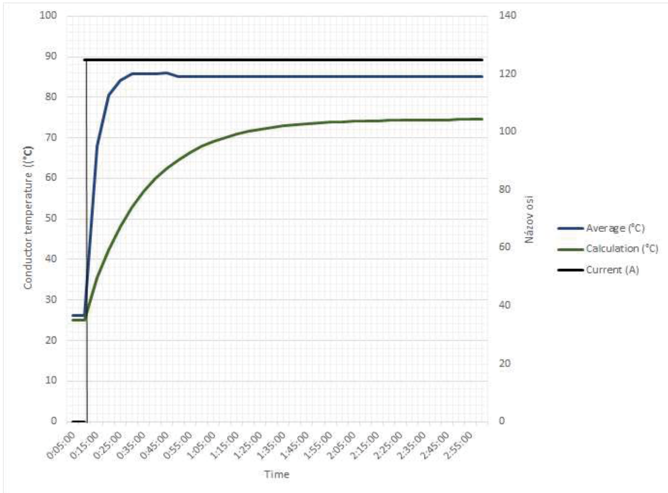

Fig. 4 Graphic comparison comparison for 24-AL1 / 4-ST1A

5. Conclusion

Power lines are one of the most important part of power system. Temperature of the conductor is function of the current value, ambient conditions, type of used conductor and their properties.

Results show that ambient conditions have most influence on the actual value of current capacity. If we can accurately determine the ambient conditions in real time, we can determine the current capacity under these terms and adapt 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 costly.

For the static part, i. steady-state conductor temperature at rated current was found to be 14.21% difference for 24-AL1 / 4-ST1A. In 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 0.5m / s difference of up to 20%. In our case, considering the combined measurement uncertainty, this result is excessively accurate. In the dynamic part, i. after switching the measuring circuit, when the nominal current flowed through the drivers, the difference was significantly higher at 67.19% for the 24-AL1 / 4-ST1A wire. 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 m / s in the dynamic part of the load. The missing parameter is the effect of mixed convection.

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