Measurement the Ground Resistance of Masts of Overhead Power Lines in HV and EHV

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Abstract — **The article deals with the measurement of resistance of grounding of masts of external power lines in HV and EHV. Conventional methods use measurement methods with disconnecting earthing ropes. There is also a measurement method without disconnecting the earthing ropes, which is difficult to use in practice. The article describes two new V-A methods that can be easier to use.**

Keywords: overhead power lines; resistance; grounding of mast; V-A methods

I. INTRODUCTION

The size of the grounding resistance of the metal poles is important both for operational reasons and for the safety of persons, respectively. animals moving in their vicinity.

STN EN 50341-1 specifies that the earthing resistance of individual poles with disconnected earthing cables should not exceed the following values under favorable soil conditions [1].

For lines with rated voltages of 220 kV and 400 kV and for lines with nominal voltages of 110 kV in areas with lower lightning strikes (less than 3 lightning / year.km^2):

- 15 Ω at the support points in the route
- 10 Ω at support points within 800 m of the power station

For lines with a rated voltage of 110 kV in areas with a higher lightning strike density (greater than 3 lightnings / year.km^2) and for lines with higher operational reliability requirements:

- 10 Ω at the support points in the route
- 7 Ω at support points within 800 m of the power station.

Higher grounding resistance values may only be allowed under adverse soil conditions. The highest grounding resistance values of the support points must then not be higher than the values given in Tab. 1

If, for cables with earthing cable, the individual support point does not have a ground resistance value according to Tab. 1 and cannot be achieved in a conventional manner, the earth resistance may be up to three consecutive support points of up to 50 Ω, provided that several adjacent support points have a ground resistance according to this table.

Thus, the grounding resistance of the metal masts must be permanently low and regularly measured. If the line does not have a grounding cable, the grounding resistance is relatively simple, because the grounding of a single pole is a simple and not a large earthing switch. To measure the overall earth resistance, it is advantageous to use conventional earth resistance measuring devices.

Table 1. The highest earthing resistance values [STN EN 50341-1]

Soil resistivity [Ω.m]		Earthing resistance [Ω]
up	to	
500	1000	20
1000	2000	30

It is no longer easy to measure the grounding resistances of MV, HV and MV grounding poles. The outer conductor with the earthing cable is, in terms of measuring the earthing resistances, an extensive set of earthing resistances of the individual poles connected in parallel by the earthing cable.

II. TAGG EARTH GROUND RESISTANCE METHOD

Mr. Tagg provides a method for determining the grounding resistance of individual masts connected by a ground wire from the measured values of three pole mast resistances [2].

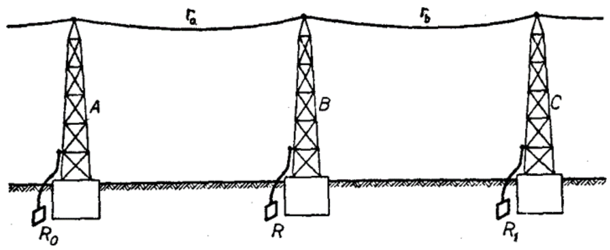

Figure 1. Earthing resistance of steel poles with earthing wire

The grounding rope is grounded on each mast. R_0, R, R_1 are the actual grounding resistances of the *A*, *B*, *C* masts.

Using the measurement circuit arrangement as shown in Figure, the apparent resistances of individual poles with the ground wire attached are measured. The measured values will differ very little, since the same set of ground resistors is always measured and the result of the measurement is more or less influenced only by the specific resistance of the soil in the vicinity of the measured pole.

If

X is the mast grounding resistance measured,

Y is the grounding resistance of the pole *B*, *Z* is the ground resistance of the *C* pole.

The actual grounding ground resistance will then be

$$R = \frac{Q \cdot (M + r_a)}{M + r_a - Q} \tag{1}$$

Where

$$Q = \frac{r_b \cdot \left(2Y - r_b + \sqrt{r_b^2 + 4YZ}\right)}{2 \cdot (r_b - Y + Z)} \tag{2}$$

And

$$M = \frac{r_a \cdot \left(2X - r_a + \sqrt{r_b^2 + 4XY}\right)}{2 \cdot (r_a - X + Z)} \tag{3}$$

In this evaluation method, it is necessary to ensure a high accuracy of measurement and reading of the results, due to the little differing measured values. As seen in equations 1 and 2, the measured values in the fraction denominator are subtracted. Any small measurement errors reading results, can significantly affect the calculated value.

III. Volt-ampere method A

Substantially more accurate results, as reported by Mr. Tagg, are provided by the volt-ampere method of measuring the grounding resistances of masts in the arrangement of Fig. 2.

Measuring principle

It is not necessary to disconnect the earthing cable when measuring. Its disadvantage is that the measured overhead line must be turned off during the whole measurement period [3].

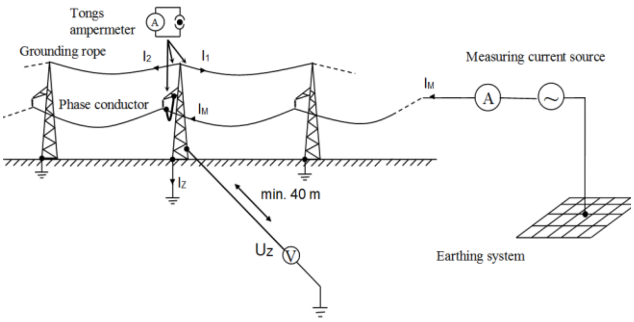

Figure 2. Volt-amper method of measurement

The source of the measuring current is connected via an ammeter at the station where the air conduction is measured, so that one pole is connected to the grounding system of the station and the other pole is connected to one phase conductor of the measured line. The measurement simulates a single-phase short circuit on each measured pole so that the powered phase conductor and the pole structure are connected via a conductor (shorting conductor wire). A part of the measuring current flows through the measured ground, ground, and ground station of the electrical station back to the source. This part of the current creates a voltage drop at the pole ground, which can be measured by a voltmeter connected between the structure of the measured pole and the auxiliary voltage electrode PE. The distance of the voltage electrode must be sufficient to capture almost all of the earthing voltage and depends on the grounding shape below the measured mast (typically 40 m). The grounding resistance can then be calculated by the equation [4,6].

$$R_Z = \frac{U_Z}{I_Z} \quad (\Omega) \tag{4}$$

While

U_Z grounding voltage,

I_Z current flowing through the measured ground,

In practice, it is quite difficult to directly measure a part of the current flowing through the measured ground. Therefore, to determine it, it is necessary to measure a part of the current that flows through the grounding cable after separation. Then, the current flowing through the pole ground can be determined as

$$I_Z = I_M - I_1 - I_2 \tag{5}$$

Where

I_M measuring current flowing through the short-circuiting set,

I_1 current flowing through the ground wire (according to wiring diagram),

I_2 current flowing through the ground wire (according to wiring diagram)

It is very advantageous to use a measuring current source with a frequency different from the 50 Hz industrial frequency. A voltmeter with high internal resistance is then required to measure the voltage. The advantage of using a different frequency is clearly reflected in the measurement of grounding resistances of poles of parallel air lines. Even with relatively short runs, several amperes flow in the earth line off the current line [5].

IV. Volt-ampere method B

The second method of measurement by a volt-ampere method, in which it is not necessary to disconnect the grounding cable and in addition to switch off the power line and can be measured during operation is shown below.

Principle of technical solution

Fig. 3 shows a circuit diagram for measuring the grounding resistance of power lines without disconnecting the ground wire.

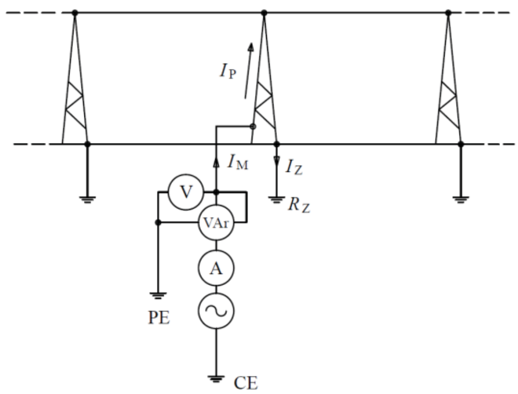

Figure 3. Wiring diagram of the measuring circuit

The measuring circuit is powered by a variable current measuring current source. The power supply is connected to the CE current electrode with one pole, the second pole through the measuring devices to the conductive structure of the measured mast. The ampermeter measures the total current of the measuring circuit I_M, which is the sum of the current flowing into the ground ground of the mast into the ground I_Z and the current flowing into the ground rope and adjacent grounding of the masts and the grounding of the electrical stations at both ends of the grounding cable I_{P}.

Voltmeter measures mast voltage U_M against reference electrode PE (remote ground). The VAr - meter is connected to the measuring circuit to measure the reactive power (inductive) flowing into the measuring circuit.

The same rules apply to the placement of the measuring electrodes CE and PE as in the case of classical earth resistance measurements by the VA method.

The replacement circuit of the measuring circuit is shown in Fig. 4

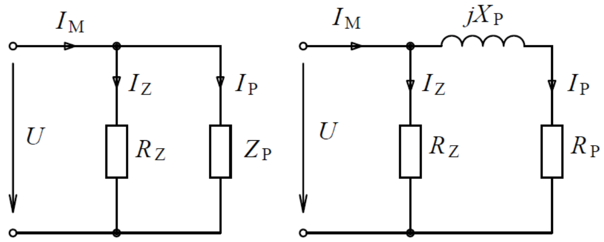

Figure 4. Replacement circuit of the measuring circuit

Where

R_{Z} the grounding resistance of the measured mast,

Z_{P} the resulting ground cable impedance and adjacent grounding resistances of the masts and electrical substations,

The impedance Z_{P} is a complex quantity and has a value

$$Z_{\mathrm{P}} = R_{\mathrm{P}} + j \cdot X_{\mathrm{P}} \tag{6}$$

When powering the measurement circuit from a variable frequency source, the ohm resistors R_z and R_p, which will always have the same value, and the reactivity X_P will vary depending on the source frequency according to the relationship

$$X_{\mathrm{P}} = \omega \cdot L_{\mathrm{P}} = 2\pi f L_{\mathrm{P}} \tag{7}$$

The following applies to the total current of the measuring circuit:

$$I_{\mathrm{M}} = I_{\mathrm{Z}} + I_{\mathrm{P}} \tag{8}$$

Where

I_{Z} is the current flowing to the measured pole ground,

I_{P} is the current flowing through the earthing switches to ground the adjacent masts and electrical stations,

Next

$$I_{\mathrm{M}} = \frac{U_{\mathrm{M}}}{R_{\mathrm{Z}}} + \frac{U_{\mathrm{M}}}{(R_{\mathrm{P}} + j\omega L_{\mathrm{P}})} \tag{9}$$

Where

U_{M} is the mast voltage to the PE reference electrode,

This relationship at a changing frequency is an equation of a circle in a complex plane (circle diagram, Fig. 5).

The end point of the total measuring point I_{M} describes the half circle in the complex plane. The center of the circle S lies on the real axis at the distance X with the radius of the circle r (at $f = 0$).

While

$$X = \frac{U_{\mathrm{M}}}{R_{\mathrm{Z}}} + \frac{U_{\mathrm{M}}}{2R_{\mathrm{P}}} \tag{10}$$

And

$$r = \frac{U_{\mathrm{M}}}{2R_{\mathrm{P}}} \tag{11}$$

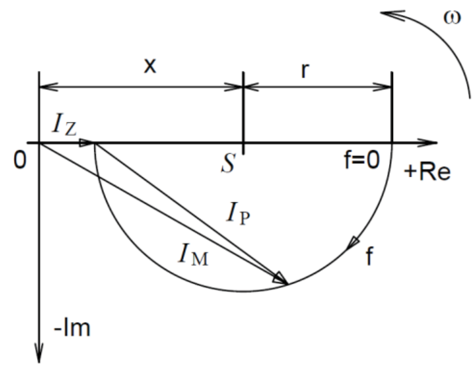

Figure 5. Circle diagram

To determine the current I_Z that flows into the ground of the measured pole, the maximum value of the reactive component is the I_{M}. That is, the maximum reactive power of the measuring circuit Q_{MAX}.

At this point in the circle diagram, the equality of the real and imaginary components of the impedance is Z_{P}, that is, $R_{\mathrm{P}} = X_{\mathrm{P}}$ (Fig. 6)

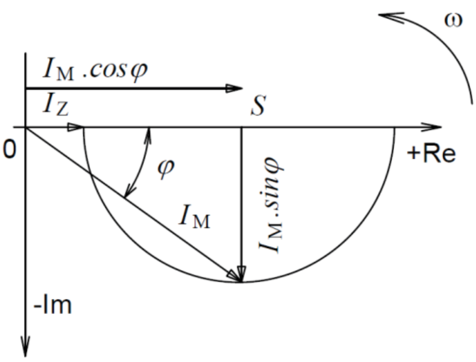

Figure 6. Circular diagram for equality of real and imaginary components

Valid formula: $Q_{\mathrm{MAX}} = U_{\mathrm{M}}.I_{\mathrm{M}}.sin\varphi$ (measured by VAr-meter)

From this relationship (known values of Q_{MAX} U_{M} and I_{M}), sin and cos are determined

Thus:

$$X = I_{\mathrm{M}}.cos\varphi\,, \tag{12}$$

resp.

$$r = I_{\mathrm{M}}.sin\varphi \tag{13}$$

Then the current flowing to the measured ground of the mast:

$$I_Z = X - r \tag{14}$$

Then

$$I_Z = I_M\,(cos\varphi - sin\varphi) \tag{15}$$

Mast Ground Resistance:

$$R_Z = \frac{U_M}{I_Z} = \frac{U_M}{I_M \cdot (cos\varphi - sin\varphi)} \tag{16}$$

V. Conclusion

The advantage of this measurement is the usability of the method in operation using conventional measuring devices without major financial demands, such as e.g. using special measuring devices.

Acknowledgment

This work was supported by the Ministry of Education, Science, Research and Sport of the Slovak Republic and the Slovak Academy of Science under No. VEGA 1/0372/18 „Výskum pôsobenia SMART sietí na distribučnú sústavu“

Authors thank Ing. Zoltán Hogya for his expert advice and material remarks when drafting the article.

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