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Universal Switch for Measuring the Resistance of the Grounding Device Supports of the 110 kV Overhead Power Line

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Abstract. At present the devices that use the pulse method to measure the resistance of a grounding device (GD) of the 110 kV overhead power line (OHL) supports have the following disadvantage: to do the measurements, various circuits must be assembled. This takes about 30% of the total measurement time. Moreover, there is no mathematical model to describe the process of measuring the resistance of the protective device for the 110 kV OHL supports. This is a gap in the studies aimed at increasing the efficiency of measuring the resistance of that protective device. We have developed a universal switch to reduce the time for measuring the resistance of the GD of the 110 kV OHL supports using the pulse method. The simplicity of the design of this universal switch means it can be assembled in the structural units of measurement companies. In addition, the developed universal switch can work with different measuring devices. The tests of the developed universal switch show its efficiency, and they indicate the prospects for developing it. The efficiency of the developed universal switch was determined using the developed mathematical model. When employees use the developed universal switch to measure the resistance of the PD of the 110 kV OHL supports by the pulse method, and if it is impossible or inexpedient to disconnect the lightning protection cable from the body of the support, it will take about 86 minutes to perform these measurements. This is 28% less time than if the measurements were performed without using this device.

Keywords: Equipment list; Grounding device; Resistance measurement; Universal switch

1. Introduction

According to several authors (Abdurrakhman et al., 2020; Astahov and Belikov, 2013; Kolobov et al., 2016; Nazir et al., 2016; Nizhevskij and Nizhevskij, 2016) the devices to measure the resistance of the PD differ in their field of application, measurement ranges, circuits, noise immunity, and frequency of the measuring current, and the operation includes various measurement methods. If it is impossible or inexpedient to disconnect the lightning protection cable from the body of the support to measure the resistance of the protective device of the 110 kV OHL supports, you can use the pulse method developed at the Moscow Power Engineering Institute (MPEI) and the method developed at the Siberian Research Institute of Power Engineering (SibNIIE).

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The method developed at SibNIIE is widely used in the power grid complex of Russia. It is based on using two potential and two current electrodes. Serial grounding testers, and the instruments from geophysical sets as well, can be used as measuring instruments when implementing the pulse method developed at SibNIIE.

Other authors (Dzhura and Selivanov, 2013; Rodrigues and Visacro, 2014; Harid et al., 2015; Kolobov et al., 2017; Junior et al., 2011) focus on the problem of increasing the accuracy and reliability of resistance measurements of the PD of OHL supports using the pulse method, but these authors do not consider the issue of reducing the number of different measurement circuits.

However, the personnel engaged in measurements spend much time assembling the circuits, which is a great disadvantage of that method.

At present more than 20 companies around the world offer modern measuring devices, which use the pulse method to measure the resistance of the protective devices of the 110 kV OHL supports, but they have the following disadvantages: to use these devices, personnel must assemble various circuits to perform the measurements. This takes about 30% of the total measurement time.

This situation takes place because there is no universal device that allows switching between measurement circuits. Therefore, an urgent task should be to develop a device that allows switching between circuits to measure the resistance of the 110 kV OHL supports. However, the organizations that measure the resistance of the PD of the 110 kV OHP supports already have devices that allow them to perform the measurements. Therefore, it is necessary to develop a universal device that could fit different measuring devices.

We conducted a patent analysis, reviewed the existing ready-made and developed devices and complexes that measure the resistance of grounding devices, searched through scientific journals and on the Internet for devices that reduce the assembly time of various circuits. We found no result, as there are no such devices that allow switching between circuits.

Also, in the literature there are no data on the number of times each year that the resistance of 110 kV OHL supports must be measured using the pulse method if it is impossible or inexpedient to disconnect the lightning protection cable from the body of the support.

The study of such data would allow scientists and specialists to predict the technical condition of 110 kV OHL supports and justify the use of new devices to make the measurement of 110 kV OHL more efficient and economical.

Studying the writings (Gracheva and Naumov, 2019; Koliushko and Rudenko, 2019; Kosyakov et al., 2019; Vinogradov et al., 2020), we discovered that there is no mathematical model to describe the process of measuring the resistance of the protective device of the 110 kV OHL supports. This is a gap in the research that aims to increase the efficiency of resistance measuring of those protective devices.

Therefore, the process of measuring the resistance of the 110 kV OHL supports when using the pulse method must be optimized by developing a universal switching device, while its efficiency must be determined by a mathematical model that describes the time process of measuring.

To correct the disadvantages described in the “Method” section, we analyzed a number of ways to measure the resistance of the GD of 110 kV OHL supports, and we developed a mathematical model to describe the measurement process. In that section, we also show how the developed universal switch reduces the time needed to measure GD resistance of 110 kV OHL supports when using the pulse method if it is impossible or inexpedient to disconnect the lightning protection cable from the body of the support (hereafter “without

disconnecting the lightning protection cable from the support"). We submit the results of the tests of the proposed universal switch in Section 3, "Results and Discussion" Then we make a conclusion about the results of the study in Section 4, "Conclusions".

2. Methods

At present there are no data in the literature on the number of resistance measurements of the 110 kV OHL supports when using the pulse method if it is impossible or inexpedient to disconnect the lightning protection cable from the body of the support. To solve this problem, we analyzed the protocols of measuring the resistance of the PD of 110 kV OHL supports. The measurement protocols were provided by the power grid company PJSC "MRSK-Center" – "Oryolenergo" (PAO "MRSK-Center" – "Oryolenergo") for the period 2015-2019.

Based on the analysis of the protocols, we determined the number of resistance measurements of the 110 kV OHL supports performed at PJSC "MRSK-Center" – "Oryolenergo" using the pulse method without disconnecting the lightning protection cable from the support. They are shown in Figure 1.

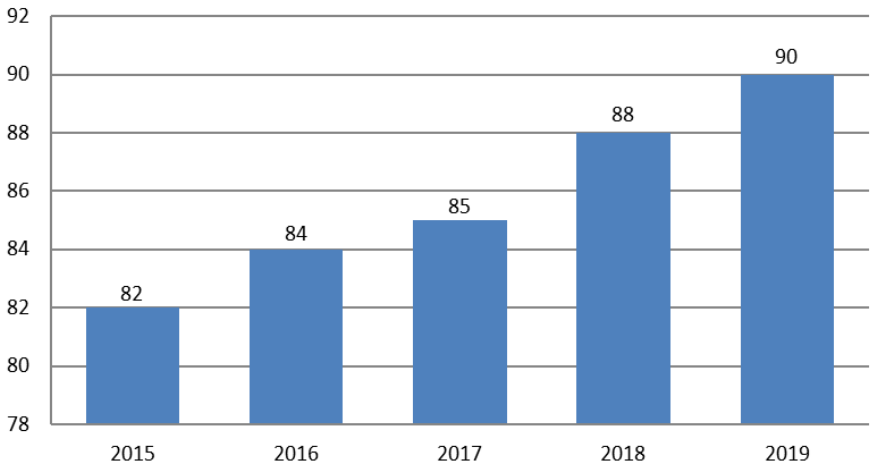


Figure 1 The number of resistance measurements of the grounding device of 110 kV power line supports performed using the pulse method if it is impossible or inexpedient to disconnect the lightning protection cable from the body of the support at PJSC "MRSK-Center" – "Oryolenergo" from 2015 to 2019

According to the results shown in Figure 1, we can conclude that over five years the company has determined the characteristics of the protective devices on 429 supports of 110 kV OHLs, while the number of measurements performed at PJSC "MRSK-Center" – "Oryolenergo" increased every year. Therefore, the same number of the company's personnel must spend more time each year measuring the resistance of the PD. As a result, the workload per employee increased, which, in turn, might have affected the quality and reliability of the measurements.

It should be noted that all resistance measurements of the protective device of the of 110 kV OHL supports shown in Figure 1 were performed using MS-08 and IS-10 devices.

To improve the efficiency of the resistance measurements of the 110 kV overhead power line supports, it is necessary to know the total value of the time spent on these measurements.

The mathematical description of the process of measuring the resistance of the PD of the 110 kV OHL supports when using the pulse method if it is impossible or inexpedient to

disconnect the lightning protection cable from the body of the support depends on the details of the work performed.

We propose to determine the time spent on measuring the resistance of the protective device of the 110 kV OHL supports by the formula:

$$T_{GDOL} = t_1 + t_2 + t_3 + t_4 + t_5 + t_6 + t_7 + t_8 + t_9 + t_{10} \quad (1)$$

where, T_{GDOL} is the total time spent by personnel to measure the resistance of the support of a 110 kV OHL, (min); t_1 is the time spent filling in a work permit, (min); t_2 is the time spent preparing for work (before leaving the production base), (min); t_3 is the travel time to the place of work, (min); t_4 is the time spent on briefing and admission to work at the facility, (min); t_5 is the time spent preparing the workplace for measurements, (min); t_6 is the time spent performing measurements, (min); t_7 is the time spent analyzing the results of the measurement, (min); t_8 is the time spent drawing up the protocol, (min); t_9 is the time spent cleaning the workplace, (min); t_{10} is the travel time to return to the production base, (min).

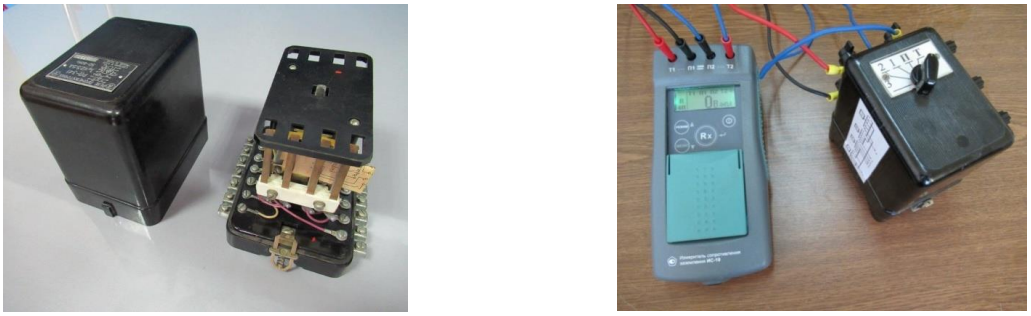
The decision to use this detailing of the work is justified by the fact that the time characteristics presented in Formula 1 are indicated as the main stages in the technological map for "Measurement of soil resistivity and resistance of grounding devices of metal and reinforced concrete supports of overhead power lines, the grounding devices of which are electrically connected by a lightning protection cable," developed at PJSC "MRSK-Center" – "Oryolenergo."

When we developed the device that allows us to reduce the time to measure the resistance of the protective device of 110 kV OHL supports using the impulse method without disconnecting the lightning protection cable from the support by switching between measurement circuits without disconnecting the contacts from two potential and two current electrodes, we also developed the following criteria:

- the device should have a low price;
- the device must be maintainable;
- the elements used in the device must be freely available on the market of electrical goods;
- the device must operate with different measuring devices.

Taking these criteria into account, we have developed the universal switch (Figure 2), which allows switching between the measurement circuits without disconnecting the contacts from the two potential and two current electrodes. This reduces the time needed to measure the resistance of the protective device of the 110 kV OHL supports, if it is impossible or inexpedient to disconnect the lightning protection cable from the body of the support.

Also, the developed universal switch can operate with different measuring devices.



(a) (b)

Figure 2 The developed universal switch (a) and the circuit for connecting the switch to the measuring device (b)

To assemble this switch, the following equipment is required: case (the case of the intermediate relay RP-241 was used); four-board five-position switch; instrument terminals (type PK-1). At this time, the main element of the universal switch is a four-board, five-position switch, the circuit of which is shown in Figure 3.

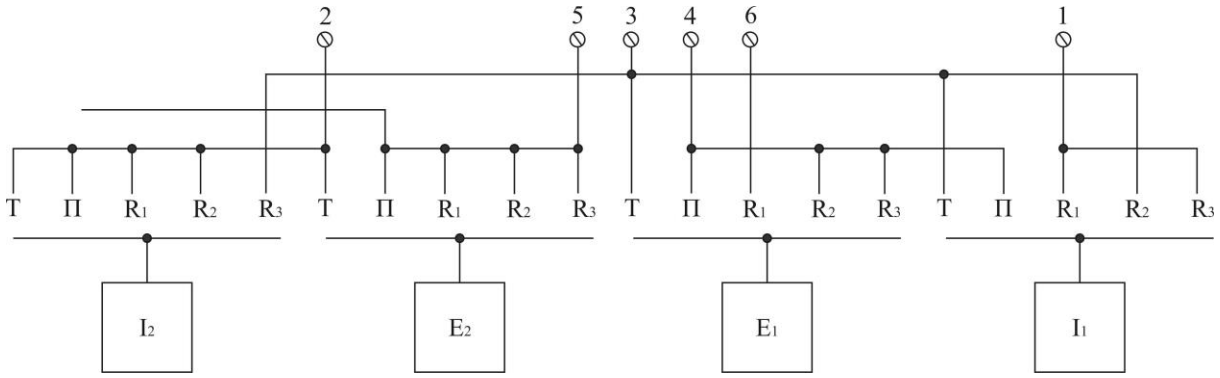


Figure 3 Four-board five-position switch board

The electrical devices used to assemble the switch are freely available. In Russia and the post-Soviet countries, the electrical devices used in the developed universal switch can be found in stock at the production bases of any power grid company. To reduce the errors when personnel connect the universal switch and to develop a document to regulate the process for using the universal switch for measurement, a schematic diagram of its connections has been developed. It is shown in Figure 4.

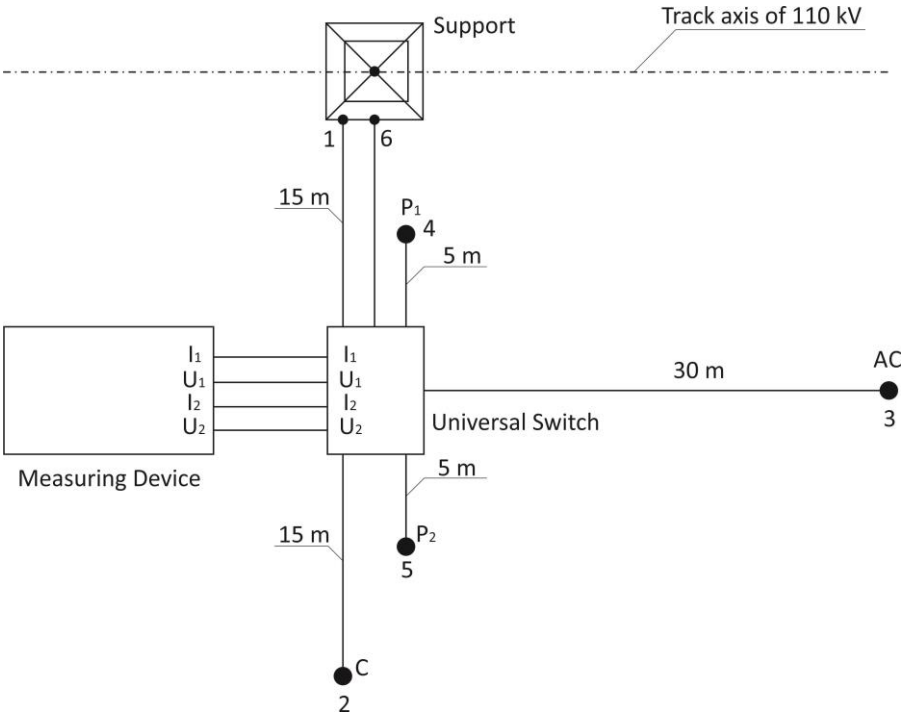


Figure 4 The schematic diagram for connecting a universal switch to measure the resistance of the protective device of 110 kV OHP supports if it is impossible or inexpedient to disconnect the lightning protection cable from the body of the support: C = current electrode; P2 = potential electrode; P1- comparative electrode; AC = auxiliary current electrode

We developed the technique that must be followed when using the developed universal switch for measurements:

- At position C, while the current is passing between the current electrodes, measure the voltage and the resistance of the circuit (it should be no more than 500 Ohm);
- At position P measure the resistance of the potential circuit (it should be no more than 1000 Ohm), while the current is passed between the potential electrodes and the voltage between them is measured;
- When the switch is in the R_1 position, as stated in Figure 3, measure the resistance when the current passes through the support and the current electrode and part of it branches off through the cable. It is necessary to measure the voltage between the grounding of the support and the potential electrode P_2;
- In the R_2 position, measure the resistance when the current passes through the current electrodes, while the voltage on the potential electrodes is measured and the ground of the support is removed from the circuit. There is no current drain;
- In the R_3 position, measure the resistance when the current is passed through the support and the auxiliary current electrode, while the voltage on the potential electrodes is measured, the part of the current branches off through the cable;
- This sequence of measurements must be performed three times using measuring instruments according to the Electric circuit diagram shown in RD 153-34.0-20.525-00. In this case, three values of resistance R_1, R_2, and R_3 are determined in succession.

The resistance required of the protective device of the support R_{GD} (when using the device without an amplifying attachment) is determined by the formula:

$$R_{GD} = R_1 \times \frac{R_2}{R_3} - R_2 \times (1.33 \times \frac{R_2}{R_3} - 1) \quad (2)$$

3. Results and Discussion

We performed the set of resistance measurements of the 110 kV OHL supports using the pulse method at the power grid company PJSC "IDGC-Center" – "Oryolenergo" from November 24 to November 27, 2020. Six brigades took part in these measurements. The measurements were performed both with and without using the developed universal switch.

The resistance measurements of the support were performed on the 110 kV OHL line "Uzlovaya-Himmash." The IS-10 device was used to measure the resistance of the support. During the measurements, we determined the time spent by the company's employees to conduct each measurement. The total time spent on the measurements was determined by formula 1 as stated above.

The results of the experiment, shown in Figure 5, show that the average of all the brigades that measured the resistance of the protective device of the 110 kV OHL "Uzlovaya-Himmash" when using the pulse method was 29 minutes or 28% faster.

The average value of the time to measure the resistance of the PD of a 110 kV OHL support without using the universal switch was 108.33 minutes. The time to conduct the measurement using of the universal switch was 77.79 minutes.

Thus, the use of the developed universal switch not only facilitates the work, but it also reduces the time needed to measure the of the PD of the 110 kV OHL support using the impulse method.

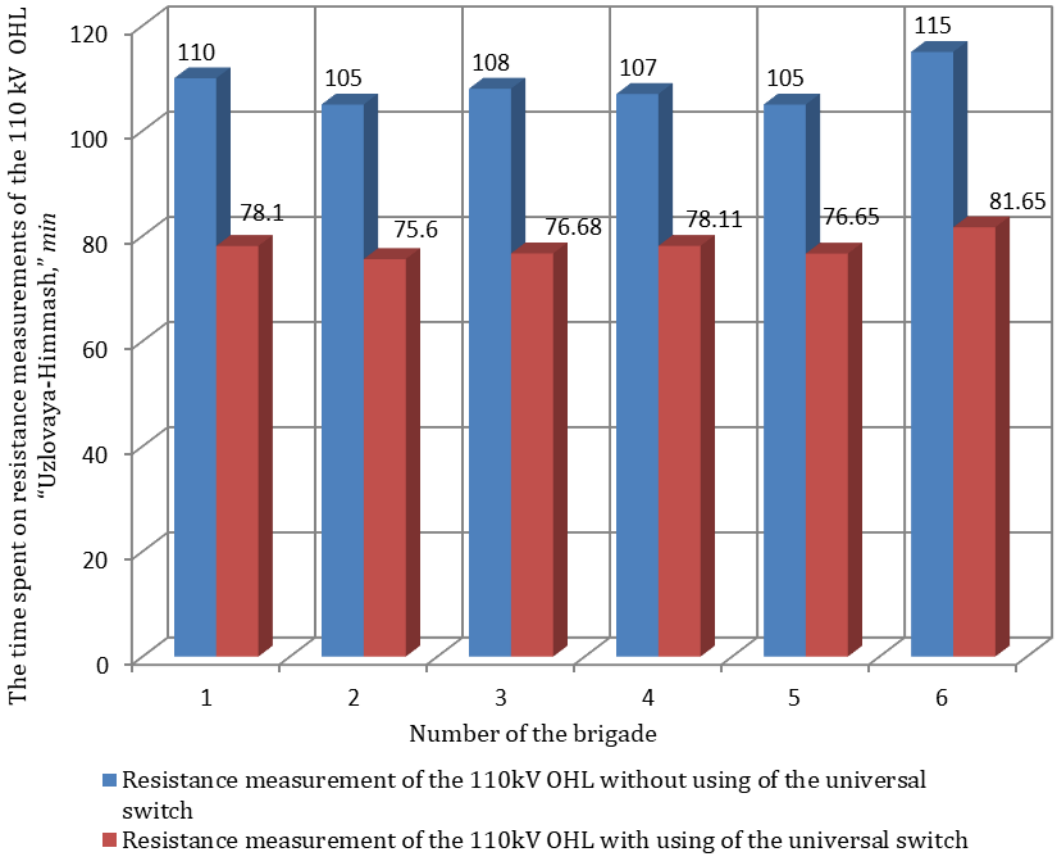


Figure 5 Comparison of the time spent on measuring the resistance of the grounding device of the 110 kV OHL "Uzlovaya–Himmash" using the pulse method with and without using the developed universal switch

At the same time, the developed switch can be used to measure the resistance of different voltage OHLs when it is impossible or inexpedient to disconnect the lightning protection cable from the body of the support. It should also be noted that the presented mathematical model describing the time to measure the resistance of the protective device of the 110 kV OHL supports using the pulse method works, so the model can be used to determine the efficiency of new devices when they are introduced into the measurement process.

The universal switch can be assembled from materials available at the bases of any regional electrical grids of the branches of PJSC "MRSK Center." This emphasizes the flexibility of its design. At the same time, the switch can be assembled by personnel who do not have high qualifications. Moreover, the developed universal switch can work with different measuring devices.

The developed universal switch was adopted by PJSC "MRSK Center" – "Oryolenergo" as a proposal for technical improvement, and it will be applied in the company.

4. Conclusions

The ability to measure the grounding resistance of the 110 kV OHL supports quickly and according to high quality standards without disconnecting the lightning protection cable enables us to consider the developed universal switch as an important, useful, and highly reliable technical improvement.

Using the device described in this article will allow companies that measure resistance to reduce the time needed to measure the resistance of the 110 kV OHL supports using the

pulse method if it is impossible or inexpedient to disconnect the lightning protection cable from the body. This will allow them to perform more measurements and reduce their operating costs.

The tests of the developed universal switch show its effectiveness, and they indicate the prospects of this development.

The simplicity of the design of the universal switch allows it to be assembled in the structural divisions of measurement companies. The assembly can be performed by personnel with less qualifications than those who conduct the measurements. The electrical devices needed to assemble the universal switch are freely available, and the developed universal switch can work with different measuring devices.

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