

## Influence of span length and impulse front time on earthing measurement accuracy of power line towers

**Abstract.** The article discusses the issue of measuring and assessing the features of power line tower earthings using fast-changing waveform. The study analyses the effect of impulse front time and the line span length on errors made during these measurements using impulse meters. It has been found that the assessment conditions similar to the static measurement results occur for the use of 4  $\mu$ s current impulses and such procedure is useful for evaluating power line tower earthings.

**Streszczenie.** W artykule omówiono zasady pomiaru i zasady oceny uziemień słupów linii elektroenergetycznych przy użyciu udarów szybkozmiennych oraz wpływ czasu czoła tych udarów oraz długości przęsła na dokładność pomiarów. Stwierdzono, że warunki oceny najbardziej zbliżone do wyników otrzymywanych przy pomiarach statycznych sugerowanych przez przepisy normalizacyjne występują przy udarach o czasie czoła 4  $\mu$ s. (Wpływ długości przęsła i czasu czoła udaru na dokładność pomiarów uziemień słupów linii elektroenergetycznych)

**Keywords:** earthing; earthing measurement; impulse earthing impedance, tower earthing measurement

**Słowa kluczowe:** uziemienia, pomiary uziemień, impedancja udarowa uziemień, pomiary uziemień słupów

### Introduction

Earthing is an important and necessary element of any energy system. Properly designed and constructed earthing guarantees safety for both people and devices located in places where a flow of dangerous short circuit or surge current caused by a lightning discharge can occur. Therefore, the earthing resistance should be made as low as possible, and its value should meet the guidelines contained in the specified standards and regulations.

During its construction and later operation, the earthing should undergo periodic inspection, mainly through measurements of its resistance [1, 2]. Control tests of the resistance carried out using the traditional method are often very time consuming, especially for earthing of power line towers.

The purpose of this paper is to describe the procedures for measuring and assessing the earthing for power transmission line towers equipped with lightning conductors. The subject of analysis is primarily the influence of the span length and front time of the used measurement impulses on the results of earthing impedance. The presented results of theoretical calculations and computer simulations have been supplemented with measurements on real objects.

### Methods for assessment of line tower earthing

Static resistance of line tower earthings is usually determined using meters operating at low frequency and implementing various types of technical methods. In the case of high voltage transmission line towers, their earthings are connected in parallel by lightning conductors, as it has been shown in Fig. 1. Therefore, there are two main methods of measurement: disconnection of artificial earth electrode from the tower or using a low frequency meter equipped with a current clamp [3].

When using a low frequency excitation, the control terminals should be disconnected for the time of measurement, and thus the connection between the artificial earth electrode and the tower structure should be removed. Such a procedure is quite cumbersome and requires removing four connections - one at each leg of the tower. In addition, the resistance value obtained in this way is caused solely by the artificial earth electrode, whereas the natural foundation earth electrode does not affect the measurement result. It should also be noted that such measurements should be made for a switched-off line.

In real earthing systems, the foundation earth electrode can significantly affect the resultant value of earthing resistance and determine the final assessment of the measurement result. The measurement results for the tower in the ground with a resistivity of about 200  $\Omega$ m and presented in Fig. 2 show that such a situation may take place. When measuring the resistance of an artificial earth electrode separated from the tower, a result  $R_s$  equal to 18  $\Omega$  was obtained, which is too high a value in relation to the standard requirements [1]. The resistance value of the analysed tower foundation is 12  $\Omega$ , and the parallel connection of both earthing elements gives the value of 7,7  $\Omega$ , which means that the requirements of the before mentioned standards are met.

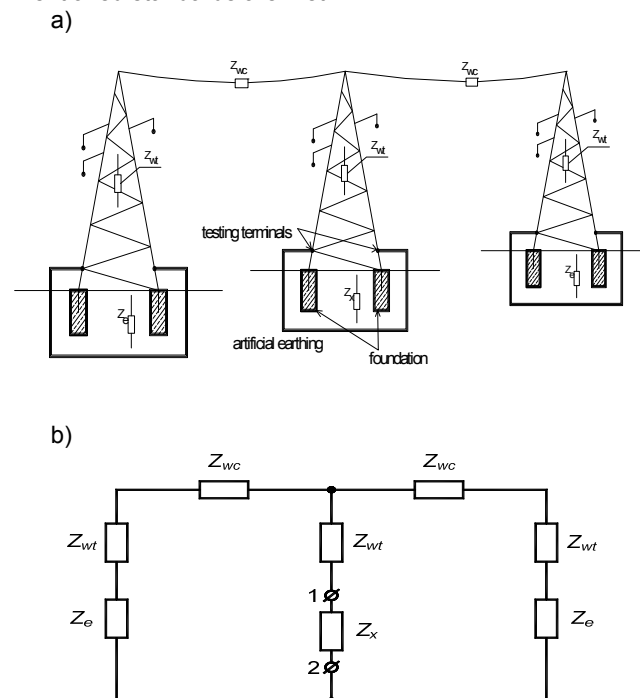


Fig. 1. Arrangement of tower earthing test with two neighbouring towers – a) and its equivalent scheme – b)

The presented impulse procedure for measuring earthing of power lines with lightning conductors without disconnecting the earthing wires from the tower structure allows this type of inspection and measurement work

without turning off the line. In addition, impulse measurements without disconnection of control terminals are affected by the tower foundation, which also participates in the discharge of actual lightning currents, and whose resistance is often comparable to the resistance of an additional artificial earth electrode. Therefore, it should not be overlooked in assessing the earthing effectiveness [3].

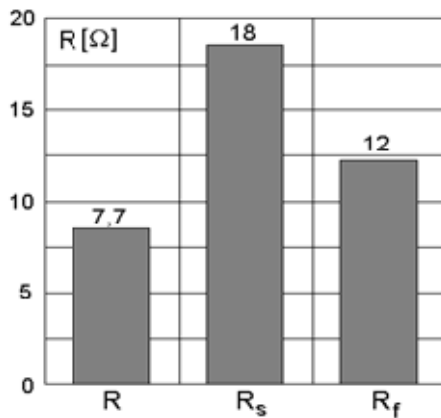


Fig. 2. The results of static resistance for earthing of 110 kV line tower with the lightning conductor disconnected from its structure: R – resistance of the parallel connection of the foundation and artificial earth electrode,  $R_s$  – artificial earth electrode resistance,  $R_f$  – tower foundation resistance

### Investigation results

The subject of the investigations was the influence of the impulse front time and span length on obtained values of the earthing impedance for power transmission line towers equipped with lightning conductors. The investigations were carried out using both computer simulations and measurements on real towers earthings. Calculations based on computer simulations were made using Matlab software with the Simulink package. The total tower earthing consists of parallelly connected artificial earthing ring and foundation earth electrode. The earthing ring is modelled using the elements R, L and C, which were determined according to the methodology developed by Sunde [4]. The foundation is modelled by a resistance calculated according to dimensions of the foundation footings [5, 6].

The parameters of a square earthing ring with a side of 12 m and tower foundation were designated for the assumed ground resistivity of 100  $\Omega\text{m}$  value. The impedance of such a modelled earth electrode was determined at the impulse current with an amplitude of 1 A and three front times equal to: 1.0, 4.0 and 10  $\mu\text{s}$  as well as at network frequency current. The simulation results are shown in Fig. 3. With the increase of front time, the impedance value of earthing decreases and at the front times of 4 and 10  $\mu\text{s}$  its value reaches the state close to the fixed state obtained for network frequency, which is determined by resistive elements applied in the analysed model.

In the next stage of calculations in Matlab, the analysed tower earthing was bypassed by two corresponding earthings, connected by a lightning conductor with the configuration shown in Fig. 1. Wave impedance in the lightning conductor - earth system was modelled as a long line using fixed parameters. The assumed span length was changed from 10 to 400 m. The simulation measurement results for impulse impedance between terminals 1 and 2 in Fig. 1 as a function of the span length for the impulse front times 1, 4 and 10  $\mu\text{s}$  are shown in Fig.4. The dashed line with a description  $R_{st}$  and

impedance  $Z_4$  for long spans correspond each other. Static resistance  $R_{st}$  has been obtained for a connection without line lightning conductor and  $Z_4$  – for a connection with the conductor. so obtained without lightning conductors. Subsequent curves show the influence of parallel connection of earthings of adjacent towers on the obtained results, and their deviation from the initial values presented in Fig. 3 (without lightning conductors) is a measure of measurement error introduce by lightning conductors connections.

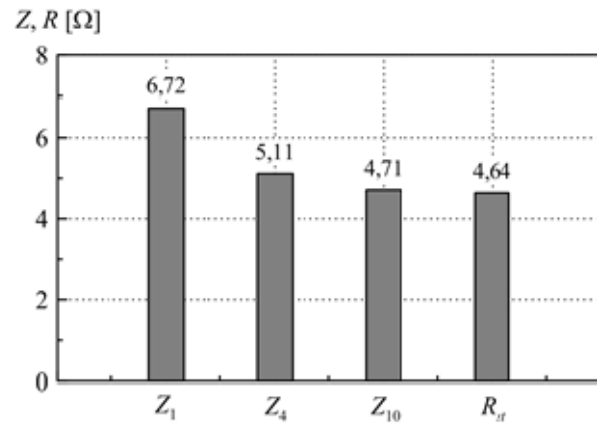


Fig. 3. Results of simulation calculations for the impedance of tower earthing at the impulse current with an amplitude of 1 A, given front times and the frequency of 50 Hz

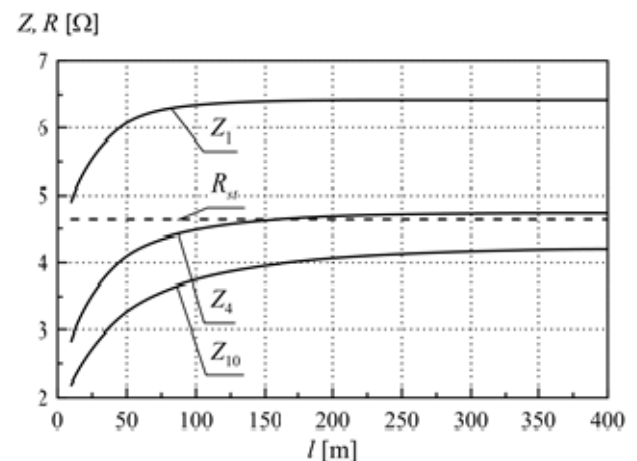


Fig. 4. Influence of the span length on the impedance of the tower earthing bypassed with earthings of two adjacent towers and lightning conductors for the following front times of measuring impulses: 1, 4 and 10  $\mu\text{s}$  denoted as  $Z_1$ ,  $Z_4$  and  $Z_{10}$  respectively;  $R_{st}$  – static resistance of tower total earthing

In the case of impulses with the front time of 1  $\mu\text{s}$  the decrease of the measuring impedance value of earthings caused by the bypassed influence of adjacent earthings is at the lowest level and does not exceed 5% for spans longer than 100 m. However, it should be noted that the same value of impulse impedance at such a short time of front significantly exceeds the earthing resistance measured in static conditions, which usually is a reference point in earthing assessment. The impulse coefficient for the tower earthing is defined as the ratio of the impulse impedance and the static resistance. In the case of impulses with a front time of 1  $\mu\text{s}$  it can achieve high values, usually in the range of 1.2-2.5. Higher values refer to earthings in towers located in grounds of high resistivity where it is necessary to use extended artificial earth electrodes [7]. In such cases,

the impedance of tower earthing measured with the impulse with a front time of 1  $\mu\text{s}$  can too often exceed the normative values reported for static conditions as it can be seen in Fig. 4.

The relative error of the measured value  $Z_m$  as a result of bypassing and the real value  $Z_x$  is determined in % based on the formula:

$$\Delta Z = (Z_x - Z_m) / Z_x$$

The error decreases with the increase in span length and increases for longer fronts of the measuring impulses, as can be seen in Fig. 5.

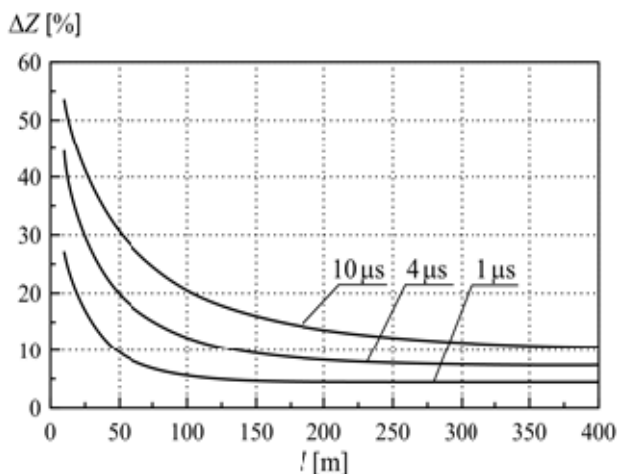


Fig. 5. Influence of the current front time of measuring impulse on impedance relative error as a function bypassed with earthing of two adjacent towers and lightning conductors of various span lengths

Measurements of tower earthing using impulses of front time equal to 4  $\mu\text{s}$  may include errors at short spans due to bypassing with adjacent earthing. This error does not exceed 10% for span lengths above 100 m. Impulse coefficient of tower earthing measured at impulse of 4  $\mu\text{s}$  is not very high and usually does not exceed the value of 1.5. Compared to the static resistance, the higher value of measured impedance is partially offset by an error introduced by the bypassing with adjacent earthing, so the results obtained in impulse measurements without isolating earthing from the lightning conductors may be related to the requirements for earthing static resistance with a good approximation. This remark is confirmed by results presented in Fig. 6.

An influence of lightning conductor presence on the impedance of real line earthing measured at impulse front times: 1, 4, 10  $\mu\text{s}$  and on their static resistance can be seen in Fig. 6. Results marked as "a" refer to earthing of transmission line towers without lightning conductors and results marked as "b" – to the same line equipped with lightning conductors. The described investigations refer to a line with span lengths of 150 – 200 m range and were carried out at repair time of the line. Differences between values denoted as "a" and "b" are the result of bypassing the measured earthing and the earthing of adjacent towers, so the differences can be taken as measurement errors. Errors in Fig. 6 are equal to 4.7%, 8.3% and 18.2% for impulse front times 1, 4 and 10  $\mu\text{s}$  respectively. The errors do not exceed values obtained from computer simulations and shown in Fig. 5.

It should be noted that the value of earthing impedance obtained at the impulse front time equal to 10  $\mu\text{s}$  is less than the static resistance of the earthing.

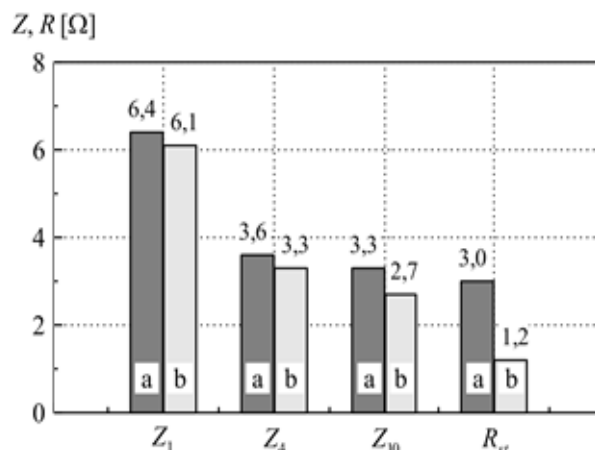


Fig. 6. Influence of lightning conductors on the impedance of actual earthing measured at impulse front times: 1, 4, 10  $\mu\text{s}$  and on their static resistance, a – tests without lightning conductors, b- with lightning conductors

### Conclusions

The discharge of the line tower current to the ground is done by both an artificial earth electrode and the foundations of that tower. Therefore, assessment of earthing resistance for the power line tower should be made when both earthing elements are tested parallelly.

The proposed 4  $\mu\text{s}$  impulse front time is a compromise between the required accuracy of measurement and the obtained impedance values referred to the earthing resistance specified in standardization rules. Even under the most adverse conditions, the theoretical error made in applying the proposed impulse method of measurement does not exceed 10%, which is acceptable in earthing tests.

During testing of tower earthing of power lines should not be used impulses of the front time 10  $\mu\text{s}$ , because impedance results obtained in such a way are usually lower than the real static resistance of the tested earthing.

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### REFERENCES

- [1] PN-EN 62305-3:2009 - Protection against lightning, Part 3, Physical damage to structures and life hazard.
- [2] PN-E 05115:2002 - Power installations exceeding 1 kV a.c.
- [3] Wojtas S., Earthing measurements for power line towers, Acta Energetica, Nr 1, 2011.
- [4] Velazquez R., Mukhedar D. „Analytical modeling of grounding electrodes transient behavior”, IEEE Transaction on Power Apparatus and Systems, vol. PAS-103, Nr 6, 1984.
- [5] Markowska R., Sowa A., Wiater J. „Simulation measurements of lightning risk of electronic systems”, Electrical Review, Nr 3, 2010.
- [6] Wiater J. “Influence of different lightning source models on current distribution in the HV substation”, Electrical Review, Nr 3, 2010.
- [7] Wojtas S. “Lightning impulse efficiency of horizontal earthing”, Electrical Review, Nr 10b, 2012.