ABOUT UNDERGROUND OVERHEAD POWER LINE

Roman GANUS[1*], Andrii POTRYVAI[1]

[1]*IEEE institute, PhD. student of Department of Electric Power Transmission, NTU "KhPI", Kharkiv, Ukraine*

*Corresponding author: Roman Ganus, mrgans.roma@gmail.com

Tutor/Coordinator: Sergii SHEVCHENKO, IEEE institute, prof. of Department of Electric Power Transmission, NTU "KhPI", Kharkiv, Ukraine**, Dmytro DANYLCHENKO** IEEE institute, docent of Department of Electric Power Transmission, NTU "KhPI", Kharkiv, Ukraine

Abstract. *In this paper, the main requirements and conditions for placing overhead power lines underground, the reasons for the relevance of such an implementation, and a methodology for calculating the optimal interphase distance for the proposed line design were determined.*

Keywords: *calculation method, line capacity, phase distance, power line protection.*

Introduction

Under the prevailing conditions in the world, when the demand and price for land plots are growing rapidly, the experience of war shows the vulnerability of the means of transmission of electrical energy, and the interest in new designs of overhead power lines (TL) is growing, it must be recognized that their traditional design is no longer always the best for solving problems of transmission of electrical energy.

The solution to all of the above problems, in our opinion, is to move overhead power lines underground. This solution has many advantages, however, the standard recommendations for the installation of overhead power lines will not create an optimal structure for construction and operation, and therefore it is necessary to revise many existing rules in order to form new ones that will achieve maximum efficiency and reliability of the structure.

Therefore, the objectives of this work are to consider the advantages and disadvantages of underground overhead power transmission lines (UOTL), review existing standards and identify issues that need to be addressed in the implementation of such a project.

Reasons for using

One obvious solution to the problems described above is the use of cable lines. The problem of using cable lines to transmit electricity over long distances is their large capacity. Thus, an attempt to transmit high voltage over a distance of 40 km or more will lead to the fact that the cable will act as a source of reactive power and it will not be possible to transmit active power anywhere. Therefore, cable lines are used mainly at short distances and small, relative to overhead power lines, voltages.

Overhead transmission lines do not have such problems, however, their dimensions and the high electric field strength around the conductors do not allow them to be brought deep enough into the city. And even if there is a path that allows you to build a line, for example, 330 kV, then the cost of these land plots will be extremely high, which will lead to the unprofitability of such a project.

Therefore, it is necessary to develop a solution that will allow transmitting significant power over long distances, will allow running a line deep into the city, while maintaining profitability, and also, for Ukraine, the requirement to protect lines from aircraft weapons will be relevant.

Details about OULT

The first disadvantage of the traditional design of high-voltage overhead power lines is their dimensions. This is due to the observance of the recommended distances between the phases and the need to create a protective zone.

The distance between the phases is affected by many parameters, but the key ones are the fluctuations that occur due to the influence of the wind, which can lead to wires lashing and breakdown of the air gap in the event of a critical approach of the wires.

The most common types of fluctuations are:

Vibration of wires (cables) - periodic oscillations of wires or cables in a run with a frequency of 3 to 150 Hz, which occur in a vertical plane during wind and form standing waves with a swing that can exceed the diameter of the wires (cables).

Dance of wires (cables) - constant periodic low-frequency (0.2 - 2 Hz) vibrations of wires (cables) in the run, which form standing waves (sometimes combined with running ones) with a number of half-waves from one to twenty and an amplitude of 0.3 - 5 m .

Sub-oscillations (oscillations of wires in sub-runs) are periodic wind-induced oscillations of a horizontally placed pair of split-phase wires that occur with the same or several half-waves in sections (called sub-runs) between adjacent intra-phase spacers with nodal points at the places where the spacers are installed.

According to [1], the protection of lines from the above types of vibrations is reduced to the use of appropriate devices (dampers) and compliance with the norms of the length of runs and phase-to-phase distances. Also in the norms "SOU 45.2-00100227-24: 2010 (Protection of wires and cables of repeated lines of electricity in the form of wind fluctuations (vibration, galloping, subfluctuations). Methodical wiring" in table B.2. the recommended values of the phase-to-phase distance for lines of different types of voltages are indicated (from 35 to 750 kV) Based on it, the choice of phase-to-phase distance is selected based on the length of the sag and the vertical distance H. Compliance with these recommendations allows you to be sure that whipping or wire breakage will not occur under most wind loads.

A fragment of this table for a voltage of 110 kV is given below, Tab.1.

The smallest displacements of wires of adjacent tiers horizontally on intermediate supports in areas with moderate dance (with a frequency of less than once every five years) for 110 kV.

Table 1.

OTL voltage, kV	**Vertical distances (H), m**	**Horizontal distance, m, with sagging booms at 0℃, м**							
		4	**5**	**6**	**8**	**12**	**16**	**20**	**>30**
110	3,0	-	-	1,15	1,70	2,40	2,80	3,50	4,15
	3,5	-	-	-	1,50	2,40	2,70	3,40	4,10
	4,0	-	-	-	1,20	2,20	2,65	3,40	4,10
	4,5	-	-	-	-	2,00	2,60	3,35	4,05
	5,0	-	-	-	-	1,80	2,50	3,25	4,00
	5,5	-	-	-	-	1,50	2,45	3,30	4,10
	6,0	-	-	-	-	1,20	2,30	3,20	4,00
	6,5	-	-	-	-	-	2,10	3,05	3,80
	7,0	-	-	-	-	-	2,00	2,90	3,70
	7,5	-	-	-	-	-	1,60	2,75	3,65
	8,0	-	-	-	-	-	1,20	2,60	3,50

In addition, the issue of interphase distance is considered in the REI (ПУЕ). Therefore, for example, the distance between the phases for an overhead line (OTL) of 110 kV according to the formula 2.5.22 [2] will be 3.3-3.6 m for a standard single-circuit version.

Moreover, this distance significantly depends on climatic conditions, such as: wind, ice loads, temperature influence and zoning according to thunderstorm activity. It is worth noting that these standards will not be relevant for UOTL, since underground climatic features will not have a significant impact, which means that these requirements can be neglected when searching for the optimal design. Then the search for the optimal design is reduced to providing the most favorable conditions for the line capacity, which directly depends on the distance between the phases [3]. The only condition that must be observed during layout is to ensure sufficient distance between the phases to prevent breakdown of the air space between the conductors.

Based on this, you can refer to the source [4], from which to determine the minimum allowable air gap Fig. 1-2.

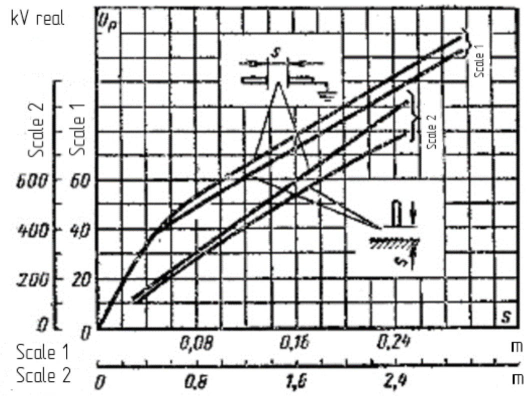

Figure 1. Discharge voltages for air gaps rod-to-rod and rod-to-plane at 50 Hz

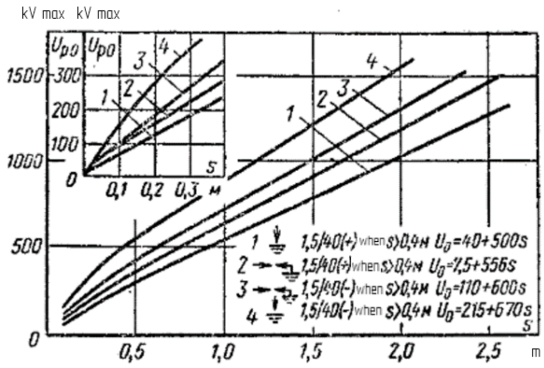

Figure 2. Discharge 50% - impulse voltage for air gaps rod - rod and rod – plane

However, the problem with these curves is that they are designed for bar-to-bar gaps. When it comes to significant phase convergence, which UOTL allows to perform, the error can have a significant impact, therefore, it becomes necessary to create curves for air gaps wire-wire and wire-plane. Accurate data can be built only by conducting an experiment, which is what the next work is planned to be devoted to.

The location of the lines underground, also, provide them with high security from enemy assets that damage the infrastructure.

To determine the required depth, it is worth referring to the statistics collected during the war in Ukraine.

For attacks on the energy infrastructure, cruise missiles of the “Caliber” and X-101 types were used. The conical shape of the funnel characterizes the charge as a normal ejection charge. This makes it possible, after a series of transformations of the formulas from the source [5], to calculate the depth of the funnel using the formula:

$$W = \sqrt[3]{\frac{L}{1{,}83 \cdot P}} \tag{1}$$

Where L is the weight of the warhead; P is the specific consumption of explosive per m^3 of blasted rock, equal to 2.43.

To prevent collapses and strengthen, it is necessary to make a layer of reinforced concrete, to clarify the thickness of which it is necessary to calculate the mechanical resistance of the material.

Thus, the UOTL takes the form of a line that is stretched inside a reinforced concrete collector of a cylindrical or parallelepiped shape with right angles. Options are shown in Fig. 3.

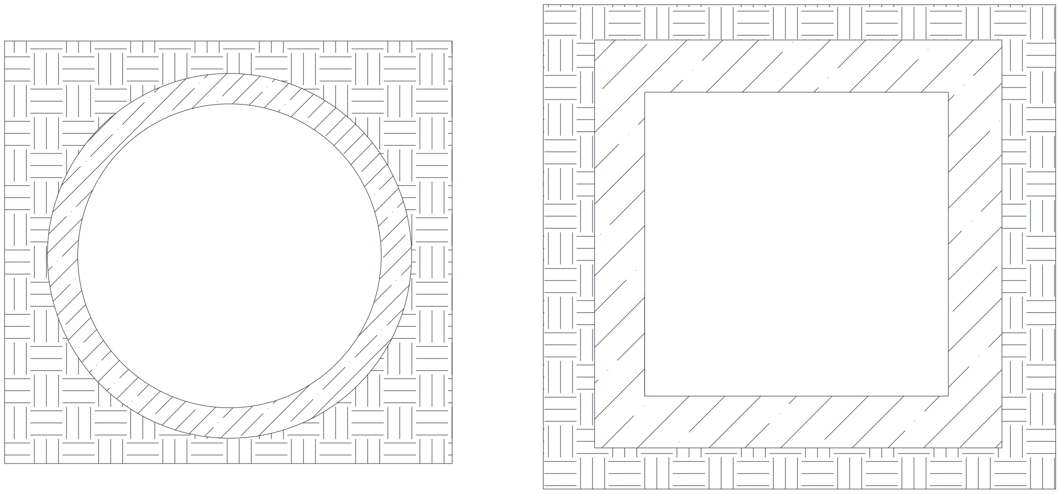

Figure 3. Schematic representation of the proposed type of the UOTL tunnel

However, this location is not without its downsides. Such a design implies the need to reduce the humidity inside the collector and adds to the calculation the need to take into account the moisture discharge voltage for the support insulators.

The need to control the humidity of the environment in the collectors can lead to the use of a large amount of expensive equipment, which will lead to a decrease in the profitability of the UOTL, but this issue needs to be considered in more detail during the feasibility study.

Conclusions

In this paper, the concept of UOTL was proposed, which is devoid of the disadvantages of classical solutions: overhead power lines of standard designs and cable lines. The advantages and disadvantages of this concept were considered.

Among the advantages, the possibility of changing the interphase distance, based solely on ensuring the highest throughput, is highlighted, since the lines are not affected by atmospheric phenomena (wind, ice, etc.). The underground location will allow the line to run deep into the city, which will reduce line losses and save on the cost of land plots through which the line could potentially pass, which significantly increases its profitability.

A method for calculating the depth of the formation of a funnel was determined, which will help determine the depth of the UOTL in the future. Two proposed types of collector are proposed.

The shortcomings of both traditional transmission lines and the proposed UOTL are considered. Its key disadvantage is the formation of condensate inside the collector, which leads to the need to control the humidity inside the system and take into account the moisture discharge voltage.

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