OVERVIEW OF THE WORLD EXPERIENCE IN THE CONSTRUCTION OF TERMINATION POINTS BETWEEN HIGH-VOLTAGE CABLE AND OVERHEAD LINES

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Traditionally, power transmission lines are divided into overhead lines (OHL) and cable lines (CL). However, in recent decades, a large number of lines have appeared that cannot be unambiguously attributed to either OHL or CL – these are the so-called mixed lines (ML), which have both overhead and cable sections. The construction and operation of ML require power engineers to solve a whole range of specific tasks, and one of them is to choose the optimal design of the termination points that have to be created at the points where the cable and overhead sections of the ML route interface with each other.

Keywords: cable line, overhead line, mixed line, termination point, lattice tower, steel pole

INTRODUCTION

The formation of ML often occurs due to the need to arrange a cable section on the OHL, for example, in places:

- passing the line in conditions of dense urban development;
- the passage of the line through the industrial territories, as well as private owners with the prohibition of landowners to pass OHLs through their territories;
- entering the line into a closed switchgear (for example, gas-insulated GIS);
- crossing the line through a water barrier.

The largest number of ML can be found, first of all, in large dynamically developing cities, where, as new territories are developed, the existing OHLs are gradually transferred to CLs in parts, and open switchgears are replaced by modern GIS.

The power system of the Moscow region is the leader in the number of ML in Russia, so it was Moscow grid company MOESK that was the first in the country to initiate an analysis of the world experience in the design, construction and operation of ML. Since there was a need for Moscow and other large Russian cities to develop a unified termination point (TP) at the points where the cable and overhead sections of the ML were connected to each other, the TP designs used in different countries were of particular interest to MOESK.

An analysis of a large number of international publications and documents has shown that, unfortunately, none of the sources contains comprehensive information on all TP problems. However, it would be unfair not to mention the standards [1] and [2], where quite successful attempts have been made to systematize the issues of creating and maintaining TP on high and ultrahigh voltage lines. Based on [1, 2], as well as other materials, the article below provides basic information about the TPs used in the world, which will be taken into account in the future when developing a unified TP for the 110 kV class for MOESK, and then for other rated voltage classes, in particular, at 220 kV.

Outside the former USSR, there is practically no 110 kV voltage class, and such voltages as 115, 132, 138 kV, etc. are common. The highest voltage for cable networks is 550 kV (whereas in Russia it is 500 kV). The closest to the 110 kV class is the problem of 110-170 kV facilities available in the world.

TYPES OF TERMINATION POINTS

In general, the TP may include the following equipment:
- cable and its terminations;
- metal-oxide surge arresters (MOA);
- current transformers (CT) and voltage transformers (VT);
- switching devices (disconnectors and/or switches);
- shunt reactors to compensate for the reactive power of CL;
- terminals of relay protection and automation;
- power supply system for own needs (batteries and their chargers);
- other equipment.

For the construction of the TP, you will also need:
- foundations;
- low resistance grounding system and lightning protection;
- access roads and U-turn platforms;
- fencing, landscaping of the territory.

From the point of view of the high-voltage equipment placement, four versions of the TP are known:
- ground TP in an open area (Figure 1, applicable to any voltage classes up to 550 kV);
- ground TP in a building (Figure 2, applicable to classes up to 245 kV);
- ground compact TP with SF6 equipment;
- TP on the OHL tower (Figures 3-4, applicable for classes up to 170 kV).

Fig.1. TP of ground execution on an open site

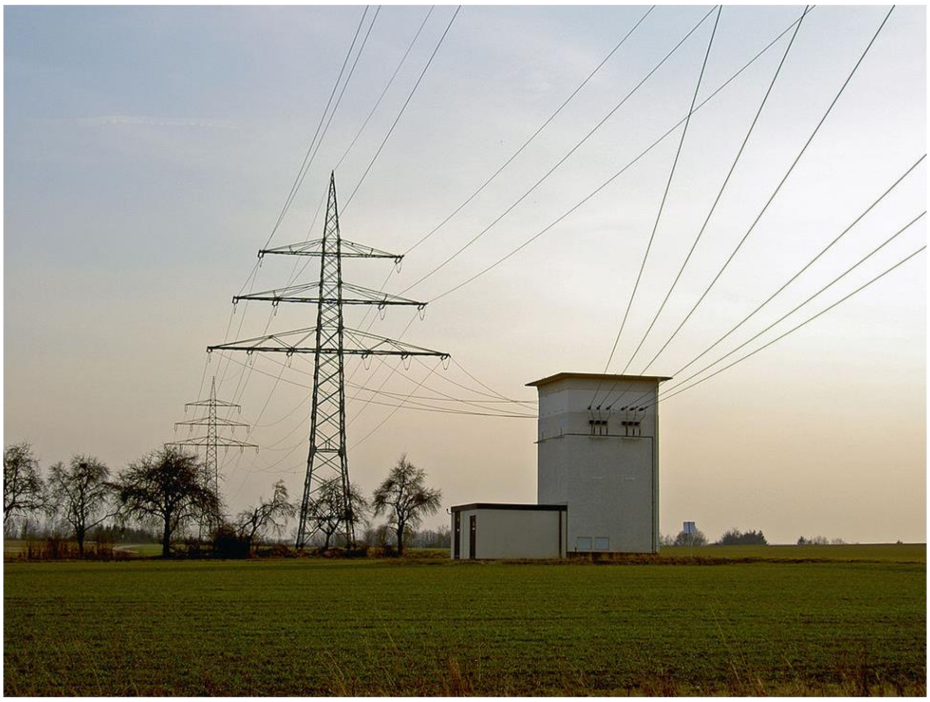

Fig.2. TP of ground execution in the building

Fig.3. Double-circuit TP on the OHL tower (lattice)

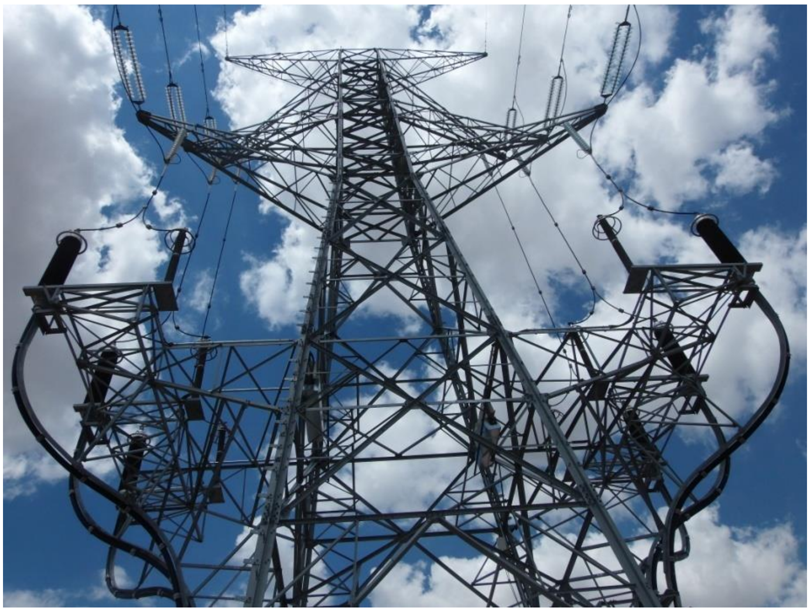

Fig.4. Single-circuit TP on the OHL tower (lattice)

The choice of a specific version of the TP (on the ground, in a building, on a tower) depends primarily on the following factors:
– rated voltage class;
– climatic conditions (low temperatures, snow and ice sticking);
– the intended composition of high-voltage equipment (the need of automatic reclosure of the line and ability to find damage points along the line route);
– availability of a free space, the cost of land, compliance with the requirements of urban architecture;
– convenience of equipment installation and maintenance;
– protection of people in case of explosive destruction of equipment;
– protection of equipment from the actions of third parties (vandals).

Advantages of TP on the OHL tower

World practice is such that more than 90% of all TP for voltage classes 110-170 kV are performed on OHL towers, and there are two main reasons for this:
1. In the vast majority of cases, the composition of the TP equipment is minimal and includes only cable terminations and MOAs – all of them can be compactly placed on the OHL tower. There is also a place on the tower for measuring CT, necessary for the organization of relay protection of ML (it is convenient to use split-type CT, which are put on the cable under the termination, or to use optical CT).
2. Installation of TP equipment on the OHL tower, especially polyhedral, allows you to allocate a small area for TP, which is very advantageous if you take into account the high cost of land in modern large cities.

Disadvantages of TP on the OHL tower

In addition to the advantages, TP on the OHL tower also has disadvantages.
1. The process of direct installation of cable and cable terminations is a complex of works at height and is fraught with some difficulties, requires the organization of special

scaffolding with cable tents (Figure 5), as well as the use of lifts. This is partly why, in world practice, TP is performed on an OHL tower, mainly for classes less than 170 kV.

2. The operation of TP, maintenance of equipment, its testing and repair are associated with the need to work at height, require the use of various special devices, inventory, materials. On the TP, emergency recovery work can be further complicated if they have to be performed during the formation of ice and snow load, the presence of hurricane winds and thunderstorm activity.
3. The TP equipment placed on the OHL tower, in the event of its explosive destruction, poses a danger to people nearby. At the same time, the higher the installation height of the terminations and the MOAs, the greater the radius of expansion of the elements. An analysis of world experience unexpectedly showed that on most TP, even when they are located in populated areas, there are no measures to protect people. The exceptions were typical towers in England and Hungary (Figure 6a), as well as one of the towers in Korea (Figure 6b), where the equipment is covered from below and from the sides with special mesh fences.
4. The TP equipment available on the OHL tower is less protected from the actions of third parties in comparison, for example, with the TP in the building. Vandals can throw to equipment various objects, shoot it with weapons, climb onto platforms and traverses. When analyzing world experience, it turned out that on most OHL towers with TP there are no equipment protection measures, among which could be:
   - side shields located around the equipment at a height and allowing to protect against throwing by foreign objects;
   - fence located around the tower;
   - barbed wire mesh stretched on the lower tiers of the lattice tower;
   - temporary dismantling of the step bolts on the lower elements of the tower structure;
   - alarm, video surveillance and other measures.

Fig.5. Construction of scaffolding around the TP, made on the OHL tower, for the subsequent installation of cable terminations

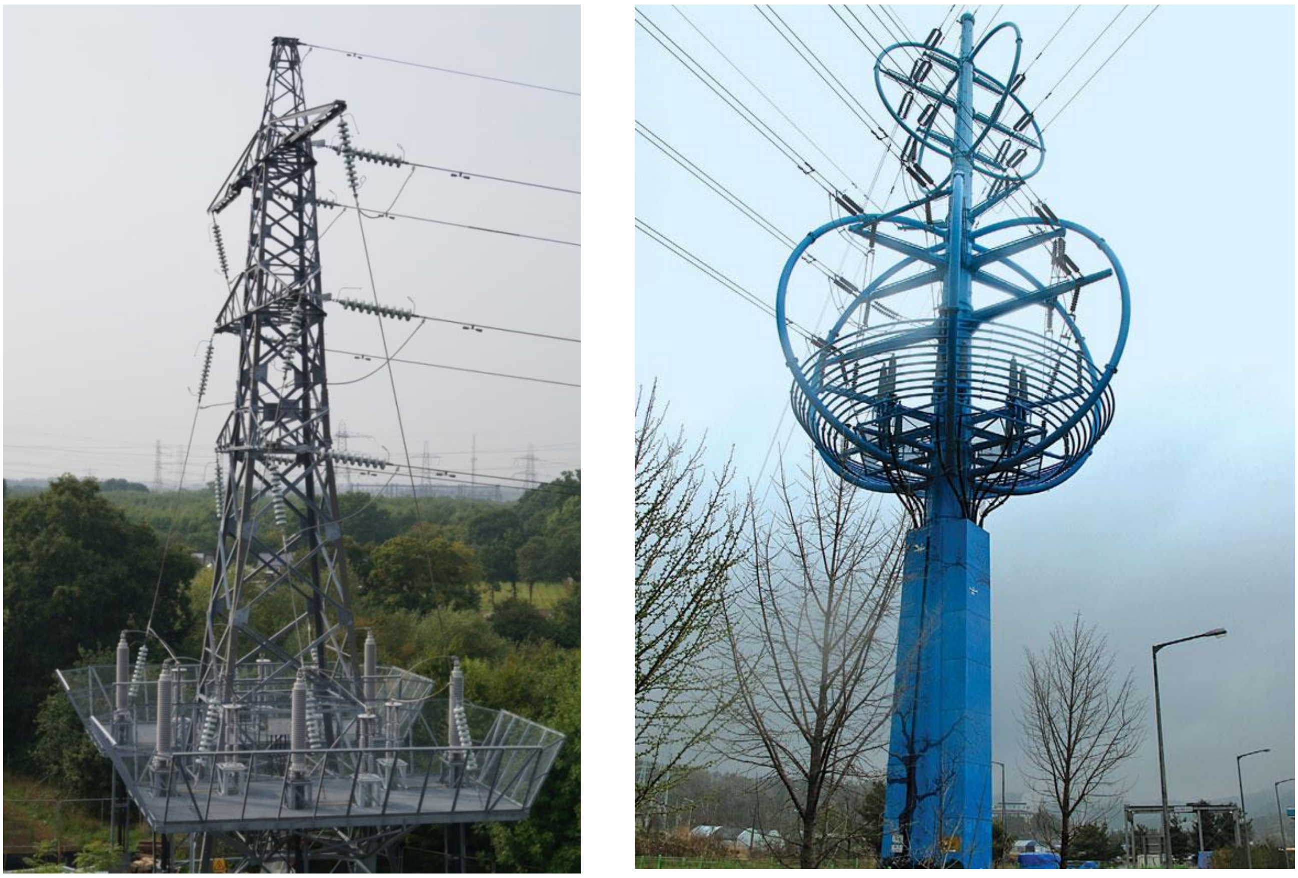

Fig.6. TP on the OHL tower having a platform for equipment covered with a grid: (a) – lattice; (b) – steel pole

The above-mentioned disadvantages of TP on OHL towers (especially in terms of protecting equipment and people) have always been taken quite seriously in MOESK, and therefore in Moscow most of the 110 kV voltage class TPs are not made on OHL towers, but in closed buildings.

The high cost of land in Moscow and certain difficulties with the construction of closed TP forced us to look for a reasonable alternative to the current technical policy, for which a large-scale work was organized to analyze world experience. The analysis showed that there is no such TP on the OHL tower in the world that would satisfy modern high requirements in terms of reliability of power supply to consumers, ease of installation, operation and repair of TP, safety of city residents and TP equipment, as well as in terms of aesthetics of the appearance of TP structures. However, studies have nevertheless shown that the development of a TP on the OHL tower that meets modern requirements for the safety and reliability of power supply to consumers of a megalopolis is possible.

When creating any TP, specialists, first of all, should decide on such basic issues as:

– the material and design of the tower;
– the number of OHL circuits on the TP tower;
– number of cables per OHL phase;
– options for laying the cable along the tower, its fastening and protection;
– type of cable terminations;
– the need for MOAs, CTs, VTs;
– the need for switching devices.

In the terms of reference for the development of a universal TP, MOESK indicated its requirements for each of the listed issues. In general, as will be shown below, these requirements do not contradict the accumulated world experience, but rather complement and develop it.

MATERIAL AND CONSTRUCTION OF THE TP TOWER

In the world, metal towers (lattice or steel poles) are used in the construction of 110-170 kV class TP, while concrete, wooden, composite ones are not used. Latticed ones can be found more often in Europe, Russia, and the countries of the former USSR, while steel poles can be found in the countries of America and Asia.

Usually, TP up to 170 kV are double-circuit (Figures 3, 6, 7), that is, they represent a double-circuit OHL tower, on which a double-circuit CL is wound. Variants of single-circuit TP (Figure 4) are quite rare. There are also rare cases when the number of phases of the OHL and the number of single-core cables does not coincide with each other – for example, in Figure 8, where for each phase of a single-circuit OHL there are two cables connected in parallel to each other and thereby increasing the current capacity of the CL to the values possessed by the air section of the ML.

In documents [1, 2], in order to increase the reliability of power supply and reduce the time of repair work, an option is proposed when, in addition to the main set of three terminations and their cables, a reserve termination with a reserve cable connected to it descending to the ground (the so-called 4th phase) is placed on the TP tower. However, it was not possible to meet such a solution in practice.

An analysis of world experience has confirmed that the optimal design for Moscow will be a TP on a steel pole due to its compactness and high degree of factory readiness.

Fig.7. TP on a double-circuit OHL tower (steel pole). Dry flexible terminations are used

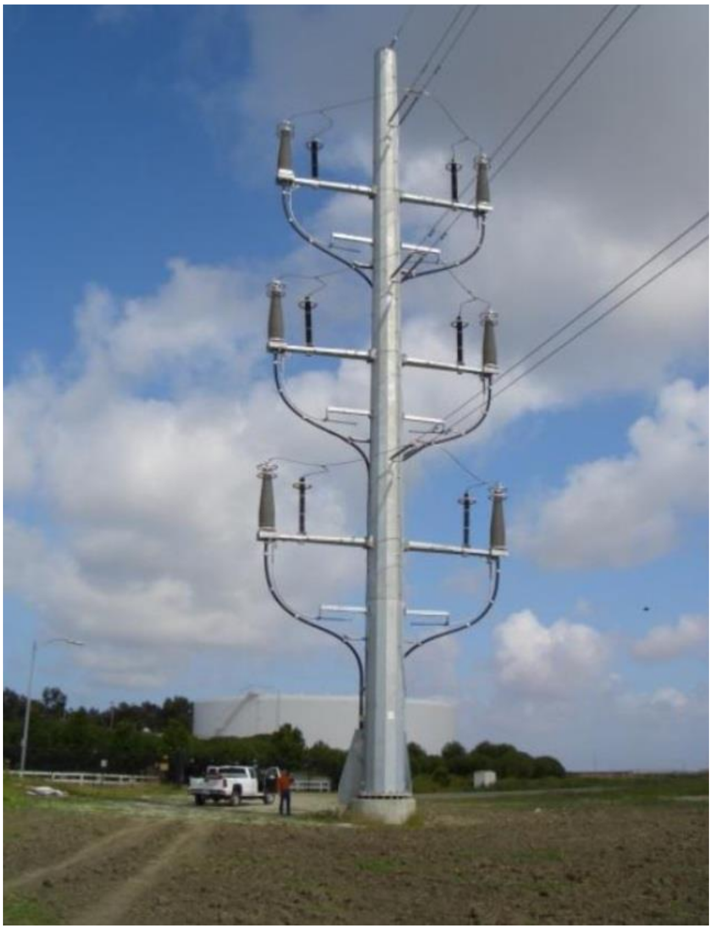

Fig.8. TP on an OHL tower (steel pole) having two cables for each phase of the OHL

CABLE LAYING ALONG THE TP TOWER BODY, ITS FASTENING AND PROTECTION

Cable laying along the tower body from ground level to the terminations installed at height can be performed both outside the tower body and inside. In the world, it was possible to find only a few cases when the cable was lifted inside the tower body – all of them belong to steel poles of a class no more than 60-70 kV (Figure 9). On other objects, especially with a voltage of 110-550 kV, cables always pass outside the tower, since it has a large diameter and permissible bending radii, and has considerable weight.

The cable is attached to the tower body using clamps, the requirements for which are set out in the standard [1]. The clamps must be strong enough to withstand the weight of the cable and the dynamic effects of short-circuit currents. Special attention to the absence of any movements of the cable should be in those places where it enters the terminations (in order to avoid deformation of the termination sealing elements and its breakdown). So, in Figures 3 and 4 it can be seen that near the terminations, the cables are fixed with clamps on special smoothly bending guides that ensure their supply from the vertical tower body to the terminations.

Cable clamps can be made of:

- non-magnetic metals (Figures 3, 4);
- various plastics in black, red (Figure 7) or other colors.

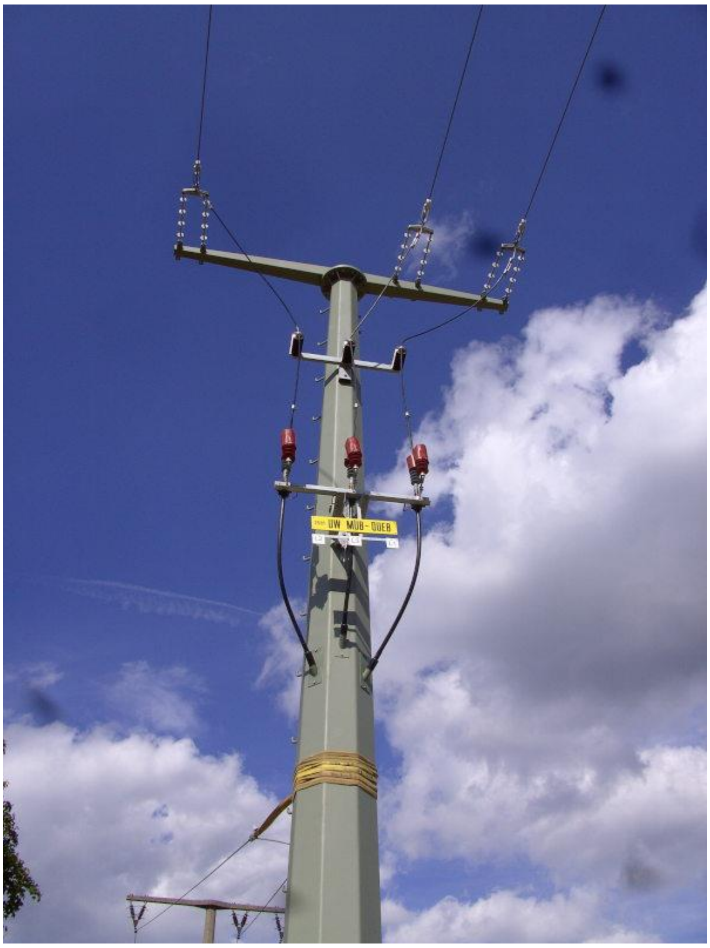

Fig.9. TP on an OHL tower (steel pole). The cable runs inside the tower

If the clamps are metal, then they, as a rule, should be made of either aluminum or non-magnetic steel [1]. At the same time, it is desirable to provide rubber or other soft pads between the clamps and the cable, which will reduce the risk of damage to the cable at the contacting points, as well as allow some thermal movement of the cable. Usually, cable clamps are placed at intervals of every 1-2 m, and the specific distance between them depends on the diameter of the cable, its flexibility and weight, the design of the metal screen and armor. It is also important that the design of the TP tower should assume the possibility of installing cable clamps, for which it should be equipped with mounting pads or holes following at the required interval.

In the world, metal clamps are most often used on steel poles (they are used mainly in America and Asia), and plastic ones are rarely used. As for the lattice, the proportions of metal clamps and plastic clamps are approximately equal there.

In places where the cable leaves the ground and rises to the tower, various methods of its mechanical protection are used everywhere in the world. One of the options is shown in Figure 4 and consists in the fact that the three phases of the cable are closed by a special steel box rising to a height of 2-3 meters from the ground. Any other options are possible, but the general rule is the following – closed circuits of magnetic materials should not form around the individual phases of the cable, and therefore, if the cable is protected with steel structures, then they must necessarily cover three phases at once at the same time. Interestingly, since the cable current capacity in a closed box or pipe is somewhat reduced, it is desirable to ensure the movement of air in the structure, for which a series of holes can be provided in its lower part, sufficient for air, but excluding the penetration of animals.

The option of fastening the cable to the tower shown in Figure 10 was used on one of the 154 kV lines in Turkey and is unique because the cable stock needed in case of replacement of the damaged termination is not laid in the ground next to the tower, but is organized directly on it. Such a solution required the arrangement of special metal guides on the tower, it is quite interesting, but cannot be implemented on a steel pole. Therefore, if the technical specification for the base for MOESK adopted a variant of the TP on a steel pole, then the cable stock will have to be organized in the ground. As for the cable clamps, this issue is not a matter of principle, and it is reasonable to leave its solution to the suppliers of cable and its terminations.

Fig.10. TP on an OHL tower (lattice). The cable stock is equipped on the tower body

CABLE TERMINATIONS

In world practice, high-voltage cable terminations are classified:

1) by type of execution (outdoor, indoor);
2) according to the type of external insulation (polymer, porcelain);
3) according to the type of internal insulation (oil, gas, dry).

Due to the significant cost of high-voltage terminations, changing the design of the main insulator from outdoor to indoor, as a rule, does not lead to notable savings, but the universality of the insulator when it is divided into different types of execution is reduced. That is why many manufacturers focus on creating a single design suitable for both outdoor and indoor electrical installations.

With the advent of terminations with polymer (composite) insulators, the popularity of porcelain terminations began to decline, and today these types of terminations are used mainly at oil refining facilities and are mostly supplied to the Middle East, South America, China. The main disadvantages of terminations with porcelain insulators:

– heavy weight;
– tendency to brittle cracking;

- relatively low permissible mechanical stresses;
- uncertainty of strength properties in the state of "bending plus torsion";
- inadmissibility of terminations tilting;
- explosion hazard (failure of the termination, as a rule, is accompanied by an explosion of the insulator with the spread of fragments for tens of meters; the explosion of one of the cable terminations can lead to the failure of nearby equipment).

For Russia and, in particular, for Moscow, the use of cable terminations with polymer insulators will be optimal.

Terminations filled with insulating liquid

In the world, cable terminations filled with insulating liquid are the most common and frequently used types of end couplings, are manufactured at a voltage of up to 550 kV, are a traditional design (in the form of an external porcelain or composite insulator filled with insulating oil), have a wide range of applications (starting with indoor electrical installations and ending with outdoor industrial areas with a high degree of contamination).

The advantages of cable terminations filled with insulating liquid are:

- low cost;
- good operational characteristics (high leakage current path length, wide operating temperature range from -60°C to +50°C, no restriction on the cross-section of the cable used up to 2500 mm^2);
- high reliability in case of proper installation.

Installation of cable terminations filled with insulating liquid is not a complicated procedure, but requires a responsible and careful approach. The quality of cable cutting, compliance with dimensions, assembly of the sealing unit, filling of the compound and other operations largely determines the reliability and service life of the termination. As a rule, these terminations do not require maintenance, however (depending on the place of application, as well as the needs of the operating organization), are allowed procedures for cleaning the external insulator, thermal-imaging control, oil sampling for analysis of its dielectric characteristics.

Terminations filled with insulating liquid have a limit on the angle of inclination from 0° to 30°, depending on the voltage class and the manufacturer. Insulation compounds are used as internal insulation of oil-filled terminations, the main types of which are:

- mineral oils;
- silicone oils;
- polyester liquids.

Gas-filled terminations

Gas-filled terminations, unlike oil-filled ones, require maintenance, and in addition to the usual periodic inspection, constant monitoring of gas pressure is necessary. Also, a significant limitation for this termination type is the low operating temperature (up to -30°C), which is why their use in areas with a cold climate requires the installation of additional heating. Currently, such terminations are made mainly for 300-550 kV.

Dry terminations

Dry cable terminations do not contain liquid or gaseous filler (this reduces the risk of environmental pollution, ensures their explosion and fire safety), have no restrictions on the installation angle, do not require maintenance (oil does not flow, there is no need to monitor gas pressure, check the dielectric and operational characteristics of the insulating carrier), are easier to install. In particular, the design of dry terminations allows for their installation on the ground, without resorting to assembling cable tents on OHL towers and other load-bearing structures, and only then lifting the termination onto the tower together with the cable attached to it. It is also interesting that dry terminations can be flexible, as shown, for example, in Figure 7.

Dry cable terminations are distinguished by a complex and material-intensive manufacturing technology; therefore, many manufacturers do not have this type of equipment for voltage classes above 170 kV. If we talk about the cost, they are more expensive than traditional oil-filled terminations.

Overview of terminations world experience

The following types of cable terminations are used in the construction of TP for ML classes up to 170 kV:

- termination filled with insulating liquid, with polymer (composite) insulator (about 65% of objects);
- termination filled with insulating liquid, with porcelain insulator (about 20%);
- dry termination (about 15%);
- gas-filled termination (less than 1%).

Cable terminations with dry insulation appeared relatively recently, have a number of significant advantages, and the number of cases of their use in the world will only increase.

THE NEED OF MOA AND GROUNDING REQUIREMENTS

According to [1], protective powerful metal-oxide surge arresters (MOA) should be installed at each end of the CL, and the characteristics of the MOA should be selected taking into account their operating conditions. As part of the review of the world experience in the construction of TP, it was not possible to find a single TP where there would not be installed MOAs. This is confirmed by the fact already mentioned in domestic publications that the provisions of the 2nd chapter of the PUE (Russian rules of electrical installations), which erroneous allow not to install MOAs at the ends of cable sections longer than 1.5 km.

The conclusions that can be drawn from the review are as follows:

- MOAs are required at all TPs of ML, regardless of the length of the CL;
- almost always the MOAs are installed vertically and rigidly connected to the tower;
- vertical installation of the MOA is abandoned, mainly only in the USA;
- cases of refusal of rigid mounting of the MOA (for example, suspension of the MOA for the upper flanges on the phase wires) are quite rare;
- the grounding of the MOA is carried out directly on the metal structure (an exception was found in the UK, where the grounding circuit of the MOA is made separately);
- equipment for the diagnosis of MOA (impulse counters, etc.) is not used.

MOA can have both polymer external insulation and porcelain. If an MOA with a porcelain case is damaged, its pieces pose a real danger to the TP equipment and to people who happened to be near the TP at the time of the accident. The negative role here is played not only by the large kinetic energy of the porcelain fragments, but also by their sharp edge. If the MOA is made with polymer insulation, then the consequences of damage are much less dangerous – therefore, for TP, especially when they are placed in a populated area, this insulation is preferable.

An important question is whether the grounding resistance of the TP is sufficient and electromagnetic compatibility is ensured for the low-voltage equipment that can be installed on the TP. In the article [3] it is shown that for the OHL tower on which the TP is made, the grounding resistance should be small, close to 0.5 ohms. An analysis of the requirements available in different countries unexpectedly showed less stringent resistance requirements:

– in the UK – up to 10 ohms;
– in Eastern European countries – up to 10 ohms (Hungary, Lithuania, Russia, Ukraine);
– in Germany, Austria – in the range from 2 to 4 ohms.
– in America, the one that ensures safety during short circuit on the tower.

Sometimes, when the OHL has short cable entries into the switchgear, the TP tower is connected to the switchgear grounding system using a metal bus [1] (for example, a single copper conductor in polymer insulation), which allows to somewhat reduce the requirements for the value of the grounding resistance of the TP tower itself.

SWITCHING DEVICES

When designing the transition from the OHL to the CL, the question may arise about special easily removable jumpers between them, which will allow to uncouple the OHL and the CL, for example, for the purpose of cables testing or repairing. The design of the TP can become noticeably more complicated if it is planned to use switching devices rather than jumpers to separate the cable and air sections of the line from each other.

Jumpers or switching devices can be useful not only for disconnecting OHL and CL, but also for cases when the OHL has two cables per phase – to disconnect cables from each other so that tests and repairs of one of two cables can be carried out without completely disconnecting the CL from OHL [1].

It should be noted that, unlike jumpers, switching devices provide a high level of safety for personnel involved in testing equipment, its maintenance, damage detection, repair. Either a load switch can act as a switching device (if it is necessary to switch the charging currents of the CL), or a "full-fledged" power switch (if switching of the short-circuit currents is required).

A review of world experience has shown that two types of switching devices can be found on conventional OHLs of class up to 170 kV:

– disconnector (Figure 11);
– a gas-operated load switch having a sequentially installed disconnector that ensures the creation of a visible gap (Figure 12).

Cases of using these devices on TP classes up to 170 kV, made on OHL towers, are:

– rare for disconnectors;
– very rare for switches.

The vast majority of TP (more than 99%) around the world are equipped without any switching devices. Cases of installation of switching devices relate mainly to the USA, where (which is very important) a significant part of the country's territory does not have a cold climate.

Moscow and the region are excessively overloaded with transport, and it is sometimes difficult for maintenance personnel to quickly get to the TP and perform the uncoupling of the overhead and cable sections of the ML from each other for the purpose of repair and testing of the cables. Therefore, despite the cold climate, equipping the TP with remotely controlled disconnectors is a prerequisite for reducing interruptions in the power supply of consumers.

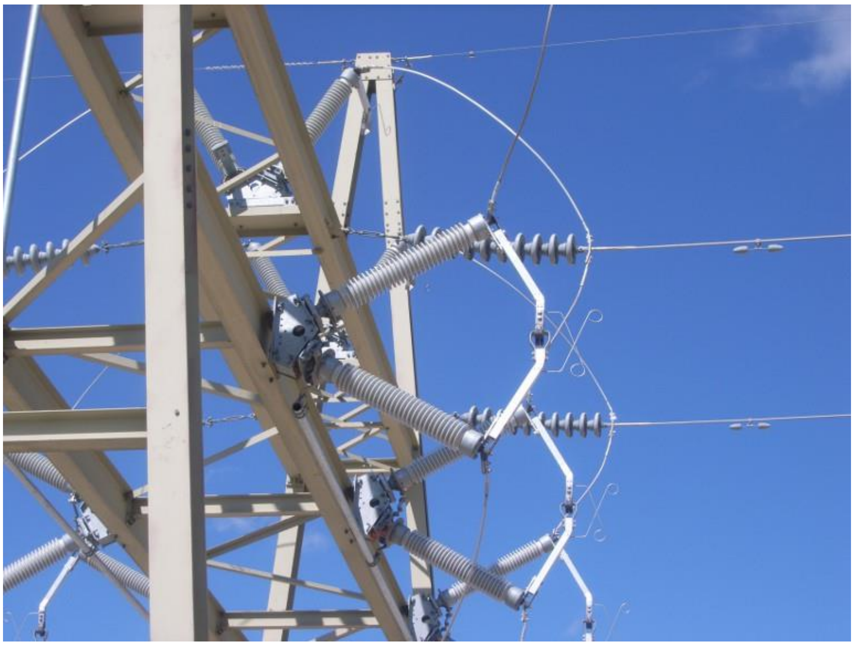

Fig.11. 115 kV class TP equipped with a V-shaped disconnector

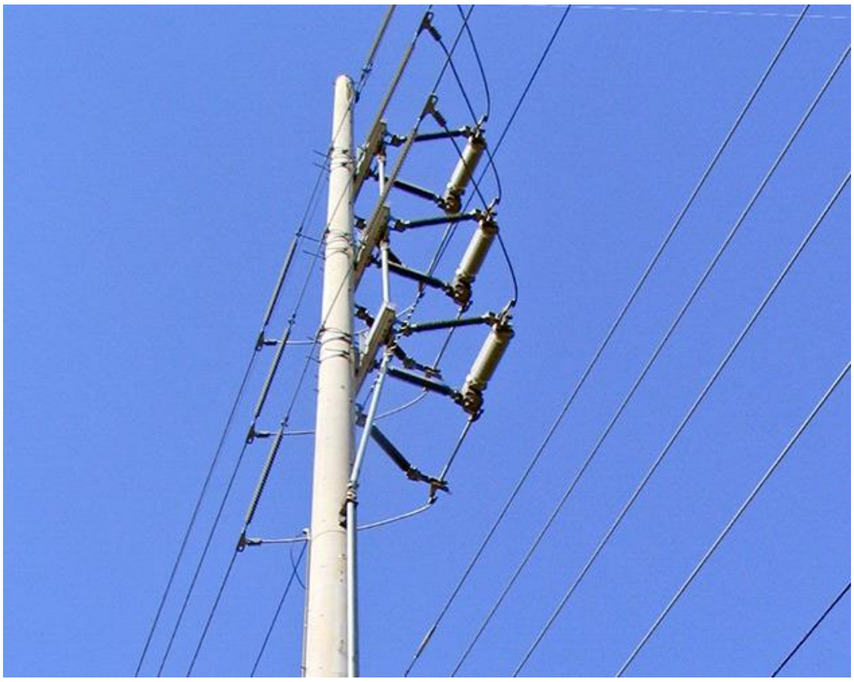

Fig.12. 115 kV OHL tower equipped with a load switch with a visible break function

RELAY PROTECTION AND AUTOMATIC RECLOSURE. THE NEED OF CURRENT TRANSFORMERS

The appearance of a cable section on the OHL complicates the relay protection of the line. The arrangement of protection also depends on whether a simple TP will be organized on the OHL tower (lattice or steel pope) or a complex ground-based TP with power switches, disconnectors and other equipment. In any case, when constructing ML protections, it is important to take into account the following [1]:

- the difference in the longitudinal impedances of the air and cable sections of the ML;
- change in the longitudinal inductive impedance of the ML, if the CL has several cables per phase at once, and one of them is out of operation;
- the presence of shunt reactors, if they are placed on the TP;
- the need to determine exactly where the damage occurred on the ML route (on the cable section or on the overhead section) in order to correctly make a decision on prohibiting or allowing line automatic reclosure (AR).

Also, according to [1], it should be taken into account that in the case of the use of AR, special measures may be required to discharge the CL before reclosure the ML under the voltage. At the same time, if electromagnetic voltage transformers (VT) connected to the line will be used for the needs of the CL discharge, then it should be checked for overheating of the VT windings and their damage.

Of all the issues listed, the most relevant to almost all ML, is the AR. Many damages on OHL are self-passing, and therefore AR is widely used on OHL. On CL, on the contrary, the damage is not self-passing, and reclosure can cause a significant development of the consequences of an accident. Therefore, it is advisable for ML to organize selective AR, which consists in the fact that in case of an accident on the air section, AR is allowed, and in case of an accident on the cable section, it is prohibited.

A review of the world experience in organizing AR on ML, described, in particular, in [4], suggests that in most countries AR is allowed (in one form or another) and only in some countries AR is completely prohibited.

The variants of AR that are used in the world are as follows:

- unconditional (the ML reclosure occurs regardless of the location of the short circuit);
- selective (the ML reclosure is possible if the short circuit is not on the cable section).

Unconditional AR is most often used:

- if the CL is adjacent to one of the ends of the ML and has a length of up to 300 m;
- if the length of all sections of the CL summary is less than 10% of the length of the route of the entire ML.

Selective AR is most often used:

- if the CL is located in the middle part of the ML;
- if the CL has a large length against the overall length of the entire ML.

Selective AR can be organized as follows:

- distant protection (effective if the CL is adjacent to the end of the ML);
- differential protection (possible at any position of the CL on the ML).

To create CL differential protection are more often used current transformers (CT):

- CT which are put on the cable itself at the cable termination (very common);

– CT which are put on the cable screen at the cable termination (only in France);
– optical TT attached to the cable at the termination (Denmark, Spain – Figure 13).

Installing the CT directly under the cable termination allows you to include only the cable itself in the differential protection zone. If the CT is installed near the OHL wire output of the termination (at high potential) only in this case the termination will be included in the protection zone. Of the high-voltage CT, the optical CT will be the most compact, the measuring loop of which is located on the upper flange of the termination.

So, when constructing ML protections and organizing selective AR, it is advisable to use optical CT mounted near the upper flange of the cable termination. The transmission of information will be carried out via an optical fiber embedded in the OHL lightning wire and in the copper screen of the CL.

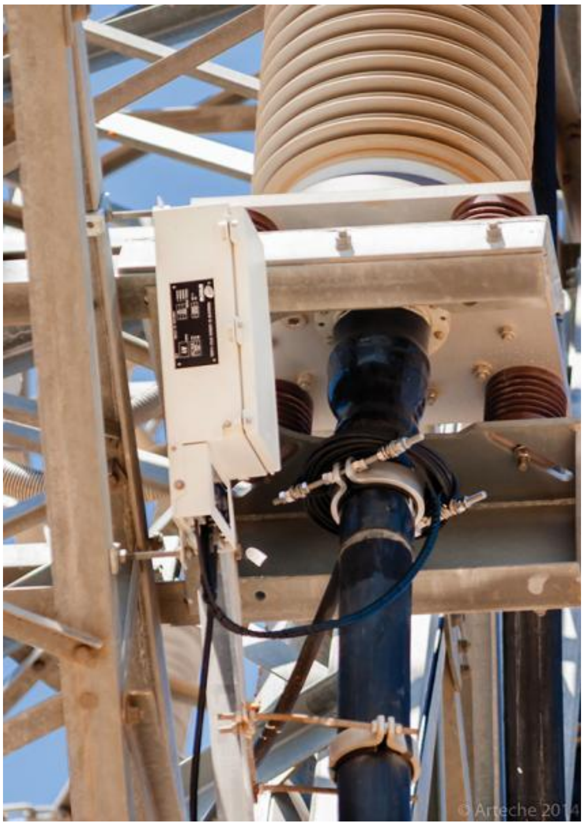

Fig.13. Measuring loop of the optical CT mounted on the cable under the termination

POWER SUPPLY FOR OWN NEEDS

According to [2], the equipment responsible for the AR should be installed on the TP in a special container so that it is well ventilated and has climate support (cooling and heating). This is necessary because:
– it is necessary to eliminate the risk of condensation, dangerous for electronics;
– relay protection and automatics works only in the range from -10°C to +55°C;
– battery life depends on temperature.

To organize the operation of differential protection of the ML cable section and signal transmission between neighboring CT, as well as to heat the terminals in winter, it is necessary to provide power supply for their own needs. In addition, power may be required for the operation of the drives of switching devices, equipment monitoring and diagnostics systems, video surveillance and access control.

In general, there are the following options for powering the needs of the TP:

– from high-voltage TN, which charge the battery through a rectifier;
– from renewable energy sources placed on the TP;
– from local low-voltage networks.

Moscow is a densely populated metropolis with well-developed networks of various voltage classes, therefore, the most profitable option for powering the TP's own needs will be connecting to the nearest 0.4 kV network, preferably through a separation transformer, which will eliminate the introduction of high potential into the low-voltage network with a short circuit on the TP.

CONCLUSIONS

The appearance of a large number of MLs poses engineers a whole range of urgent technical tasks, one of which is the creation of a TP that meets a number of requirements:

– compactness;
– security;
– aesthetic appearance;
– ease of installation and maintenance.

The study of world experience has not allowed us to find TPs that fully possess the listed qualities. Therefore, MOESK decided to develop its own TP for the 110 kV voltage class with the possibility of spreading ideas to other classes. A separate article will be devoted to the new TP.

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