Induced Voltage From Traction Networks and Methods of Reducing its Influence on Adjacent Communication Lines

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Abstract

The article investigates the influencing factors from the influence of the line under voltage on the distribution diagram of electrostatic and electromagnetic components of the induced voltage generated on the disconnected line, as well as the use of special measures to eliminate them. The possibility of eliminating the induced voltage arising from the influence of electrostatic components of the induced voltage by grounding at least one place of the disconnected line and reducing the value of the electromagnetic influence to a certain value due to the installation of suction and reduction transformers, as well as arresters and throttle transformers is substantiated.

Key words: Induced voltage, electrostatic effect, the electromagnetic effect, the suction-type transformers, regulating transformers, the reverse wire.

Regardless of the voltage present in the power transmission lines, the voltage generated by the adjacent lines is called the voltage or induced voltage due to the effect of the adjacent line.

Depending on these factors, the technical safety regulations for the use of electrical equipment shall specify safety measures during the maintenance of power transmission lines. Also, protection measures are set out in separate paragraphs for cases where grounding does not help to reduce the effect of the induced voltage on the disconnected wire below 25 volts.

However, from time to time there are cases of electric shock injuries to workers servicing power transmission lines due to induced voltage. Such situations occur due to a lack of understanding of the origin, nature, and original nature of the induced voltage. In any case, there is a risk that touching a wire exposed to an induced voltage from an adjacent line, even if the disconnected line is grounded to all requirements, may result in electric shock. The essence of this situation is that any power transmission line is constantly under the inductive effect of an adjacent line passing parallel to it, so it also produces an induced voltage.

The value of the induced voltage generated when the electromagnetic field interacts between the lines depends on the value of the operating voltage and the distance between the line phase wires, as well as the length of the parallel placement of these wires. Each line consists of two components, i.e., a potential generated by electrostatic and electromagnetic effects.

The electrostatic effect is the first component, the induced voltage generated in the line switched off by the action of this component depends on the value of the electromagnetic field acting on the adjacent line. The value of the induced voltage depends on the value of the affected adjacent line located parallel to the line, even when all the rules of technical use are followed. The induced voltage in the switched off power transmission line is the same along the entire length of the line and is determined by the following expression [1]:

\[ U_\text{e} = k \cdot U_{\text{T,a}} \]

here is \( k \) - the capacity dependence coefficient of the line; \( U_{\text{T,a}} \) – the operating voltage of the affected adjacent line; \( U_\text{e} \) - electrostatic induced voltage.
The distribution diagram of the induced voltage is shown in Figure 1.

![Figure 1. Distribution diagram of induced voltage](image)

When the switched line is grounded at least from one place, it is possible to reduce the voltage value generated by the effect of the electrostatic component of the induced voltage to a safe value along the entire line or to completely eliminate the effect of the electrostatic organizer on the adjacent line. When servicing a power transmission line that is switched off and the end of the line is grounded, it is advisable to ground the work area in accordance with safety regulations.

The electromagnetic component of an induced voltage differs from the electrostatic component in its mechanism of action. The induced voltage generated by the electromagnetic component is based on the effect of the magnetic field of the current of the corresponding phase wires on the affected line. Thus, the value of the induced voltage generated electric power (EP) in the switched line is determined by the following expression [1, 2]:

$$E_\text{u} = M \cdot L \cdot I_{\text{T},\lambda},$$

where is $M$ - the inductive dependence coefficient of the line; $L$ – the length of a parallel line; $I_{\text{T},\lambda}$ - affected line current.

The value of the inductive dependence coefficient of the line considered in this expression does not change, but the value of EP is determined by the length of the line section located parallel. It is also the value of the load current that matters, not the value of the voltage on the affected line. The voltage generated relative to ground at point $x$ from the beginning of the line is determined using the following expression [1, 3, 6]:

$$U = -\frac{E_\text{u} \cdot x}{L} + \frac{E_\text{u}}{2},$$

Where is $E_\text{u}$ – induced EP; $L$ – the length of a parallel line; $x$ - the distance from the beginning of the line to the point $x$.

It is known from the expression that the voltage generated by the electromagnetic component of the induced voltage is $+\frac{E_\text{u}}{2}$ at the beginning of the line, at the middle of the line $0$, and $-\frac{E_\text{u}}{2}$ at the end of the line. When a line cable is grounded from one or more points, the value of the voltage generated by the electromagnetic component of the induced voltage does not change.

An increase in the number of ground points can only lead to a shift in the zero potential points on the line. This feature of the induced voltage electromagnetic component is detailed in the technical safety regulations.

It is known from the diagrams in Figure 2 that the distribution of the potential generated by the electromagnetic component of the induced voltage in the off line depends on the location of the grounding. If the power transmission line is grounded from a single point, the zero point of the induced potential will overlap with the grounded point. These diagrams substantiate a potential hazard for workers servicing the line, i.e., if the repair work is carried out at one point in one or more locations of the power transmission line at the same time, the line will be exposed to EP generated by the electromagnetic component of the induced voltage. If one of the brigades is operating at point C, the voltage value there will be zero. The second, i.e., the point of zero potential, is located between points D and C when the workplace at point D is also grounded. In this case, the voltages between points D and C may exceed the safe value and endanger human life.
A similar process occurs in the case of disconnectors under the influence of induced voltage from the power transmission line. The disconnector must be grounded by the line, if this grounding is unique to the line being serviced, the safety of the workers is fully ensured.

Otherwise, for example, if another grounding is installed at a substation located at the next end of the service line, the induced voltage at the point of execution may exceed the maximum value and workers may be at risk.

It is also possible to run a service line by dividing it into several unrelated sections and servicing them separately, and then reconnecting them in series. This situation serves the safety of people even though it requires additional costs. When working under voltage, several brigades can serve a single line at the same time.

During the preparation of the workplace for the brigade, special attention is paid to the protective earthing of the phase wires and their connection contacts are checked.

![Diagram of the distribution of the induced voltage relative to different melting points](image)

If the phase wires lose contact with the winding device, the zero potential point will immediately move to another location and the workplace will be exposed to the induced voltage and the lives of the workers will be endangered. Therefore, for reliability, it is always necessary to install a protective grounding device on both sides.

The maximum part of the induced voltage electromagnetic component corresponds to the boundaries of the line interaction section, and partly to the disconnected disconnectors. Measurements are carried out at the given points, i.e., at the point of descent of the separator busbars or at the first support, when both ends of the line are grounded. Voltmeters with a measuring range of 500-1000 volts are used in the measurement work.

When the maximum current of the acting line is accurate, the maximum value of the induced voltage after measurements in the current mode can be calculated using the following formula [4, 5]:

\[
U_m = U \cdot \frac{l_m}{l_{r.a}}
\]

Where is \( U \) – measured induced EP; \( l_{r.a} \) – affected line current; \( l_m \) – the maximum current of the impact line.

Based on the above considerations, the development of measures to protect against induced voltages under the influence of the parallel line is one of the most pressing issues today. In an electrified railway power supply system, the electromagnetic effect of the contact network induced voltage on adjacent lines can be reduced by interconnection of wires, installation of dischargers, limiting filters and reduction transformers. It is also possible to
reduce the effect of induced voltage by placing adjacent lines away from the traction network and using shielded cables for communication lines.

There are active and passive methods of protection of the adjacent line from electromagnetic influences, the active method is carried out by installing suction transformers (ST). When protecting adjacent lines from electromagnetic effects through STs, the greater the number of adjacent lines, the higher the level of protection should be. The purpose of installing STs is to increase the shielding effect of the rails, and in this case the electromagnetic effect of the contact network relative to the adjacent lines is reduced to 2 times. As a result, the interaction between the contact network and the rails is increased.

When the interaction between the contact network and the rails is carried out by installing special suction transformers, STs force the load current to flow along the rail [7, 8]. Figure 3 shows two different options for installing STs.

The transformation coefficients of the STs are equal to or close together. The operating mode of the STs is close to the short-circuit mode similar to a current transformer. The current in the windings of the transformers shown in the two schemes in Figure 3 is opposite to each other, and the value of the voltages in the windings is not so great.

![Figure 3. Installation options of suction transformers for cases where a) there is no return wire and where b) there is a return wire](image)

Figure 4a shows one electric locomotive and three STs on the site and shows the operation process of the ST group, the contact network and the current distribution along the rails for the case where the rails are separated. Figure 4b shows the operation of the group of STs, the current distribution diagrams along the contact network, rails and return wire for the case where there are three electric locomotives and three STs on the site.

![Figure 4. Installation of suction transformers a) and current distribution in the contact network b), rails v) and return wire g)](image)
From the graph of the current distribution along the rail, it can be concluded that the value of the current in the ST line is much larger than in the non-ST line, and the shielding effect of the rail is very strong.

Drainage coils are used to reduce the electromagnetic effect of high-frequency circuits on adjacent lines (Figure 5). Drainage coils consist of two identical half-coils wrapped in a ferromagnetic core, and in this circuit the valve dischargers are used as the main protective element. Dischargers are grounded through the midpoint of the choke-transformer, and a circuit breaker VK-220 is installed to protect electrical equipment from short circuits in the traction network. [7].

Reduction transformers are used to protect cable lines from the dangerous electromagnetic effects of electrified railways (Figure 6). This method is included in the passive methods of protection of the adjacent line from electromagnetic influences. This method reduces the electromagnetic effect of adjacent lines relative to communication lines by increasing the shielding coefficient of the cable sheath. That is, when the inductive resistance of the cable sheath is increased, its shielding effect also increases.

Reducing the dangerous and interfering electromagnetic effects of adjacent lines can be achieved by dividing galvanically independent two-wire communication lines into specific sections using transformers (Figure 7). In this method, communication lines are divided into specific sections using n transformers. In this case, it is possible to reduce the effect of the dangerous magnetic field on the communication lines of the traction network by up to n times.
Figure 7. Application of splitting transformers

The following conclusions and results were obtained by studying the voltage and protection measures against the side line:

Safety precautions should be taken into account when carrying out measurements and it should be taken into account that the connecting wires, the disconnecting frame and the voltmeter itself may be under voltage. In order to organize a safe operation, it is first necessary to assemble the measuring circuit and then connect it to the source and check that the insulation of the connecting wires is resistant to a minimum voltage of 1000 volts. Workers servicing the traction system during work must wear dielectric gloves and boots. As a result, the safety of workers servicing electrical equipment and devices of the contact network is ensured;

It was found that when using suction transformers to protect adjacent lines from the electromagnetic effects of the traction system, the distance between them should be selected as 1.5 km in the absence of a return wire and 4.5 km in the presence of a return wire. As a result, the electromagnetic effect of the traction system on adjacent lines is reduced by 4-10 times;

It was found expedient to use specially insulated and high-conductivity armored cables to reduce the electromagnetic effect of the contact network on the communication lines, and to place the main cable lines at a distance of 25-100 m from the contact network to reduce the impact voltage to the required level. The result is a reduction in interference affecting the communication cables;

it was found that by installing reduction transformers every 5-10 km, cable lines can be protected from the dangerous electromagnetic effects of the traction system. As a result, the shielding coefficient of the power system was reduced to about 10 times;

in the induced voltage generated by equipping the communication cables with dividing transformers, an additional phase shift angle is created, the symmetry of the circuit is increased and, accordingly, the sensitivity coefficient and the interference effects are reduced.

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