The Aspects of Catenary Maintenance of Direct Current (DC) and Alternating Current (AC)

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Abstract

A rapid social and economic development of the European Union countries, their technical progress, and world trade globalization tendencies generate a huge demand for high-quality transportation services. The countries of the Western Europe, being concerned about safety, environment, sustainable use of the energy and other resources, use economic and legal measures to encourage transportation of passengers and freights. A catenary is a complex technical mechanism of electrified railways, for which specific requirements are applied, depending on the type of current, the capacity of electrified trains, speed, traffic intensity, road profile, geographic location and other conditions influencing constructional solutions and the peculiarities of maintenance. The article analyses the peculiarities of direct current and alternating current catenary maintenance in summer and winter periods. The solutions are provided for the improvement of the contact of a pantograph current collector of an electric train and the contact wire.

1. Introduction

Currently, the prevailing catenary systems in the world are those of traditional electrified railway current (DC) 750V, 1500V, 3000V and alternating current (AC) 15 kV, 16 2/3 Hz and 25 kV, 50 Hz (Accessibility for People with Reduced Mobility of the Trans-European Conventional and High Speed Rail System. 2006). Electric trains that
collect their current from overhead line use a device such as a pantograph. It presses against the underside of the lowest overhead wire, the contact wire. Current collectors are electrically conductive and allow current to flow through to the electric train. To achieve good high-speed current collection, it is necessary to keep the contact wire geometry within defined limits (Liudvinavičius et al. 2007, Mera et al. 2000).

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Overhead line and pantograph current collector must ensure the supply of current for the electrified train going at a determined speed under all climate conditions. Beside this, it is important that the wear of the contact inserts of the overhead line and electrified train pantograph current collector is minimal. In winter, it is especially difficult to ensure a proper contact of the electrified train pantograph current collectors and the overhead wire.

2. Specific requirements for catenary wire

*The requirements sectioning of the catenary line.* To allow maintenance to the overhead line without having to turn off the entire system, the line is broken into electrically separated portions known as “sections”. Sections often correspond with tension lengths as described above. The transition from section to section is known as a “section break” and is set up so that the locomotive’s pantograph is in continuous contact with the wire.

*The requirements for arranging the overhead line.* An example of the overhead line arrangement with regard to the path axis is shown in Figure 1. To ensure a uniform wear of the pantograph current collector contact carbon inserts, the overhead line is arranged in a form of a zigzag with regard to the path axis. The positions of the overhead line with regard to the path axis (a) and typical suspension (b) are provided in Figure 1 (Olofsson et al. 1995).

As the contact wire makes contact with the pantograph, the carbon insert on top of the pantograph is worn down. The “straight” wire between the supports will cause the contact wire to cross over the whole surface of the pantograph as the train travels around the curve. On straight track, the contact wire is zigzagged slightly to the left and right of centre railway rood.

The width of the zigzag is 400 mm.

*Typical catenary systems* is: simple equipment or trolley wire catenary, stitched wire catenary, sagged simple catenary, compound wire catenary.

*Typical catenary suspensions.* Depot areas tend to have only a single wire and are known as ‘simple equipment’ or ‘trolley wire’. Stitched equipment – uses an additional wire at each support structure. Compound equipment uses a second support wire, known as the “auxiliary”.

![Fig. 1. The positions of the overhead line with regard to the path axis (a) and typical catenary suspension (b).](image)
Catenary wires are kept at a mechanical tension because the pantograph causes mechanical oscillations in the wire. For medium and high speed train, the wires are generally tensioned by weights this method is known as "auto-tensioning" (AT). Tensions are typically between 9 and 20 kN per wire. For low speeds and in tunnels where temperatures are constant using fixed termination (FT) equipment. The tension is generally about 10 kN. This type of equipment will sag on hot days and be taut on cold days. With "auto-tensioning" (AT) there is a limit on the continuous length of overhead line due to the change in the position of the weights with temperature as the overhead line expands and contracts. This movement is proportional to the tension length, the distance between anchors.

The tension of the overhead line, the change of the contact wire length (in winter and in summer) with regard to the position of the contact wire, the fluctuation of the contact wire in the horizontal and vertical direction to reduce the strong wind blowing, to correct the weight of lines (including cases of ice-cover) compensation systems are applied. As strong wind is blowing, swelling of the contact wire is possible. In all the aforementioned cases, the system of the contact wire must ensure minimum changes of the contact wire position with regard to the path axis and height. The system of catenary must ensure a uniform wear of the contact elements (coal inserts) of the pantograph current collector of the electric train on the entire contact surface. All these requirements have direct influence on the construction of the catenary. The equipment of the catenary differs at the stations, substations, curves, switches and direct section. The fluctuations of the catenary and their influence on pantograph have been provided in Figure 2.

Due to the changes in the temperature of the environment, the length of the contact wire between the props changes. During the winter time, the length of the contact wire becomes shorter, and in summertime it increases. Figure 3 illustrates the change of the length of the compensatory line c between the pulleys, compensator positions a₂, b₂ in summer time, compensator positions a₁, b₁ in winter time.

The distances a and b of the correction of tension of the contact wire are indicated according to the diagrams in Figure 5. Should electric trains be used in the region, where the change of air temperature is from minus 50 ºC up to +50 ºC, the correction distances a and b are indicated according to diagram 1. Should electric trains be used in the region, where the change in air temperature is from minus 40 ºC up to +40 ºC, the correction intervals a and b are indicated according to diagram II, where the change in air temperature is from minus 30 ºC up to +40 ºC, the correction intervals a and b are indicated according to diagram III, by evaluating the length of the contact wire up to the place of fixing the compensator. The compensatory diagrams of the change of the contact line length in summer and winter and the compensatory schemes and compensatory position correction diagrams are provided in Figure 3. The length of the robe of the compensatory system between pulleys c in summer must be not more than 1 m, and in winter not more than 3.5 m.

DC 3,3 kV traction system equipment (direct current 3,3 kV electrified railway equipment) have been submitted in Figure 4 (AENOR 2004). The catenary overhead line and the contact conditions of the pantograph current collectors of the electrified train largely depend on the capacity of the electrified train. Where the capacity of the electrified train is 1MW-6MW, the current with the voltage of 3000 V on the contact wire is 330 A–2000 A. Where the contact wire current is 2000A, the conditions of the pantograph current collector contact of the electrified train deteriorate (Liudvinavičius et al. 2011).
Fig. 3. Catenary line length deflection compensation depends on the temperature in winter and in summer circuit diagrams: a₁, b₁ – compensator positions in winter; a₂, b₂ – compensator positions in summer; C – compensator line length between pulleys; a, b – length to compensators; I, II, III – diagrams of the catenary length change depending on the geographic region of the electric train maintenance.

Fig. 4. DC 3.3 kV traction system equipment: TS – traction substation; T – degrading transformer; RL – running circuit line; UR – uncontrolled rectifier; P – pantograph; M₁, M₂ – electric train DC traction motors; CB – circuit breaker.

In separate cases, the contact of the pantograph current collector is marked as sparking regime. This sparking regime is especially evident in the case of an ice-covered contact wire. Where the static pressure force of the pantograph current collector into the contact wire is reduced, the sparking is increased, which is especially evident when the current on the contact wire is 1000–4000 A.

3. The system of heating direct current of 3 kV voltage catenary wire in winter

Having analysed the aspects of the catenary maintenance in winter, the authors suggest 3 kV, 25 kV, 50 Hz catenary wires for ice-covered wire heating by electric current in winter to use control DC voltage equipment HA, which comprises of single-phase transformer T and a controlled rectifier CR (Liudvinavičius et al. 2010).

Heating of the ice-coated contact wire is completed from two power sources: a separately controlled voltage equipment HA and a 3.3 kV traction substation. The controlled voltage equipment is comprised of a single-phase transformer and a thyristoric rectifier. The heating of the ice covered contact wire from the controlled voltage equipment HA is completed when there are no power consumers in the section – electric traction rolling stock. The heating of the ice-covered contact wire by power is completed by forming a controlled voltage equipment HA load circuit. The load of the controlled voltage equipment HA is a section of the contact wire, the length of which must be such that the resistance \( R_L \) of the contact wire is such that the current running on the circuit does not exceed the allowed limits (3 A/mm²). The currents running on the circuit have been indicated by arrows. Where there is a need for urgent heating of the ice-covered contact wire, the thyristoric rectifier is used to increase the rectified voltage, by simultaneously increasing the circuit current and making the contact wire heat faster. As the electrified train moves on the 3 kV voltage electrified section current (which have been marked in blue arrows), which heat the contact wire. Depending on the power developed by the locomotives to pull the train by a 3 kV contact wire, the current
running is even 2000-4000A. In this case, the contact wire does not need to be heated from a separate voltage source.

The scheme of 3 kV catenary line of ice-covered wire heating by electric current in winter. The switchers of the electric circuits marked in black background in Figure 5 are turned on. The arrows in blue indicate the course of the currents on the contact wire at the traction regime, the red arrows indicate the currents of the contact wire heating circuit. For heating of 25 kV, 50 Hz contact wire line ice-covered wires by electric power in winter, the authors suggest using control DC voltage equipment, which comprises of a single-phase transformer T and the controlled rectifier. Figure 6 indicates the diagram of 25 kV, 50 Hz catenary line of iced wire heating by using electric current circuit in winter. To create a heating electric circuit of the 25 kV, 50 Hz of the contact wire ice-covered wire it is necessary to put a temporary catenary line connection of the traction substation at a certain distance. A temporary catenary line connection will consistently connect the contact wire of the phases a and b into one electric circuit. The length of the consistently connected temporary catenary line connection will join the line of phases a and b contact wire into one electric circuit. The length of the consistently connected phases a and b contact wire line depends on the active resistance $R_1$ of the contact wire of 1km line. The active resistance of the contact wire within 1km line is 0.04 $\Omega$ (Pilo et al. 2000). If we connect the 10 km line of the contact wire of phases a and b consistently into a single electric circuit, the total active resistance will be 0.8 $\Omega$. If the ice-covered wires of the contact network are heated by 500A electric circuit, the voltage of the controlled rectifier exit must be 40V. To increase the speed of heating the wire line of the ice-covered contact network by a 1000A electric power, the output voltage of the controlled rectifier must be 80V. By using the controlled DC voltage device HA, one can regulate by opening of angle $\alpha$ of the controlled rectifier thyristor the current of the ice-covered heating circuit of the contact network line in a wide range. Dark background indicates that the electric circuit is switched on.

Fig. 5. 3 kV catenary line OHL heating circuit diagram in winter: T1, T2 – traction transformer; R1, R2 – reactors; HA – control DC voltage equipment; UR1, UR2 – uncontrolled rectifiers; CR – controlled rectifier.

4. The system of alternating current 25 kV, 50 Hz voltage catenary wire heating in winter

The scheme of 25 kV, 50 Hz contact network ice-covered wire heating by electric current in winter. Figure 6 illustrates the scheme of 25 kV, 50 Hz voltage catenary ice-covered wire heating by electric power in winter. The heating of the ice-covered 25 kV, 50 Hz voltage contact wire from the controlled voltage device HA is completed during the traffic breaks between individual trains. To this end, the controlled voltage device HA connected to the
section of the contact wire is indicated by a **bolded line**. It is well established that the wires of the contact network are sectioned (divided into different parts) therefore to create a closed circuit, switches A, B, C, D are connected. To heat the ice-covered contact wire of 25 kV, 50 Hz resistance, double-track section contact wire is connected by consistently putting a temporary catenary line connection (see the scheme in Figure 7). In this case, a section of the contact wire of several kilometres comprises a generic active resistance \( R_L = R_{L1} + R_{L2} + R_{L3} + \ldots + R_{Ln} \). The current running on the electricity heated contact wire, which is calculated as follows:

\[
I_L = \frac{U_{dp}}{R_L}
\]

where: \( U_{dp} \) is the output voltage of the controlled rectifier. The amount of heat output is calculated as follows: \( P_L = I_L^2 R_L t \).

The switchers in black background are turned on (Fig. 6)

![Fig. 6. 25 kV, 50 Hz catenary line heating circuit diagram in winter](image)

**Fig. 6. 25 kV, 50 Hz catenary line heating circuit diagram in winter:** HA – control DC voltage equipment; A, C – phase B switches on; B, D – phase A switches on; CB – circuit breaker; T – single phase transformer; CR – controlled rectifier.

5. **A single-phase thyristoric controlled rectifier**

The authors of the idea of the contact network ice-covered heating by electric current in winter suggest using a single-phase thyristoric controlled rectifier. The electric scheme of the single-phase controlled thyristoric rectifier that is used for the contact network ice-covered wires by the heating electric current in winter and the parameters temporal diagrams are submitted in Figure 7. By changing the thyristoric control angle \( \alpha \), the thyristors may be opened by corresponding time moments and the total duration may be changed, during which the thyristor releases the current, and in this way a smooth regulation of the average rectified voltage value will simultaneously the contact network ice-covered wire heating of the electric current value. By increasing the opening angle \( \alpha \) of the thyristor, the thyristor is opened later and later, therefore, the average rectified voltage \( U_{avg} \) will be smaller. By increasing the control angle \( \alpha \) of the thyristors, the curves of the rectified voltage are reduced and the abscissa load are is restricted as well as the average rectified voltage \( U_{avg} \). The greatest value of the rectified average voltage \( U_{avg} \) is reached when \( \alpha = 0 \), and equals zero, when \( \alpha = 180^\circ \).

With active load, the value of the rectified voltage is calculated as follows:

\[
U_{da} = \frac{1}{\pi} \int_0^\alpha \sqrt{2}U_2 \sin \omega t \, d(\omega t) = \frac{2\sqrt{2}}{\pi} U_2 \frac{1 + \cos \alpha}{2}, \tag{1}
\]

here: \( U_2 \) is the effective value of the source voltage. The effective value of the load current is calculated as follows:

\[
I_{da} = I_{da} \sqrt{\frac{\pi - \alpha}{\pi}}, \tag{2}
\]
here: \( I_{da} \) is the effective value of the load current, where \( \alpha = 0 \). The average current value of the thyristors S1, S2 and diodes D1, D2 is calculated as follows:

\[
I_T = \frac{\pi - \alpha}{2\pi} I_{da} .
\]

6. Conclusions

1. By using the system of contact network ice-covered wire heating by electric current in winter, the maintenance costs of the electrified trains and contact catenary will be reduced;
2. The maintenance conditions of the electrified train pantograph current collectors and the contact catenary will be improved;
3. The regime of the pantograph current collectors and contact catenary ... will be reduced and there will be no more possibility to overheat the contact catenary;
4. By using a single-phase thyristoric controlled rectifier one can smoothly regulate the values of the contact catenary ice-covered wire heating electric current;
5. By changing the control angle \( \alpha \) of the controlled rectifier thyristors, one can smoothly regulate the time of contact catenary ice-covered wire heating electric current.
6. By using a single-phase thyristoric controlled rectifier, if needed, one can quickly heat the ice-covered contact catenary and to restore the current collector of the electric train pantograph current and the conditions of the contact catenary contact.

References

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