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Methods of Reducing the Negative Influence of Weather Phenomena, Icing in Particular, on the Operation of an Overhead Catenary

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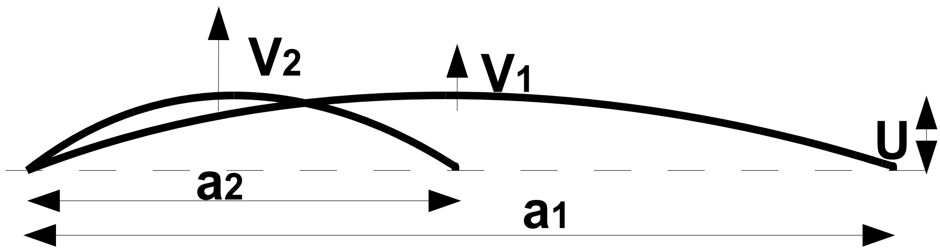
1. Introduction

An overhead catenary is an element of a traction vehicle power supply system that provides electric energy to trains, trams and trolleybuses. This catenary is located above railway and tram tracks, mainly in the areas that are unprotected from the direct exposure to atmospheric phenomena. It is required that the catenary operates reliably, regardless of environmental impact, mainly atmospheric one. The external environmental impact affects the structural details of a catenary. Environmental changes enforcing adapting the design. For a proper cooperation between a catenary and a pantograph, it is required to maintain constant longitudinal tensions in catenary wires, as well as the shape of a catenary. Temperature changes, wind, icing, as well as frost negatively influence the shape of a catenary (Kloow 2006). The catenary is adapted to work in variable weather conditions that occur quite frequently, but are within certain limits. The impact of more extreme weather phenomena, such as: increased wind speed, rainfall, snow, icing, maximum temperature, requires compensation of their influence by introducing some design changes. It also requires certain changes in the design. The lack of such compensatory measures contributes to reduced transport capacity of the line under extreme weather conditions. It may include: limiting vehicle's speed, decreasing railway line capacity, stopping traffic, accelerated wear or damage of a catenary. The expected lifetime of a catenary is 50 years. Some design changes cannot be introduced upon completion of a catenary, e.g. the distance between supporting structures. Therefore, it is required to predict possible climate changes in a given area for many years in advance.

2. Compensating the influence of wind and temperature

Increases in maximum temperatures, as well as maximum wind speed require adjusting a catenary to new boundary operating conditions. It does not entail significant design changes, but it has influence on some parameters of a structure. In practice, compensating the influence of these changes leads to increased costs of catenary construction and operation. Wind speed, which will affect the catenary, and at which traffic operation is planned, influences distance between supporting structures – poles. In most cases, it directly affects the distance in a proportionate manner. Since the supporting structures are the basic component of catenary costs, the number of these structures is a key component in catenary construction costs.



U – permissible instantaneous deviation of a catenary from a track axis
V – maximum permissible wind speed
a – distance required between the poles for mounting a catenary

Fig. 1. Distance between catenary poles depending on wind speed
Rys. 1. Odległość między słupami sieci trakcyjnej w zależności od prędkości wiatru

$$a = \frac{k \cdot U}{V} \quad (1)$$

where:
k – fixed factor characteristic for a given structure of a catenary.

The ambient temperature affects the distance of catenary wires. Changes of temperature require length compensation in order to maintain the shape of a catenary. Increase in maximum ambient temperature associated with climate changes forces structural changes. In order to ensure fixed tension of a catenary, which assures its stable shape, it is required to use complex structures called a tension span every 1.3 km. Higher values of maximum temperatures and a larger range of temperature changes in the period of several decades force an increase in the number of tension spans on a given line. It also influences investment costs.

3. Icing and frost of a catenary

Such phenomena are quite often in Poland between autumn and spring. However, they are considerably rare and short-term on railway or tram lines. As a result, one does not implement system type solutions for the problem of icing on all the lines with a catenary. Apart from extreme cases of icing, e.g. in Slovenia (Segrate 2014), damages to a catenary structure are a very rare phenomenon. This is due to the fact that the catenary is characterised by a high resistance to load increase caused by icing. However, in such a state the normal use of a catenary is not possible. Upon removing the icing, the catenary resumes its original condition. The problems occur if the catenary is exploited under such conditions. Layer of icing or frost is a form of isolation for a current flow and is a reason for the appearance of an electric arc during a current flow (Koclęga 2010). Before resuming normal operation, it is required to remove icing or frost. In Poland, a train ride with a current flow or mechanical removal from a servicing train is implemented as a solution.

3.1. Removing icing from a catenary during train passage

With a small amount of frost accumulated on contact wires, a locomotive or a tram rides with a raised pantograph. Such ride causes a contact gap and appearance of an electric arc between a vehicle pantograph and catenary wire (Haag 2010, Heyun 2012, Jarzębowicz 2014, Kloow 2006). Then, an accelerated wear of contact strips of pantographs and wires occurs (Mizan 2013, Karwowski 2015). It is caused by local damages to the surface of wires and contact strips. Such situation poses a risk of burning pantograph sliding plates and damaging a catenary (Maciołek 2014). Provisions of the TSI allow occurrence of contact gaps in a very narrow scope and only at high speeds. Contact gaps with duration time less than 5 ms that occur at maximum speed of a vehicle are deemed irrelevant (Commission 2014). However, at low speeds, contact gaps and the occurring electric arc significantly influence the state of a catenary. A single instance, in a given area, of a short-period electric arc of less than 5 ms causes damage to a contact wire.

Fig. 2. Electric arc resulted from a ride with a frosted catenary (Koclęga 9)
Rys. 2. Łuk elektryczny powstały w wyniku przejazdu po oszronionej sieci (Koclega 9)

Furthermore, it is related to a low speed of a ride and a large amount of energy accumulated on a small area. Research conducted by the authors showed that even an arc of 2 ms and several hundred A causes millimetre size damages to the surface of a contact wire. These damages are the larger, the higher is current and the lower is ride speed. At 1 m/s speed and arc current up to 1 kA, the length of a damaged part is 5 mm. Depth of the damage is even up to 0.2 mm. The depth of damages to the surface of a contact wire is inversely proportional to speed. The higher the speed, the smaller the density of energy that affects the surface of a wire. Occurrence of arc breaks during a ride at high speed is less harmful than the arc break at a low speed. The consequence of this small damage is the appearance of bumps and craters on the surface of a wire. During ride at an operational speed, they cause subsequent contact gaps, which quickly deepen the damage. As a result, the catenary wire might be damaged entirely at the place of damage within just several days of operation (10 years – required durability). On high speed railway lines, damage to a wire with a length of a few mm at a single point, which exceeds a permissible limit, forces a replacement of the whole wire over a length of more than 1 km. It is therefore not allowed to apply such a method on the high speed lines (Szeląg 2013).

The second method is to remove icing or frost mechanically (local hit), (Haag 2010, Heyun 2012). Such solution requires a ride of a special maintenance train. Since in Poland there is only a few of such trains, traffic breaks are very long. In the case of large-scale phenomena of icing, traffic breaks last up to several tens of hours (required train time of arrival to the line plus travel time at low speed).

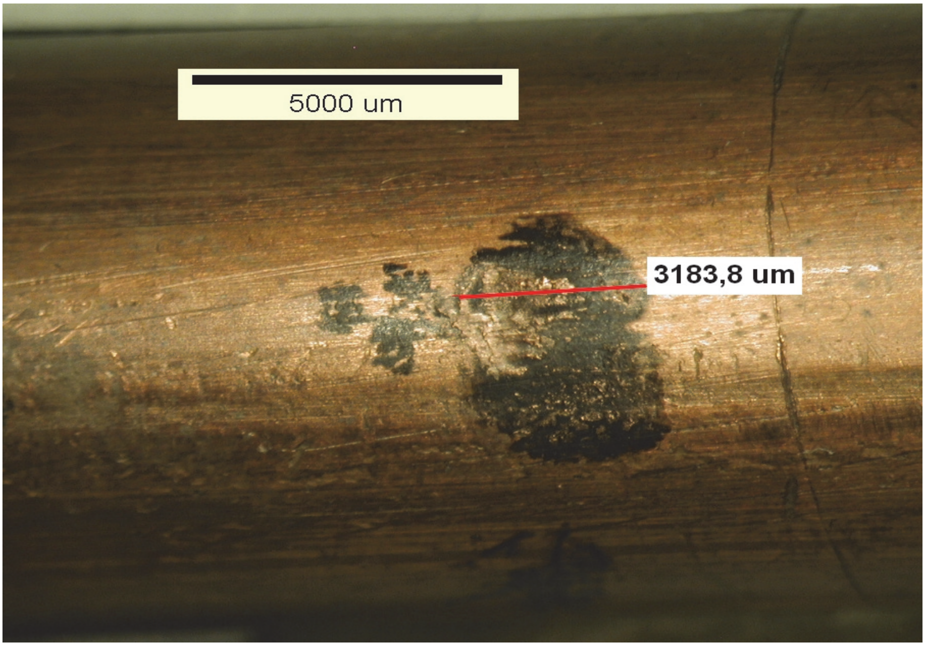


Fig. 3. Damage of the contact wire resulting from a single, short-period impact of a 400 A electric arc that lasted for 2 ms
Rys. 3. Uszkodzenie przewodu jezdnego pod wpływem jednokrotnego krótkotrwałego, działania łuku elektrycznego o prądzie 400 A i czasie 2 ms

Another method that is attempted to be applied in Poland is a precautionary spraying of a catenary with a special agent that prevents ice crystals from accumulating. A considerable amount of the agent is released into the environment. However, this agent provides only short-term protection (several weeks) (Haag 2010). Given its characteristics, the agent is harmful – it changes the properties of a surface on which it has accumulated, and impedes natural chemical and biological reactions.

3.2. Preventing ice deposition by means of catenary heating

Heating a catenary with the use of current is a harmless solution in terms of environmental impact. The temperature of wires that is higher than 0°C does not allow for the accumulation of ice. During train traffic, such phenomenon is a completely normal side effect of catenary operation. The problem appears when a break in traffic takes over an hour. In such case, an additional heating of a catenary during traffic break is required. In Europe, additional heating is applied, e.g. in Germany, Italy and France. In AC power supply systems (Germany, France, Sweden) such method is relatively easy to be achieved. Special taps in substation transformers are used for additional supply in order to force circulating current flow in catenaries (Farzaneh 2010).

For proper protection of a catenary against accumulation of icing or frost, it is sufficient to maintain the temperature of a catenary at 1-2°C. In case of DC systems (Poland, Italy), the solution to this problem is much more difficult. It is possible to supply catenary short-circuit to rails with lowered voltage. In such case, it is required to stop train traffic on a railway route. In Italy, a popular solution consists in connecting additional resistors to a catenary, between substations, which causes an additional flow of load current, without interrupting passage of trains (Segrate 2014).

In Italy, one applies additional resistors that are connected to a catenary in order to force additional current heating the catenary. Resistors (Re) are switched on by means of breakers (Ro). Breaker used in a heating system has a limited number of switching actions. Therefore, one uses periodic catenary heating to the temperature of approx. 25°C. Then, power is switched off for the period of cooling down until the temperature of 2°C is reached. The amount of required energy depends on the ambient temperature and maximum temperature of wires. Heating to temperature higher than 2°C causes an increase in electric energy consumption, but does not improve the level of protection.

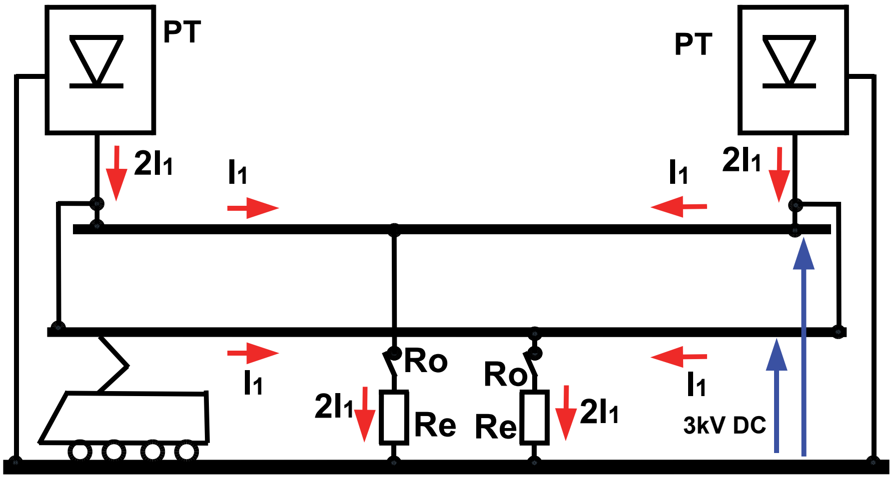
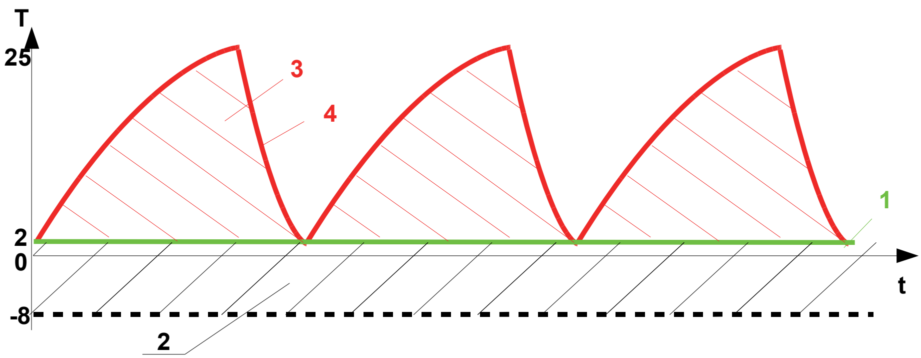


Fig. 4. Resistor type system of catenary heating
Rys. 4. Rezystorowy system nagrzewania sieci trakcyjnych



1 – catenary temperature in a converter type system required for protection
2 – amount of energy required for protection against icing
3 – energy lost for unnecessary heating of a catenary in a resistor type system
4 – catenary temperature in a resistor type system

Fig. 5. Wire temperature curves during heating in a resistance and converter type of a system
Rys. 5. Przebiegi temperatury przewodów w trakcie grzania w systemie rezystancyjnym i przekształtnikowym

Breakers switch on resistors at the temperature of contact wires of 2°C and switch off at 25-30°C. Temperature curve over time is presented in Fig. 5. For a catenary of two tracks with a cross-section of 2x440 mm^2 that is used in Poland, one needs at least two sets of Ro resistors for current I_1 of 2kA, which gives total current (from two substations) of 4000 A.

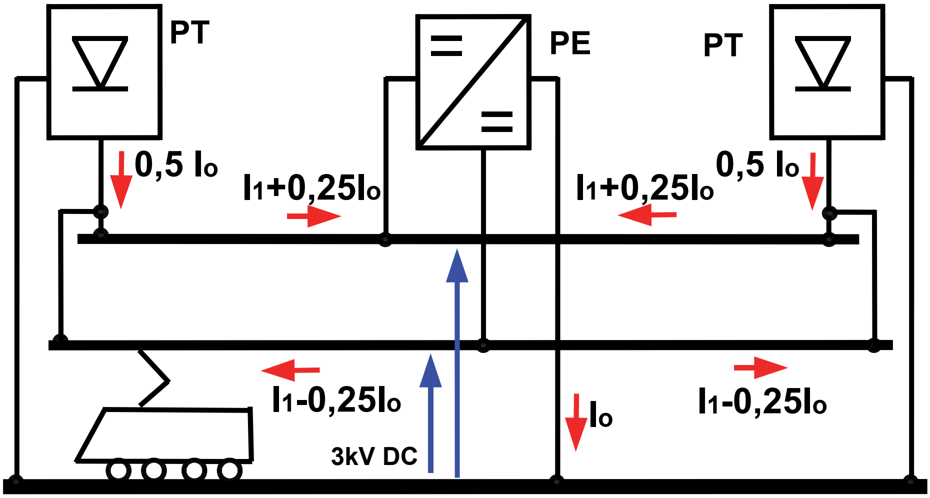


Fig. 6. Converter type system of catenary heating
Rys. 6. Przekształtnikowy system nagrzewania sieci

Maximum power consumed by resistors will amount to 12 MW in total. Average power at the low external temperature is approx. 8 MW. In a resistor system, what occur are high energy losses in resistors that are not used for heating of wires. A converter type system that has small energy needs was proposed as a method for reducing the amount of required energy. System that has been developed at the Warsaw University of Technology is based on a power electronic converter that forces a current flow in an overhead catenary (Maciołek 2014). Operation of the system is also rooted in providing the flow of heating current in a catenary of a value close to I_1, which will provide the wire temperature of approx. +2°C regardless of external conditions. In case of lack of the flow of current consumed by traction vehicles, the attached de-icing system forces flow of current of a required value in the catenary of two adjacent tracks. Current collector by a traction vehicle which is about to enter the track, will induce decrease of additional heating current to the level of 0, if a traction vehicle current causes the required temperature to be reached. Such system can be used on two-track lines. Its operation provides suitable protection on a section from a traction substation to the place of its installation. Almost all energy of system supply is emitted in catenaries. It is related to a high level of capacity of a converter (approx. 95%). With short sections of a catenary and ambient temperature of several degrees below zero, current Io may constitute 3% of current I_1. Sensors of temperature, humidity, voltage and current ensure that the energy consumption is minimised, while providing protection against icing.

Table 1. Estimated power and energy consumption of a resistor and converter type system
Tabela 1. Szacowane pobory mocy i energii systemu rezystorowego I przekształtnikowego

Catenary is 440 mm^2 on two tracks. 10 km section. Current 2x1000 A. Ambient temperature of -6°C		
System	Resistor type	Converter type
Maximum consumed power	12 MW	0.3 MW
Average consumed power	8 MW	0.3 MW
Energy – 10 h protection	80 MWh	3 MWh
Maximum temperature of wires	25°C	2°C

In a resistor type system, losses in resistors do not depend on the length of a section of a protected catenary. These losses constitute the main source of energy consumption. The energy consumption decreases with the increase of ambient temperature, but to a very small degree. In a converter type system, energy consumption decreases proportionally to the increase of ambient temperature. Energy consumption is also proportional to the length of the protected catenary. Replacing the resistor type system used for protection of a catenary against icing with a converter type system would provide the same level of protection, but at the same time it would require dozens of times less electric energy in comparison. Currently, preparations for applying such a system on one of the Polish railway lines are in progress.

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Metody zmniejszenia oddziaływania zjawisk pogodowych, szczególnie oblodzenia, na funkcjonowanie napowietrznej sieci trakcyjnej

Streszczenie

Elektryczne układy napędowe w systemach transportu są dobrze znane jako środki przyjazne środowisku. Przeważnie do zasilania napędów stosowane są ze względu na ich zalety sieci trakcyjne, co wymaga dedykowanego systemu zasilania trakcji. System ten obejmuje: systemy zasilania sieci jezdnej, sieci powrotnej i źródeł energii (podstacje trakcyjne). Pojazdy trakcyjne są ruchome, a połączone do obwodu w punktach styku: sieć trakcyjna z odbierakiem prądu i koła do szyn: punkt styku z siecią powrotną. Kolejowa i tramwajowa trakcja elektryczna mają górne zasilanie wykonane jako wieloprzewodowe linie napowietrzne, a sieć powrotna obejmuje szyn toru. W zelektryfikowanych systemach transportu kolejowego, sieci trakcyjne są wrażliwe, podatne na awarie i działają bez możliwości rezerwowego dostarczania energii elektrycznej ze źródła zasilania trakcji elektrycznej (podstacji trakcyjnej) do pojazdu trakcyjnego (ruchomego pociągu).

Ze względu na brak możliwości rezerwowania, wymagania eksploatacyjne nałożone na sieci trakcyjne są niezwykle wysokie, tj.:

- ciągłe i niezawodne dostawy energii dla elektrycznych pojazdów w okresie eksploatacji przez kilka dziesięcioleci,

- właściwa współpraca z odbierakami prądu (pantografami), które wraz z pojazdem stanowią ruchome połączenia elektryczne,
- minimalizacja zużycia przewodów oraz nakładek stykowych pantografów podczas obecności zjawisk elektrycznych i mechanicznych, które wpływają na jakość prądu w punkcie styku przewodu jezdnego z pantografem ruchomego pojazdu,
- wytrzymałość na zmienne temperatury i zjawiska atmosferyczne, również w ekstremalnych warunkach (temperatura, opady, wiatr, lód, mróz).

Przedstawiono koncepcje rozwiązań technicznych, które mogłyby przyczynić się do ochrony sieci trakcyjnej przed lodem i szronem gromadzącym się na przewodach sieci trakcyjnej, zanim w pełni ją pokryją i uniemożliwią bieżącą eksploatację pojazdów trakcyjnych. Proponowane rozwiązania są technicznie skuteczne w stosunku do wcześniej stosowanych rozwiązań: umożliwiają monitorowanie on-line sieci trakcyjnej w zmiennych warunkach pogodowych, bez zakłócania bieżącego rozkładu jazdy pociągów, ich ruchu i zapewnią oszczędzanie energii.

Słowa kluczowe:
Sieć trakcyjna, lód, szron, mróz, przewód jezdny, odbierak prądu, pantograf, przekształtnik, system anty oblodzeniowy, oszczędność energii

Keywords:
overhead catenary, ice, frost, contact wire, current collector, pantograph, converter, anti icing system, energy-saving