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Analysis of damage to medium and low voltage cable lines in tram traction stations – maintenance experience

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Abstract
The article discusses the problem of damage to the traction cables of medium and low voltage systems for DC tram traction power devices. It presents types and mechanisms of damage to various types of cables and compares a number of failures. Some chosen particularly interesting cases have been discussed.

Introduction

A traction substation as an object of the power system is used for transforming the energy of the alternating current into the energy of the direct (rectified) current supplying traction vehicles. Substations absorb the power from the medium power (MP) network, 15 kV. Using rectifying transformers the voltage is lowered to the level of 525 V of the effective value of the alternating current and in this form it is delivered to silicon rectifiers in which it is rectified and further sent to the 660 direct current switching stations [1, 2].

The 15 kV voltage is supplied to the substations from the Main Supplying Points (MSP) or from neighbouring substations via cable lines running underground, in cable ducts, on constructions etc. Due to the required high operational reliability, traction substations are supplied via at least two independent MP lines operating in the Automatic Transfer Switching Equipment (ATSE) system.

MP cables in the traction supply system serve the following functions:

- MSP – substation connection;
- substation-substation connection;
- connection of the MP rectifier unit switching station field – rectifier transformer.

Throughout the supplying traction cables of positive potential, power is sent to the road traction network from the 660 V direct current switching station. The electrical circuit gets closed throughout tram rails and a network of return traction cables connected to the negative busbar of the substation [1].

Constructional solutions of cable networks

All the cases of the damage were observed and were described in this paper are confined to the area of operation of one of Polish tram companies. The construction of the power network should ensure:

- high reliability of supplying power to traction substations and catenary;
- safety of outsiders and operational personnel;
- safety of natural environment [3].

In the discussed case, the 15 kV lines are made with the following types of cables:

a) HAKnFtA 3×120 mm^2 – cross-section area cable with aluminum cores in lead coating with steel sheathing in a fibre protective tube;
b) XRUHAKXS 3×1×120 mm^2 – cross-section area with an operational aluminum core insulated with cross-linked polyethylene with a return concentric copper core sealed in the axial and

radial direction with a thermoplastic polyethylene coating;

c) NA2XSY 3×1×120 mm^2 – cross-section area one-core power cable with an aluminum core insulation made of cross-linked polyethylene with a return concentric copper core and a PCV coating.

In case where the connections are made inside the station cable cross-sectional area is 50 mm^2.

Cable lines of the direct current, both the supplying and the return ones, are made with the use of the YAKY 1×630 mm^2 cross-section area – cable with aluminum cross-linked PCV with a return concentric copper core [4, 5, 6]. The oldest sections of supplying traction cables come from the year 1972, whereas the newest – from 2012.

In the case of the MP cables, the HAKnFtA type, also called the traditional one, is the oldest solution and it is not used when cable lines are modernized or when new ones are built, however in the discussed examples they comprise a decisive part of the network. The participation of particular cables in the power system of a substation is shown in the pie diagram presented in figure 1.

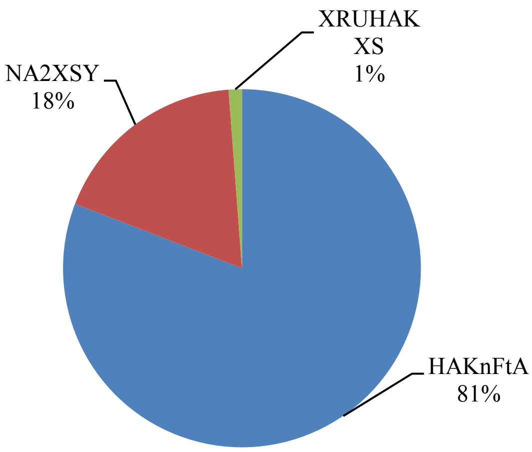

Fig. 1. Percentage participation of MP type cables used for supplying traction substations

The oldest cables of this type were placed in the first half of the seventies. At their ends cable heads were mounted. Figure 2 shows an example of a cable head construction.

Cables of the XRUHAKXS and NA2XSY types are the so called dry cables, which are a newer construction. In the studied case, the XRUHAKXS type cable is used only for short segments of cables before the substation. The total length of MP cables to which the damage presented in the article refers is equal to 37 638 m, whereas the length of traction cables is 112 097 m. Experience gained at their operation was a source of information for the statistics presented in this study.

Fig. 2. View of a cable head of the 3GOw type

Damage to cable lines

In this chapter representative cases of damage to MP and direct current cable lines occurring in the years 2007–2013 were discussed, whereas for traction cables cases of damage were registered in the period from 2009 to 2013.

MP Cables

Figure 3 presents a bar graph showing the number of cases of damage to MP cable lines, supplying tram traction substations, which occurred in the period 2007–2013. Traditionally, there are not more than a few cases of damage in a year.

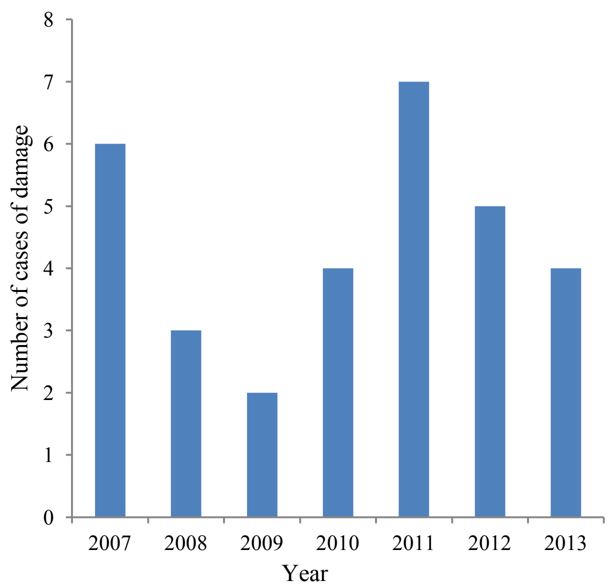

Fig. 3. The number of cases of damage to MP cables in the period 2007–2013

Damage to MP cable lines (as well as that for other levels of voltage) can be divided into faults caused by:

- aging of material (aging of insulation, oil leakage, mounting faults);
- mechanical faults due to haphazard situations (for example caused by excavators during construction works).

Figure 4 showing percentage participation of different causes of damage to MP cable lines in the years 2007–2013 is a statistical confirmation of the fact that in most cases damage is due to the aging of insulation material. It leads to a conclusion that the lines are to a certain extent worn out and that they were constructed without maintaining proper technological culture (rushing, stretching of the cables by lorries – stretching cable cores and inaccuracies at muff construction) [3, 7].

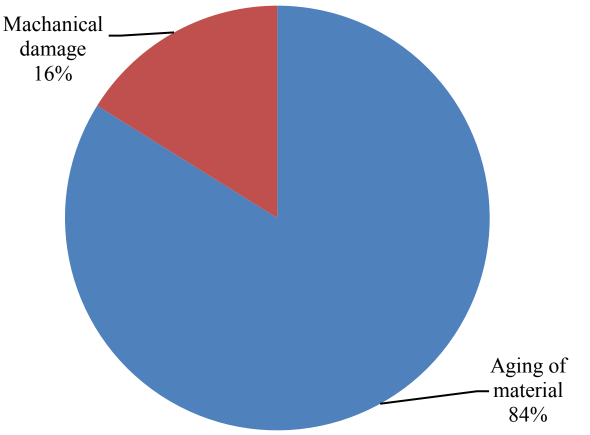

Fig. 4. Percentage participation of MP cable damage causes in the period 2007–2013

Cable damage may result from degradation of condition of cable muffs, cable heads or segments of cables. The pie diagram in figure 5 presents percentage participation of different locations of damage.

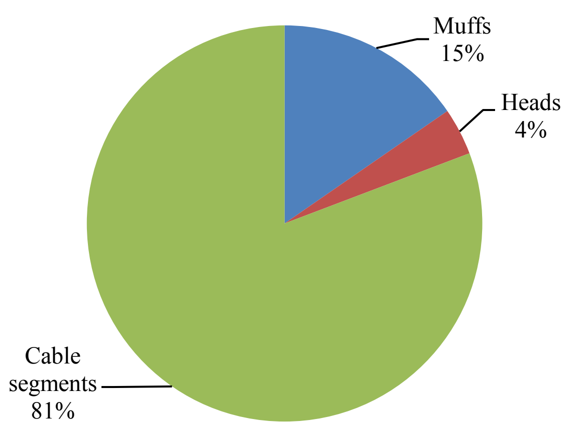

Fig. 5. Percentage participation of location of MP cable damage connected with material aging in the period 2007–2013

Degradation of technical condition of cable insulation is due to the following causes:

- physical ones – changes in the crystal structure;
- chemical ones – induced by temperature, oxidation and radiation;
- electrical ones – partial discharges, insulation treeing [8].

Partial discharges are spatially limited electrical discharges partially bridging the insulation. When the local field exceeds the value of voltage initiating discharging, then in the presence of a starting electron a whole avalanche of electrons is formed. They can be a direct cause of insulation damage or just a symptom of other faults occurrence. Depending on the insulation type the causes of partial discharges may be as follows:

a) polyethylene insulations:
   - gaps and inclusions formed at cable production;
   - mechanical faults;
   - in muffs and heads – faulty assembling;
   - thermal degradation in muffs and heads (badly made connections);
   - uneven layers of semiconductor;
   - water treeing;

b) paper insulation:
   - dry areas which may disappear due to migration of the filling at load changes;
   - drying of insulation in muffs;
   - losses of filling in heads [7, 9].

At the same time partial discharges may be due to a number of different causes e.g. micro cracks among others. Based on the acquired experience, degradation mechanism can be limited to the following cases:

- degradation in micro cracks and gas inclusions of the insulation;
- degradation throughout treeing – see the example shown in figure 6;
- degradation of insulation surface;
- degradation due to discharges in oil [10, 11, 12].

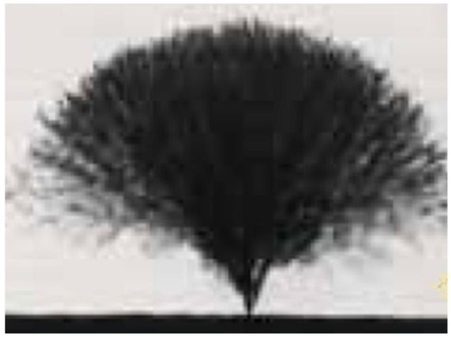

Fig. 6. View of water treeing in polyethylene insulation of a cable [8]

In the majority of cases, aging processes are responsible for the causes of damage in cable heads. In particular, in the case of external heads the main causes of damage are: high humidity and high temperature; in summer months daily amplitudes of temperature and switching overvoltage. Then damage usually entails their total destruction as a result of an explosion whose consequences can be seen in the figure 7 (visible place of breakdown in the column of L2 phase, the explosion led to severing a lid under the columns). Insulation faults cause phase – to – phase and earth faults. Much less frequent are the failures of head fittings e.g. bridge faults [13].

Fig. 7. View of a damaged cable head

Traction cables

The number of cases of traction cables damage in the period 2009–2013 is shown in figure 8.

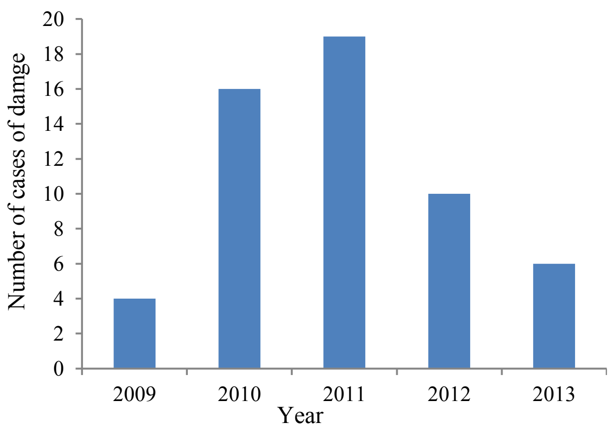

Fig. 8. Number of cases of traction cable damage in the years 2009–2013

Aging process is the common cause of power cable damage. The other ones occur at earth works (usually because of excavators) when construction works are carried out in highly urbanized areas. Figure 9 presents the causes of traction cable damage in percentages.

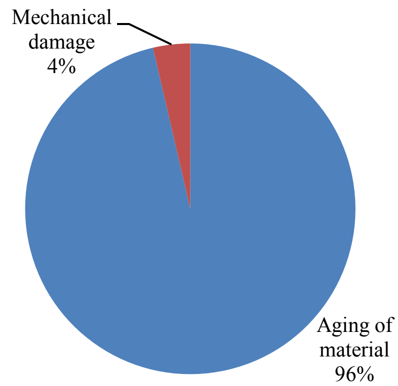

Fig. 9. Causes of traction cable damage in the period of 2009–2013 in percentages

The result of damage of cable core insulation, which not always – due to the kind of power supply (rectified voltage) – leads to the line switching off, is in most cases a slow process of aluminum oxidation which is induced by water and aggressive soil components, especially chlorides, entering the core [14]. The consequences of oxidation of an aluminum cable core are shown in figure 10.

Fig. 10. A view of the consequences of the oxidation process

Another important cause of damage to traction cable lines of low voltage is their overheating due to high intensity of the flowing currents. An example of cable damaged in that way is shown in figure 11.

Fig. 11. A view of a damaged traction cable core

Conclusions and final summaries

Most damage and failures of cable lines installed in tram traction substations are the results of their age which directly influences degradation of their insulation systems.

The number of failures of cable lines is a symptom of their technical condition and indicates the need for their replacement. Making an operational decision on the replacement of a segment of the network has to be performed taking into account the required reliability and economic study where the cost study of potential hold up of tram traffic has to be considered as well as the financial possibilities of the facility owner.

The system of technical supervision of cable lines, which was introduced in the tram company in 2007, will in a natural way stimulate undertaking rational operational decisions based on reliable statistical data.

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