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Analysis and prevention of accident-caused faults in power cable lines

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Abstract. To ensure fault-free operation of power cable lines it is essential to make a thorough analysis of the type of faults and their location. The paper considers the most common type of faults and main reasons for cable damage. The case study of cable faults at an urban network (Zabaikalsky Krai) shows that the root cause is insulation deterioration, especially with the cables reaching the end of their 35 year lifetime. Therefore, to prevent faults and mitigate the threats it is necessary to increase surveillance of cable systems and use cables with higher reliability and functionality, e.g., XLPE cables.

1 Introduction

The draft of the new Energy Strategy up to 2035 clearly indicates that energy efficiency will be among the priorities in the energy sector [1]. According to the National Audit Chamber of Russia, the deterioration of Russian utility networks has reached 60%. This is due to ineffective management and a lack of transparency from utility companies in relation to the costs and expenditure on capital construction and renovation. Obviously, it is becoming vitally important for the Russian energy sector to focus on the need to limit installation and service costs and obtain higher performance, reliability, and asset life.

One of the factors ensuring uninterrupted energy production is the cable system reliability. Cable systems are degrading over time and subsequently more failures are recorded. The unscheduled interruption of energy production, resulting from cable failures, entails overhead and labor costs associated with downtime. Downtime can be minimized through proper handling and maintenance of cables, continuous monitoring and analysis of their condition.

Today's industrial environments need superior mechanical protection for the power cables. The higher demands by the electricity industry force manufacturers to make innovative cable designs (e.g., cross-linked polyethylene insulation, PVC insulation) to address important technical and reliability problems. In Russia, however, 95% of power cables are paper insulated and cannot ensure proper protection from oil based products as well as acids that can cause electrical cables to fail over time.

To effectively meet the challenges awareness of state of the art at Russian utilities can be of great value. The article attempts to give an overview of the type of cable faults and their typical location. The presented case study of cable faults at an urban network

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(Zabaikalsky Krai) shows that the major reason for their damage is cable deterioration. The undertaken comparative study of paper-insulated cables and cables with cross-linked polyethylene insulation aims to show the ways to improve energy efficiency and to minimize the need for fault-recovery at Russian utilities.

2 Types and reasons for cable damages

The most common types of cable line damages:

- insulation damage, resulting in one-, two- or three-phase short circuit to the ground;
- insulation damage, resulting in phase-to-phase faults;
- one-, two- or three-phase fault without grounding, with grounding of broken cores, with grounding of unbroken cores.

Single-phase damages is the most common type of faults in 1-10 kV power cable lines in which one of the cable cores is short circuited to the shielding. Single-phase faults can be divided into three groups by the value of transient resistance at the short circuit location:

1) with transient resistance equal to tens and hundreds of mega ohms;
2) with transient resistance equal to up to hundreds of Ohms;
3) with resistance close to zero.

Interphase damages account for about 20 percent of all types of faults. They fall into two groups of damages: damages with transient resistance at the fault location close to zero and with resistance from some kilo ohms to hundreds of mega ohms.

The main reasons for cable faults can be traced back to:

- errors in design (deterioration of the insulation properties caused by unacceptable overheating of load currents due to low cross-section of cable cores; damages in emergency modes due to improper choice of protective equipment, etc.);
- manufacturing defects (cracks or through holes in the cable sheath; matching of several paper tapes; burrs on wires of current-carrying cores, etc.);
- cable laying defects (sharp bends of cables at turning angles of a line routing; mechanical damage (pits, cuts, twists of cables); ignoring the acceptable distance to the facilities which can affect cables performance (heat transport system, electric railways, etc.)
- cable joints defects resulting from uneven distribution of electromagnetic field strength in cable fittings, as well as non-observance of the cable joints manufacturing technology when installing cable fittings in the field;
- damages during cable maintenance (accidental mechanical cable damages; insulation deterioration; metal corrosion of cable armature or lead coating caused by ground current or chemical composition of ground, etc.) [2].

3 Statistical analysis of accident-caused damages

Scarcity of relevant data on cable performance can be a factor impeding its proper maintenance and improving its reliability. Therefore, a case study of cable faults was done at an urban network (Zabaikalsky Krai).

Table 1. Distribution of accidents according to the features of damage causes.

No	Causes of damages	Number of accidents, 2014	Number of accidents, 2015 (the first half)
1	Due to insulation deterioration:	36	13
1.1	Damage in the unbroken place	27	7
1.2	Cable joints damages	9	6

2	As a result of inappropriate installation of cable lines by the contracting organization	1	3
3	As a result of mechanical impact during excavation by third-party organizations	2	1
	Total	39	17

As is seen from the table the major reason for cable damage is insulation deterioration, i.e. damages associated with cable maintenance, mostly in the unbroken place. A positive trend is the decrease of the number of emergency outages of 6/10 kV cable lines equipment from 39 accidents in 2014 to 17 accidents in 2015 (reduction by 56%). It entailed lost energy decrease from 25,23 to 6,64 megawatt hour (reduction by 74%) and decrease of the total duration of power interruption from 34,95 to 14,82 (reduction by 58%).

To find out causes of the significant decrease in cable damages, dependence of the number of accidents on cable lifecycle was determined.

Table 2. Distribution of accidents according to the cable life time.

No	Life time / years	Over 2014 / number	Over the first half of 2015 / number
1	Up to 5	6	2
2	From 5 to 15	7	2
3	From 15 to 25	8	2
4	From 25 to 35	12	5
5	From 35 to 45	3	4
6	Over 45 years	3	2
	Total	39	17

Table 2 shows that in 2014 a surge of faults was recorded with the cables reaching the end of their 35 year lifetime. The obtained data are supported by the evidence of Federal Grid, suggesting that ageing of power cables accounts for 31% of damages on Russian utilities. The raising concern is that a considerable number of cable lines exceeding the licensed 35 year lifetime are still in service.

The first half of 2015 exhibits a slight decrease in damages, which can be attributed to more accurate monitoring and maintenance and well-timed replacement of old cables. Prevention of cable damages is an urgent task for utilities. To increase the rate of cable faults detection a variety of fault detection techniques is used. These methods fall into two groups: conventional and modern. Conventional methods are visual inspection, insulation resistance test, voltage proof test. Modern methods are partial-discharge test with oscillating wave test system, time domain reflectometry, heat monitoring, etc.

The key issues to be considered in a workable cable maintenance program are 1) choice of a proper cable design that is consistent with voltage, safety and expected performance; 2) well-managed cable installation; 3) record of causes of cable failures; and 4) prompt remedial actions based on records. Ideally, cable asset management should start at an early stage and continue through the cable lifecycle.

Currently, the globally preferred cable for both transmission and distribution is XLPE (cross-linked polyethylene insulation) cables (Japan, Finland, France, Sweden – 100% of the cable market; Germany and Denmark – 95%; Canada and the USA – 85%). Russian utilities, however, mostly rely on paper-insulated cables. Let us consider pros and cons of both types of cables.

Paper-insulated cables have shown fairly good electrical properties and have, in general, given very good service. Their main failure mode is insulation deterioration (as is shown in Table 1) due to partial discharge. Other failures include:

1) cable manufacture is rather complicated;

2) thermal runaway due to mutual heating from neighboring cables or overloading;

3) restrictions on a cable vertical run resulting from adhesive leaking;
4) inconvenience with fixing oil leakage from cable sheath and cable sealing;
5) heavy construction due to a lead sheath.

The first cables with cross-linked polyethylene insulation had a poor service record. However, arrival of developments in manufacturing techniques has improved their performance. Today, despite some drawbacks, such as instability to high temperatures and faster ageing under UV exposure, XLPE cables exhibit far better performance. Their major highlights are:

1) scarce records on cable laying defects;
2) higher cable performance owing to the increase of a core temperature limit (permissible loading current is generally 15-25% higher than with paper-insulated cables);
3) continuous load (90°C versus 70°C);
4) enhanced thermal and moisture resistance;
5) in case of short circuits conventional thermal current is up to 250°C;
6) small insulation losses (0,001 versus 0,008);
7) relative eco-friendliness (no lead, oil, bitum);
8) smaller dimensions and weight;
9) cheaper cable maintenance [3,4].

Opponents of XLPE cables, however, claim that high production costs outweigh the above-mentioned advantages. Nevertheless, to ensure reliable and uninterrupted energy supply, Russian utilities will have to reconsider their strategies for increasing energy efficiency and gradually introduce XLPE cables.

4 Conclusion

Thus, to prevent faults and mitigate the threats it is necessary to increase surveillance of cable systems with modern methods and use cables with higher reliability and functionality. A number of leading Russian power systems are targeted at the use of medium and high voltage XLPE cables when laying the new cable lines and replacing or maintaining the old ones. To establish competitive advantage of Russian power systems on the international level it is necessary to improve reliability of cable lines that will eventually contribute to enhancing efficiency of electrical networks.

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