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Analysis of the 6 – 10 kV Cable Lines Faults in Vilnius City

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Introduction

Reliable and safe electrical energy supply to consumers ensures a continuous manufacturing process for industrial enterprises guarantees regular electrical transportation work as well as satisfying and relaxing conditions for people. At present in Vilnius together with the development of new construction sites and carried out renovation of buildings the number of electrical energy consumers has greatly increased and there appeared the need for expanding electrical energy supply and distribution network.

Nowadays medium voltage power cables with saturated paper type insulation (PI) are substituted by the cables with an insulation made of reinforced cross-linked polyethylene (XLPE). Such a change has been caused by the increased number of faults in Vilnius city cable lines and constantly growing requirements regarding the organizations dealing with cable maintenance and concerning their technical characteristics. The main reasons causing failures in cables and damaging their insulation are cases when underground level is water as well as soil is chemically active, excavation works might damage cables as well as their exterior casings or there appear mechanical damages during the laying out of cables. During the maintenance of cables the temperature changes in power cables are caused due to variable load regimes, overloading, short connections.

At present there are articles on the research done analyzing insulation ageing problems and faults connected with them. In article [1] there are presented data of the electrical strength analysis of the insulation made of cross-linked polyethylene XLPE . The experimental samples of such insulation have been under the influence of the positive and negative high voltage impulses of various duration. The power cable with oil – paper insulation diagnosis method which is based on wave reflection from the damaged places on cables has been analyzed in article [2]. Article [3] deals with oil – paper insulation quality characteristics under the influence of various hazardous indicators. There have been investigated the following reasons for insulation ageing in high voltage substations.

The objective of the article is to evaluate Vilnius city 6 – 10 kV cable lines state and to set the reasons of their faults.

Cable Insulation Technical Characteristics

6 – 10 kV cables with cross – linked insulation allow us to solve many problems of electricity supply reliability, let us optimize city electricity network in some cases even change traditional electrical network schemes. Stock company „Rytų skirstomieji tinklai" (Eastern Distribution Networks) possesses data regarding cases registered in the USA and Canada on cables with XLPE insulation the number of which comprises 85%, while in Germany and Denmark such cables comprise 95% from all the used cables, and in Japan, France, Finland and Sweden in the medium voltage networks only the cables with XLPE insulation are used.

While maintaining the cable and its insulation there constantly act a strong enough electric field. Due to this cable the insulation is getting heated. The heated insulation is received due to dielectric power losses in the insulation itself:

$$P = U^2 C\omega \,\mathrm{tg}\delta \,; \qquad (1)$$

where U – is the cable tension; C – is insulation capacity; ω – variable current frequency; δ – angle of dielectric losses.

When the temperature is 20^0 C, the polyethylene tgδ = $(2 – 4)\mathrm{x}10^{-4}$, depending on the density of the polyethylene. After the increase of temperature up to 80^0 C, dielectrical losses in the polyethylene insulation increase and then is the following tgδ = $(5 – 7)\mathrm{x}10^{-4}$. The tangent of the angle of dielectric losses of polyvinylchloride insulation is significantly higher and at the temperature of 20^0 C, at the frequency of 50 Hz, it reaches to tgδ = $20\mathrm{x}10^{-4}$. When the temperature rises up to 140^0 C, polyvinylchloride is tgδ = $1000\mathrm{x}10^{-4}$.

The influence onto the resistance of cable insulation materials there plays the intensity of electrical field. If there is only one electric field functioning then the dependence of polyethylene specific volume resistance on the cable tension is possible to express in the following way:

$$\rho = k\frac{e^{-\alpha\theta}}{U^{\gamma}} \,; \qquad (2)$$

where k – is coefficient of correction; α = 0,13 (does not depend on the amount of the tension); θ – is the tempera - ture of the polyethylene; γ = (2,1 – 2,4) – coefficient , characterizing the change of the resistance due to the change of the electric field .

The insulation resistance of the minimum single-core cable or one core of 1 km length at the temperature of 60^0 C, is expressed in the following way:

$$R_{ins} = 32 \ln \frac{s + 2b}{s}; \quad (3)$$

where s – is the cross section of the core; b – is the thickness of the insulation.

Polyethylene power cable insulation is widely applied due to the low and nearly constant relative permittivity which does not depend on the temperature and electrical field frequency.

Partial discharges in cable insulation

Partial discharges appear in the weakest part of the insulation layer: in damp, polluted with admixtures, cable sealing boxes and cable sleeves. The most dangerous discharges are formed in the gas micro voids of insulation and in the cracking and joints of cable layers. For the analysis of partial discharges and for their determining there may be used imitation model of the cable insulation described in Fig. 1.

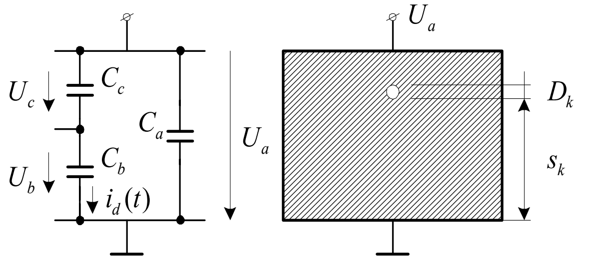

Fig. 1. Imitation model of cable insulation: D_k – diameter of micro void; s_k – distance of micro void up to the electrode

The equivalent of micro void in hard insulation layer is considered a charge, the capacity of which is C_c, capacity of insulation layer on the type of the discharge current – C_b, but the capacity of all insulation is – C_a. The intended charge of the partial discharge in the micro voids is calculated in the following way:

$$q_c = C_b \Delta U_c; \quad (4)$$

where ΔU_c – is the voltage drop in the micro void.

The tension of cutting through the micro void is expressed in the following way:

$$U_c = U_a \frac{C_b}{C_b + C_c}; \quad (5)$$

where U_a – is the voltage acting upon the insulation of the cable .

For measuring the equal size micro voids spaced at the same distance from the central axes , there are used two cylindrical form electrodes, then the ratio of the corresponding charges in the micro voids is calculated in the following:

$$\frac{q_1}{q_2} = \frac{\ln\left(\frac{r_{2e}}{r_{2i}}\right)}{\ln\left(\frac{r_{1e}}{r_{1i}}\right)}; \quad (6)$$

where r_{1e} and r_{2e} – are the external radiuses of the electrodes; r_{1i} and r_{2i} – are the interior radiuses of the electrodes.

When two flat electrodes are used in the micro voids for determining the charges but they are not of the equal thickness ($d_2 > d_1$), from the equation (6) we receive:

$$\frac{q_1}{q_2} = \frac{d_2}{d_1}; \quad (7)$$

The obtained result proves the conclusion once more that while tightening the insulation it becomes more difficult to detect the charges of partial discharges, at the same time the micro defects of the insulation. Insulation service life L, its thickness b and the strength of the electrical field E unite the following empirical dependence:

$$L = \frac{k_1}{(bE)^n}; \quad (8)$$

where k_1 – is the coefficient of proportioning; n – the index of the degree, which depends on the insulation material type and the quality of its making.

If in the insulation of the cable is formed gaseous spherical micro void in which the electric field intensity is E_c, then the intensity of the electric field influencing the whole insulation is possible to express in the following:

$$E = E_c \frac{2\varepsilon_r + 1}{3\varepsilon_r}; \quad (9)$$

where ε_r – is the relative permittivity of cable insulation. Then the received equation is inserted into (8), we obtain:

$$L = k_1 \left(bE_c \frac{2\varepsilon_r + 1}{3\varepsilon_r} \right)^{-n}. \quad (10)$$

Equation (10) makes it to analyze the service life of the insulation in accordance to its parameters. When the values n, b, ε_r and k_1 are constant, insulation service life time becomes shorter, when increasing the intensity of electric field acting in the micro voids.

Statistical data of the faults of cable lines

A great part of 6 – 10 kV cable lines maintained in Vilnius city were installed more than 30 – 4 years ago. There are even lines that have been operating for more than 45 years. The degree of wearing as well as the degree of reliability of such lines varies greatly. No wonder such cables have been out of order constantly, they fail in electricity supply, the operational control of such cable network has been aggravated.

Further on here find submitted the diagrams that have been compiled based on the statistical data of Vilnius city electricity network. Cable line and overhead line density (km/100km^2) in Vilnius region is submitted in Fig. 2, the distribution faults in the general 10 kV network is presented in Fig. 3.

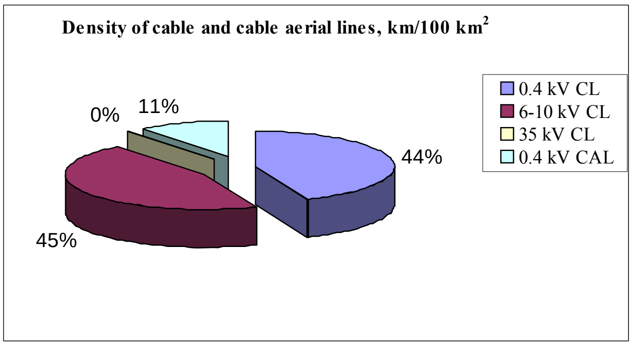

Fig. 2. Density of cable (CL) and cable aerial lines (CAL) in Vilnius region

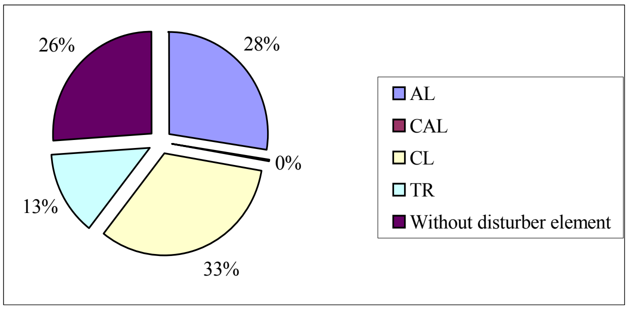

Fig. 3. Failure in distribution the general 10 kV electricity network: AL – aerial lines; CAL – cable aerial lines; CL – cable lines; TR – transformer substations

In 1960 – 1970 all the cables maintained are serviced preventively every year by testing them under the high – voltage test. At present in most European countries cables are tested with high – constant voltage before starting their maintenance. During the recent years in Vilnius region the capacities of cable tests have been reduced. That is why there have increased the number of faults in the old cable lines. Fig. 4 presents the idea mentioned above in the diagram.

Conclusions

1. The analysis of statistical data presents the fact that majority 6 – 10 kV cable lines in Vilnius region have been serviced for 30 – 40 years. The armoured cables with lead casings have been used for more than 45 years.
2. It has been determined that the most dangerous and risky partial discharges are formed in the gaseous micro voids of cable insulation, in the joints and cracks of cable layers. The imitation model of partial discharges in the cable insulation is submitted, enabling to investigate the interrelation of insulation material service life time on the electric field intensity operating in the micro void.
3. After reducing the number of cable tests applying high-voltage test there have appeared the increased number of emergency cases in the 6 – 10 kV cable network. The defects and faults in the network comprise 33% of the total faults, meanwhile the faults in the aerial lines comprise 28%, cable aerial lines make 26%, in the transformer substations there have been registered 13% faults.
4. In renovating the old cable lines as well as in laying out the new ones it is functional to recommend in Vilnius region to use power cables possessing insulation made from reinforced cross – linked polyethylene XLPE and operating as transversal and longitudinal water barriers.

Acknowledgement

The author would like to thank Vilnius Electricity networks for the submission of statistical data.

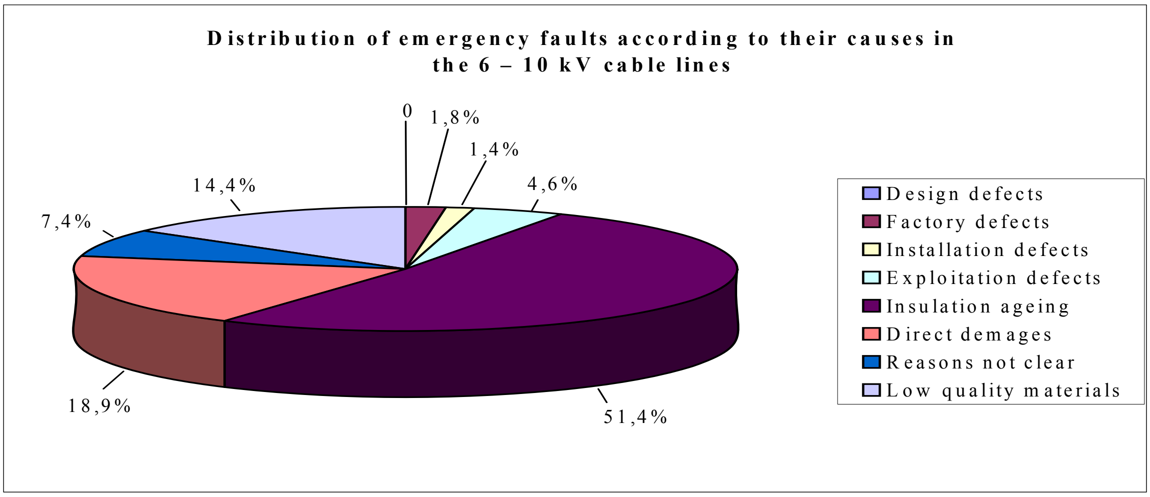

Fig. 4. Distribution of emergency faults according to their causes in the 6 – 10 kV cable lines

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B. Karaliūnas. Analysis of the 6 – 10 kV Cable Lines Faults in Vilnius City // Electronics and Electrical Enginering. – Kaunas: Technologija, 2006. – No. 3(67). – P. 51–54.

Reasons and causes of faults and defects in 6 – 10 kV cable lines in Vilnius city and in the neighborhood regions as well as renovation possibilities in cable lines are analyzed. While expanding the construction works and renovating old buildings in Vilnius city the power cables with oil – paper insulation are being substituted by reinforced cross – linked polyethylene cables (XLPE). The present state of cable lines is analyzed as well as cable insulation technical characteristics. The imitation model of insulation of partial discharge in the micro voids is presented in the article, allowing to investigate insulation life time dependence on the intensity of operating electric field.

The analysis of statistical data indicate the fact that when the number of tests on cables using high – voltage tests was reduced there appeared emergency faults in 6 – 10 kV cable networks. The faults in this network comprise 33% of the total faults, in aerial lines 28%, in cable aerial lines faults make 26%, in transformer substations there were registered 13% of faults. The most usual reasons of the registered faults and defects are the following: cable insulation ageing 51,4%, direct cable damages 18,9%, low quality materials 14,4%, errors in designs 7,4%, maintenance failures 4,6%, installation defects 1,4% and manufacturing defects 1,8%. Il. 4, bibl. 8 (in English; summaries in English, Russian and Lithuanian).

Б. Каралюнас. Анализ отказов 6 – 10 кВ кабельных линий в городе Вильнюс // Электроника и электротехника. – Каунас: Технология, 2006. – № 3(67). – С. 51–54.

Рассматриваются причины отказов 6 – 10 кВ кабельных линий в городе Вильнюсе и в окружающем регионе, а также перспективы обновления кабельных сетей. По мере расширения масштабов строительства и при реконструкции старых зданий в городе Вильнюсе силовые кабели с пропитанной бумажной изоляцией заменяются кабелями с изоляцией из армированного полиэтилена (XLPE). Анализируется состояние существующих кабельных линий и технические характеристики кабельной изоляции. Представлена имитационная модель частичных разрядов в микропорках изоляции, позволяющая определить срок службы изоляции в зависимости от напряженности электрического поля.

Анализ статистических данных показывает, что в связи с уменьшением испытаний кабельных линий повышенным напряжением, увеличилось число аварийных отказов в кабельных сетях напряжением 6 – 10 кВ. Такие отказы составляют 33% от всех отказов, в то время как отказы в воздушных линиях электропередачи составляют 28%, в кабельных – воздушных линиях – 26%, в трансформаторных подстанциях – 13%. Причинами отказов кабелей являются: старение изоляции – 51,4%, повреждения кабелей – 18,9%, низкокачественные материалы – 14,4%, ошибки в проектах – 7,4%, эксплоатационные ошибки – 4,6%, монтажные дефекты – 1,4%, заводские дефекты кабелей – 1,8%. Ил. 4, библ. 8 (на английском языке; рефераты на английском, русском и литовском яз.).

B. Karaliūnas. 6 – 10 kV kabelinių linijų gedimų Vilniaus mieste analizė // Elektronika ir ylektrotechnika. – Kaunas: Technologija, 2006. – Nr. 3(67). – P. 51–54.

Nagrinėjamos 6 – 10 kV įtampos kabelinių linijų Vilniaus mieste ir aplinkiniame regione gedimų priežastys ir kabelinių tinklų atnaujinimo perspektyvos. Plečiantis statyboms ir rekonstruojant senus pastatus Vilniaus mieste jėgos kabeliai su įsodrinta popierine izoliacija keičiami kabeliais su izoliacija iš armuoto sukryžminto polietileno (XLPE). Analizuojama dabartinė kabelinių linijų būklė ir kabelių izoliacijos techninės charakteristikos. Pateiktas kabelio dalinių išlydžių izoliacijos mikroertmėse imitacinis modelis, įgalinantis tirti, kaip izoliacijos eksploatavimo trukmė priklauso nuo veikiančio elektrinio lauko stiprio.

Statistinių duomenų analizė rodo, kad, sumažėjus kabelių bandymams paaukštinta įtampa, padaugėjo avarinių gedimų 6 – 10 kV kabeliniame tinkle. Čia šio tinklo gedimai sudaro 33% visų gedimų, o oro linijų gedimų buvo 28%, kabelinių oro linijų – 26%, transformatorinėse pastotėse užregistruota 13% gedimų. Dažniausiai pasitaikančios gedimų priežastys yra šios: kabelių izoliacijos senėjimas – 51,4%, tiesioginiai kabelių pažeidimai – 18,9%, nekokybiškos medžiagos – 14,3%, projektų klaidos – 7,4%, eksploatacijos klaidos – 4,6%, montavimo defektai – 1,4% ir kabelių gamykliniai defektai – 1,8%. Il.4, bibl. 8 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

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