Diagnostics of a shipboard cable by measuring the dielectric loss tangent

A Vlasov, S Buev

Murmansk State Technical University, Murmansk, Russia
E-mail: buevsa@mstu.edu.ru

Abstract. Until now there has not been created a system to assess the residual resource and to predict the probability of shipboard cable failure during its operation by non-destructive methods. Periodic high voltage tests are prescribed by various guidelines. As a result of such diagnostics, the damaged section is identified and the entire cable route is replaced. Obviously, this technology does not prevent an emergency situation, does not provide information about the residual resource, and finally, worsens the properties of an already aged cable exposed to high voltage. Insulation quality control on ships is of great importance and significance. The question arises about the suitability of one or another cable route for further work after long-term operation. That is why the issues of predicting the service life of a cable and assessing its current technical condition are relevant. Modern technologies make it possible to obtain materials with improved characteristics; however, currently rubber-insulated cables are the most common. In this work, diagnostics of the state of a shipboard cable is carried out by determining the dielectric loss tangent of its insulation. This method can be used along with traditional methods for technical audit of shipboard cables, such as testing the hardness of the cable sheath, infrared diagnostics of electrical equipment. In this case, the conclusion about the current state of the cable and the forecast of its service life, in the opinion of the authors, can only be made on the basis of the results of comprehensive diagnostics performed by several methods.

1. Introduction

The issue of developing a system for technical audit of power cable insulation by non-destructive methods remains relevant. It would be possible to assess the residual resource and predict the probability of cable failure during its operation.

The diagnostic parameters and the accepted limits of deterioration of the insulation state are not sufficiently coordinated with the electrical insulation characteristics, the physicochemical aging processes of the insulation, developing in time, have not been sufficiently studied [6].

Accidents at large energy facilities and enterprises, in some cases, are associated with a violation of the insulation of power cables, their spontaneous combustion and loss of electrical insulating properties. Such accidents are especially dangerous at nuclear power plants, large oil refining enterprises, in the cable networks of industrial enterprises, etc.

The objects of increased fire and electrical hazard include sea and river vessels, the electrical equipment of which is subject to the most stringent electrical safety requirements.

Insulation quality control on ships is of great importance and significance. In the process of ship repair and replacement of cable routes, the question arises about the suitability of one or another cable
route for further work after long-term operation. That is why the issues of predicting the service life are relevant.

Modern technologies make it possible to obtain materials with improved characteristics; however, rubber-insulated cables are the most common. The aging process of the insulation of electrical cables on ships is characterized by several important factors: increased temperatures and air humidity. Therefore, the development of methods for predicting the service life of insulation is closely related to the specification of operating conditions.

2. Materials and methods

Trouble-free and long-term operation of the cable routes of the sea vessel is ensured by continuous monitoring of the insulation resistance.

Operation of the cable at high ambient temperatures or direct heating of the insulation due to high currents of the load cores causes accelerated aging of the insulation and a reduction in its service life. The permissible heating of conductors of cables with plastic insulation in emergency mode should be no more than for PVC (polyvinyl chloride) plastic compound – 80 °C, polyethylene – 80 °C, vulcanizing polyethylene – 130 °C [3].

Due to the difficulty of directly determining the temperature of the cable core $T_{cor}$, it is recommended to recalculate the measured temperature of the cable sheath according to the relation [3]:

$$T_{cor} = \frac{T_{hose} + I^2 n \rho S_c}{100 q}$$

(1)

where $T_{hose}$ – is the temperature along the sheath of the cable, °C; $I$ – is the electric current; $n$ – is the number of cable cores; $\rho$ – resistivity of copper or aluminum at a temperature close to the core temperature, Ohm∙mm$^2$ / m; $S_c$ – the sum of thermal resistances of insulation and protective covers of the cable, Ohm; $q$ – is the cross-section of the cable core, mm$^2$.

The literature indicates values for the core temperature of the cable, at which a long service life is ensured. So for cables with sheathing with PVC compound, the core temperature should not exceed 70 °C [3].

In the power industry, it is recommended to carry out temperature control using a thermal imager at least 2 times a year on sections of cable routes where there is a danger of overheating [7].

Analysis of the thermal state of various sections of cable routes on ships shows that in some rooms the temperature of cable routes exceeds 80 °C (Fig. 1) [3]. We can see that the most percentage of cables on ship have the temperature 47 °C, 10 % of cable lines have the temperature 60 °C, about 5% of cables have the temperature more than 70 °C. And excess of the temperatures of cable above the temperature of environment temperature is 25-35 °C.

Depending on the load current, the temperature of the shipboard cables may vary. It is impossible to identify sections of the route with elevated temperatures with the standard devices of the shipboard electrical power system, however, the use of thermal imaging equipment makes it possible to reliably identify local overheating. However, due to the peculiarity of laying cable routes, it is not always possible to identify emergency defects using a thermal imager.
3. Results and discussion

The shipboard cable was subjected to accelerated thermal aging at a temperature of 110 °C in order to observe the change in the dielectric loss tangent over time.

For testing, we chose KNRP cable (non-combustible cable with rubber insulation and steel wire braid) 7x1, which is used on sea vessels.

This cable was placed in a thermostat with a temperature of 110 °C. To measure the mechanical characteristics (parameters of hardness, elasticity) of its insulation, a shore rubber hardness tester NOVOTEST was used; Tangens-2000 insulation parameter tester was used to determine the dielectric loss tangent.

Before measuring the insulation parameters, the cable was removed from the thermostat. Measurements of the tangent of the angle of dielectric losses were carried out after the equilibrium temperature was established at 18-22 °C. The measurement results are shown in Fig. 2-3.

The first tanδ measurement after 23 hours of the cable being in an elevated temperature of 110 °C showed a twofold decrease in tanδ compared to the value measured before testing (Fig. 2). In the following hours of thermal aging of the cable, the tanδ readings decrease by another 100% in 1000 hours. Further, in the period from 1000 to 2000 hours, the value of the dielectric loss tangent changes insignificantly. After 2500 hours and up to 3000 hours, a slight increase in the tanδ value is observed (Fig. 3).
Figure 3. The results of measurements of $\tan \delta$ during 3000 hours of testing of shipboard cable

From this graph (Fig. 3), it can be concluded that, apart from the sharp drop in the $\tan \delta$ value from 4% to 2% in the first few hours of observations, in the subsequent observation time, the $\tan \delta$ readings vary from 1 to 2%. Stabilization of dielectric loss tangent values may indicate on the cable suitability, however, as shown by the results of previous studies [1-3], the hardness of the cable sheath, and even more so the hardness of the cable core insulation, reaches critical values, in which the hose insulation and cable core insulation lose their elastic properties, their hardness increases, and micro cracks accumulate in the insulation, after 300 hours of the cable being at a temperature of 110 °C, and subsequently the hardness values only increase. Thus, by controlling the $\tan \delta$ parameter, it is necessary to additionally monitor the hardness indicators of the cable insulation.

In fig. 4 shows the dependence of the $C(t)$ value. In the period of time 300 - 3000 hours, changes in capacitance values are not significant. The value of the shipboard cable capacitance drops sharply in the first 200 hours when the cable is at a temperature of 110 °C, this is due to the fact that plasticizers, so-called polar substances, which give elasticity to the material, actively come out of the cable insulation when heated. Then the cross-linking of molecules gradually increases, the material becomes more rigid, the value of the parameter capacitance stabilizes.

Figure 4. The value of the capacitance of a shipboard cable subject to thermal aging at a temperature of 110 °C
To study the dependence of $\tan\delta$ on temperature, a series of measurements were performed while the cable was cooling. In the process of lowering the cable temperature to the ambient temperature, its temperature was monitored using a thermal imager FLUKE Ti400 with simultaneous measurement of the dielectric loss tangent. In Fig. 5 shows the thermogram of the shipboard cable in the cooling process with the connected equipment for measuring the dielectric loss tangent $\tan\delta$, the cable temperature is about 40 °C.

![Figure 5. Thermogram of the shipboard cable (aged at a temperature of 110 °C for 2313 hours)](image)

The values of $\tan\delta$ and cable capacitance $C$ when the cable temperature drops from 100 °C to 20 °C are shown in Fig. 6 and Fig. 7. In contrast to the monotonic decrease of capacitance (Fig. 7), the parameter $\tan\delta$ does not change during cooling from 100 to 60 °C (Fig. 6). However, upon cooling from 60 to 20 °C, the $\tan\delta$ value decreases by more than 80%.

![Figure 6. Dependence of the $\tan\delta(T)$ value when the cable temperature decreases from 100 °C to 20 °C](image)
4. Conclusion

The presented results of the $\tan\delta$ values show that the proposed method allows to make an expert decision on the further operation of a shipboard cable or its replacement. It is necessary to be guided by a set of diagnostic results by various methods. We prefer the quantitative infrared diagnostics, the method of measuring the hardness of cable insulation and values of $\tan\delta$.

Taking into account the high fire hazard of cable routes, it is recommended to carry out regular diagnostics to identify dangerous areas.

The tangent of the dielectric loss angle can be used as a diagnostic parameter for predictive assessment of the shipboard cable condition.

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