Estimation of the Remaining Life Time of Oil-Filled Cable Systems Based on Mathematical Modelling their Electrical Insulation Ageing Process

Mikhail **SHUVALOV**, Izjaslav **PESHKOV**, Vladimir **OVSIENKO;** JSC "VNIIKP", (Russia),shuvalov@vniikp.ru, vovsienko@vniikp.ru

ABSTRACT

Thermal ageing is the main process which determines the life time of oil-filled (OF) cables. It is accompanied by the growth of dielectric loss tangent tanδ, which is highly sensitive to the physical and chemical state of the OF cable insulation and creates a positive feedback in the course of ageing. Mathematical model is presented which describes the ageing process in terms of tgδ growth and takes into consideration tanδ vs. temperature dependency. The data are given necessary for the cable life time evaluation using the abovementioned model, together with the results of the remaining life forecast for the particular 220 kV OF cable system containing 5 circuits being in operation for 17–19 years.

KEYWORDS

oil-filled cable; thermal ageing; power factor; lifetime evaluation.

INTRODUCTION

A large portion of the existing high-voltage cable systems (CS) in the Russian Federation are composed of oil-filled cables (OFC). Since the first CSs of this kind were installed as far back as before the World War II, and the production of OFCs that was launched in the 1930s was closed in 1996, it must be admitted that the specified service life of OFCs which according to [1] averages between 25 and 35 years, depending on the voltage rating, has been exceeded completely or to a significant extent. Replacement of OFCs in a high-voltage CS with modern XLPE-insulated cables is quite expensive, and the utilities do not always have the appropriate budget; what is more, cable replacement should be carried out in a timely manner. Therefore, the issues of predicting the residual life of OFC, as well as its possible extension are definitely relevant.

AGEING MODEL AND ITS APPLICATION

The All-Russian Scientific Research and Development Cable Institute (JSC "VNIIKP") addressed the problem of OFC life assessment in the early 1980s when these cables were not only produced but also new cable designs were developed.

According to the accepted vision – see, for example, [2÷5] – the ageing of OFC electrical insulation (EI) is a thermal process and in the main it involves decomposition of the cable paper with the formation of more or less low-molecular products; a considerable part of these products dissolve in cable oil forming a true (probably colloidal) solution in it. The decomposition process accelerates as the temperature increases.

In the course of ageing an obvious degradation of EI characteristics is observed including the tanδ which increases during cable operation. The rise of tanδ may be explained in the context of the ageing mechanism briefly described above: the ageing products are forming new charge carriers by way of dissociation into ions or formation of colloidal charged particles. The increase of charge carriers concentration corresponds to the increase of EI conductivity and hence the tanδ growth. The tanδ, as a parameter characterizing the degree of ageing, has the following peculiarities:

- a high sensitivity to the current physical and chemical state of EI;

- in the course of ageing it develops a positive feedback loop: the larger is the tanδ, the higher is the EI temperature, and accordingly the higher is the speed of ageing, which in its turn leads to even greater increase of the tanδ.

The "family" of mathematical models of OFC EI ageing had been developed by the authors to describe this process just in terms of the "autocatalytic" growth of the *tanδ* [6-11].

However these models had a significant limitation: they considered the *tanδ* of OFC EI at each moment of time as a number, though the *tanδ* is actually a temperature function that varies in the process of ageing. These variations are illustrated by the data shown in Fig.1.

The refined mathematical model of OFC EI ageing taking into account the above mentioned essential fact is based on the following provisions and assumptions:

a) The ageing process may be characterized by single effective activation energy;

b) The current load, the temperature and the environmental thermal resistivity are considered as time functions (see below).

c) The thermal field in the cable at each moment of time is assumed to be quasi-stationary. This condition is ensured by the inertia of aging [10];

d) EI is considered as a system with lumped parameters. At the same time, in accordance with the approach to thermal calculation set forth in the IEC standard [12], the dielectric losses are considered concentrated on the geometric mean radius of EI. Taking into account the assumptions c) and d), the EI temperature may be expressed by equation:

$$\theta = z + y \cdot tan\delta, \qquad (1)$$

where *z* and *y* are determined by the ambient temperature θ_0, the total heat release in the current-carrying conductor and sheath/tube P_M, the overall thermal resistance of the system R_m, voltage *U*, electrical capacity *C* and mains frequency *f*:

$$z = \theta_0 + R_T \cdot P_M, \qquad y = U^2 \cdot 2\pi f \cdot C \cdot R_T \qquad (2)$$