A MOLECULAR APPROACH TO THE ELECTRICAL AGING OF XLPE CABLES

Jean-Pierre CRINE, Consultant, St-Bruno (Canada), jpcrine@ieee.org
also with Ecole Polytechnique de Montréal (Canada)

ABSTRACT

The relation between electrical aging and breakdown of XLPE and its molecular characteristics is examined. We show that our new aging concept describes the electrical aging process of XLPE and, in fact applies to all polymers with free volume. The physical significance of the basic parameters (activation energy and volume) is discussed and it is shown that XLPE cable aging directly depends on the breaking of C-C bonds. The influence of samples size is briefly discussed as well as the influence of temperature cycles. Testing under high frequency might be reliably translated to power frequency condition with our model.

.

KEYWORDS

Electrical aging, testing, molecular properties, size effect.

INTRODUCTION

Electrical aging of polymer insulated cables is still poorly known and customarily accelerated aging results are plotted according to an inverse power law, such as $t = CF^{-n}$, where t is the time, F is the applied field, C and n are constants characteristic of the cable. We have shown in previous work (1,2) that life extrapolations made from such graphs are, at best, dubious since the linear relation between log field and log time does not hold for long aging times (1,2) and it is not always evident at short aging times. In fact, results fit much better a semi-log plot between F and log t. We have proposed an aging model that describes very well actual accelerated aging data (1,2). There are few other models able to predict lifetime at the temperatures where most transmission cables operate (3-6). The Crine (1,2), Dissado and Montanari (3-4), and Lewis (5-6) models of aging predict the times to failure more accurately than the empirical inverse power law model that is currently used in cable design. Some of the models have constants that have to be determined experimentally, and it is likely that these constants will vary according to the extrusion conditions. The three models predict a threshold electrical stress, below which there is little or no electrical aging. Above the threshold stress, the times to failure decrease with increasing electrical stress. One major theoretical question often raised concerns the physico-chemical origin of the basic parameters (i.e. the activation energy and volume) in our model and their evolution with the aging conditions. One objective of this paper is to answer this question.

It should be made clear that these models do not entirely solve all the complexities involved in the electrical aging of actual cables in service. One difference between accelerated aging in the laboratory and service is usually the size difference of the cable samples. It is well known, although poorly understood, that breakdown decreases with increasing insulation thickness and with the cable length (1,7,8). We present preliminary calculations attempting to correlate the sample size with the activation volume of the tested samples. Another problem is that some cables are successfully operated at ~15 kV/mm, and some have undergone prolonged aging tests at stresses greater than 20 kV/mm, which are well above the so-called threshold field, i.e. in a domain of accelerated aging. Although we do not have a complete answer to this apparent paradox, we nevertheless submit some ideas that might explain the significant difference between tests performed at constant temperature and aging in service under temperature cycles. The implication on the significance of accelerated aging tests on the prediction of cable life in service is also discussed. Finally, the accelerating influence of frequency on electrical aging is discussed and calculations are presented to show it is possible to significantly and reliably shorten the duration of aging tests by using high frequencies fields.

THE BASIC PARAMETERS IN OUR AGING MODEL

Our model based on the rate theory has been presented elsewhere and we will give here only the main equation. The time t needed to reach the final (aged) state is given by

$$t = (h/2fkT) \exp(\Delta G/kT) \operatorname{csch}(\tfrac{1}{2} \varepsilon_0 \varepsilon' \Delta V F^2/kT) \qquad (1)$$

where f is the field frequency; the factor 2 comes from the fact that there 2 changes of polarity for each field cycle. Equation 1 predicts that at zero field, t will be equal to infinity since csch (0) = ∞. Thus, there will be some sort of "tail" at low fields, where t will slowly tend toward ∞ . At high fields, Eq. 1 reduces to

$$t = (h/2fkT) \exp[(\Delta G - \tfrac{1}{2} \varepsilon_0 \varepsilon' \Delta V F^2)/kT] \qquad (2)$$

which predicts a linear relation between F^2 and log time. In Refs. 1,2 we have shown that various dry aging results of XLPE cables are well described by the linear relation at high fields (Eq. 1) and the tail (Eq. 2) at low fields (see Fig. 1). From the slope and intercept of the high field regime in F^2 vs. log t plots, it is then possible to determine ΔV and ΔG,