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Water treeing as diffusion-with-reaction process

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Résumé

On représente un modèle mathématique des arborescences d'eau basé sur les faits expérimentaux bien établis. La simulation se fonde sur la conception théorique courante de la destruction des polymères sous l'action des milieux d'attaque. A l'aide du méthode de la mise en moyenne on remplace le système initial d'équations différentielles aux dérivées partielles par des équations différentielles ordinaires. Le modèle examine le développement des arborescences d'eau en termes de deux variables interdépendantes – de la longueur relative des arborescences d'eau et de la concentration de microcavités. On représente et on étudie des résultats de la simulation numérique et des particularités des expériences orientées sur l'estimation de la valeur des paramètres du modèle.

Abstract

Mathematical model of water treeing is presented based on well-established experimental facts. The simulation is derived from generally accepted theoretical approach to polymer decomposition by aggressive environment. Original system of partial differential equations is replaced by ordinary differential equations with the help of the method of averaging. The model treats tree growth in terms of two interconnected variables – relative tree length and concentration of microvoids. The results of numerical simulation are presented and discussed together with peculiarities of experiments aimed at estimation of model parameters.

Water treeing is the most commonly occurring kind of power cable plastic insulation aging. This phenomenon has been known for about 30 years, and certain success has been achieved in studying it. However there still remains much unclarified about water trees (WT), physical and chemical mechanisms of water treeing being among the unanswered questions.

The lack of study of these mechanisms results in significant difficulties when practical problems are solved, such as diagnostics of the cable state during operation, estimation of its remaining service life or life estimations for new products based on the long-term test results.

Difficulties involved in the investigation of physical and chemical nature of treeing and, respectively, in the mathematical simulation of tree growth are caused by the following:

1) the main processes constituting the essence of treeing develop on a microlevel and are characterized by microscopic heterogeneity which causes complications in their experimental study;
2) these processes are rather specific. Chemical and morphological peculiarities of the destructed material, cable design and manufacturing technology, conditions of cable electrical and thermal loading and moisture exchange with the environment, as well as random nature and dimensions of the tree-initiating defects, etc. result in a significant scatter in WT sizes and growth rates, their morphology and chemical behavior.

The existing theoretical WT models may be divided into two groups.

The first one treats polymer destruction within WT as an electrochemical process (water electrolysis followed by oxidation). This approach is presented in [1, 2].

An alternative view on WT growth as a mechanical destruction process is reflected in the other category of models described in [3, 4].

In these papers the Maxwell stresses that develop in the electric field at the interface of two dielectrics, in this particular case – polymer and microcavity or water-filled microcrack in it – are believed to be the cause of the insulation degradation.

These investigations made a considerable contribution to the development of the problem, however the theories suggested remain qualitative. From our point of view quantitative models are of greater interest. One may overcome the mentioned above limitations and difficulties of theoretical WT investigation by using a hierarchical approach to WT simulation involving successive development of more and more general and exact models (as a whole this approach implies a combination of principles "from general to special" and "from simple to complicated") [5]. To this must be added that due to specificity of the chemical processes proceeding on a microlevel in WT and because of impossibility to interpret them unambiguously, the models (at least those of the first approximation) should be phenomenological or semi-phenomenological. They must be based on well established and reproducible experimental data and use wherever possible well known general theoretical schemes, proposed for the description of polymer destruction under the exposure to aggressive media.