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Active high voltage insulation

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Abstract

This paper presents a new concept for an active high voltage insulation system with dynamic and adaptive features. The governing principle is based on surface charge accumulation on dielectrically covered electrodes in air under atmospheric pressure. This accumulation results in a charge-induced electric field component which steers the field distribution within the system advantageously. At equilibrium, the electric field component in the air gap normal to the dielectric surface will be zero, except for the field component needed to balance charge losses. Consequently, in the ideal case, the electrical breakdown strength of the electrode coatings determines the breakdown strength of the entire system. Nevertheless, in order to reach equilibrium, a dynamic phase with changing electric field distribution in the insulation system has to be passed. The dynamic system aspects of the concept are demonstrated in numerical simulations. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: High voltage; Gas insulation; Covered electrodes; Dielectric coatings; Charge accumulation; Surface charge; Charge-induced electrical field; Discharge stabilization; Numerical simulations

1. Introduction

Today gas-insulated high voltage equipment in electric power applications mainly use atmospheric air or pressurized sulphurhexafluoride (SF_6) as the insulating medium. The conventional open air-insulated systems are well developed and further improvements seem difficult to achieve. The strongly electronegative SF_6 gas has excellent electric and thermal properties, but it has one severe drawback, it contributes to the greenhouse effect through its efficient infrared absorption aggravated by its slow decomposition and is, therefore, included in the Kyoto

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protocol as one of the gases which should have limited emissions [1,2]. The development towards a more compact design of high voltage equipment and systems along with cost awareness and environmental compatibility, has led to radically increased demands on the requirements and the performance of electric insulation. In addition, there is also a relatively new but growing trend towards using dc instead of ac. It is not unrealistic to extrapolate all these ongoing tendencies: The need for new knowledge, new materials and new environmental friendly insulation principles in both ac- and dc-voltage applications will most certainly increase rapidly in the near future [3]. This paper presents a radically new concept for an insulation system and describes the basic ideas behind it, from a systems perspective.

In most cases, charge accumulation is unacceptable in high voltage insulation systems, since it usually changes a highly optimized electric field distribution in an unfavourable or even hazardous way. Nevertheless, the fundamental idea behind what this paper calls the *concept of active insulation* is the intentional and beneficial use of surface charge on dielectrically covered electrodes to gain improved breakdown performance of air-insulated systems.

It is of interest to note that there are few comments in the literature on intentional charge accumulation being used to increase breakdown voltages in high voltage insulation systems for electric power applications. However, the basic principle that accumulated charge affects field distribution in a system of dielectrics is not new in any sense: It is simply a result of Gauss' law in Maxwell's equations

$$\nabla \cdot \boldsymbol{D} = \rho \tag{1}$$

which leads to charge inevitably accumulating when the medium in the field is inhomogeneous, i.e., when

$$\nabla\left(\frac{\varepsilon}{\sigma}\right) \neq 0. \tag{2}$$

2. Concept of active insulation

Active insulation is a hybrid insulation system in which solid and gaseous dielectrics are advantageously combined together with free charge from an "external" source. The dynamic process of surface charge accumulation adds active properties since the charge-induced electric field component *actively* redistributes the electric field in the insulation. The concept is basically nothing other than a field steering technique based on a charge-induced electrical field component.

Consider a one-dimensional insulating structure consisting of an air gap bounded by two dielectrically covered electrodes, Fig. 1.

Voltage $v(t)$ is applied across the electrodes. If free charges are available in the gap or in the air volume surrounding the structure, charge can be expected to accumulate on the dielectric surfaces due to electrostatic attraction. This accumulation process will continue as long as there is a driving field, i.e., as long as $E_g(t) \neq 0$.