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COMMUNICATIONS

THE NOTION OF THE "EARLY STAGE OF AGEING"INDOOR AND OUTDOOR INSULATION REGARDING SURFACE DISCHARGES: A SHORT REVIEW

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Phenomena at the insulating solid/insulating gas interface are highly interesting since they may cause changes leading ultimately to a reduction of the insulating capability of the whole insulating system. The resulting flashover and/or erosion of the solid is preceded by a so-called "late stage of ageing" and an "early stage of ageing". It is the aim of the present contribution to particularly stress the importance of the latter, to comment upon the surface mechanisms responsible for the "early stage of ageing" and to review the work done until now.

K e y w o r d s: early ageing, indoor insulation, outdoor insulation, surface ageing mechanism

1 INTRODUCTION

The significance of interfaces between solid and gas (with the applied electric parallel to the interface) has been stressed by various authors [1–3] reported that in ambient air, for example, the flashover voltage at the insulator may drop to about 50 % of the original value, if no precautions are taken [2]. How good an interface may be, depends on the profile of the insulator, the solid material of which the insulator consists, the effect of contamination *etc* [4].

The aim of the present work is to comment on some aspects of the solid/gas interface as they appear in both indoor and outdoor applications. Particular emphasis will be given to the surface mechanisms which may result in ageing and eventual failure. Our main interest will be focused on the role of surface mechanisms during the "early stage of ageing". Here, it should be noted that indoor applications differ from outdoor applications in that they are more electrically stressed. Moreover, indoor applications are not subjected to rain or snow but are subjected to occasional condensation [5]. The interface in question consists of a solid insulating material and a gas which is the atmospheric air. Condensation causes water droplets on the surface of the solid. These droplets in combination with light contamination — which may exist on the surface — and the influence of a sufficiently high electric stress may cause partial discharges (PD). PD activity may change the properties of the insulator surface.

This paper tackles the question of surface mechanisms, with emphasis on the early stage of ageing. Both indoor and outdoor insulation with respect to this stage of ageing are considered. It should be noted that the present paper does not attempt to tackle the question of diagnostics of the "early stage of ageing" and/or to analyze in length the surface water droplet issue. Something like that would go beyond the scope of this paper. It does attempt, however, to comment on the surface mechanisms related to the early stage of ageing and the possibly common ground between indoor and outdoor insulation.

2 INDOOR AND OUTDOOR INSULATION

Outdoor insulation is subjected, in general, to lower electrical stresses than either Air Insulated Switchgear (AIS) or Gas Insulated Switchgear (GIS). Outdoor insulation is subjected to very high environmental stresses the result of which is the formation of layers of foreign matter on their surface. Such layers possess high volume conductivity. This in turn leads to a high layer conductivity [6].

For indoor insulators, the degree of pollution is much smaller. Self cleaning effects, for example, are not observed in indoor technology whereas they are prominent in outdoor insulators. Environmental stresses, on the other hand, are very high for outdoor insulators and rather low for indoor insulators. The consequence of this is that the layer conductivity is also much smaller [7]. Evidently, the combination of electrical stress and pollution layer presents a common danger to all types of switchgear technology. It should not be forgotten, however, that the ageing processes depend on the stress and design parameters of each technology.

3 SURFACE AGEING MECHANISMS

Resin-type insulators — which are used as indoor insulators — present, in general, hydrophobic properties as a result of residual traces of mold release agents containing

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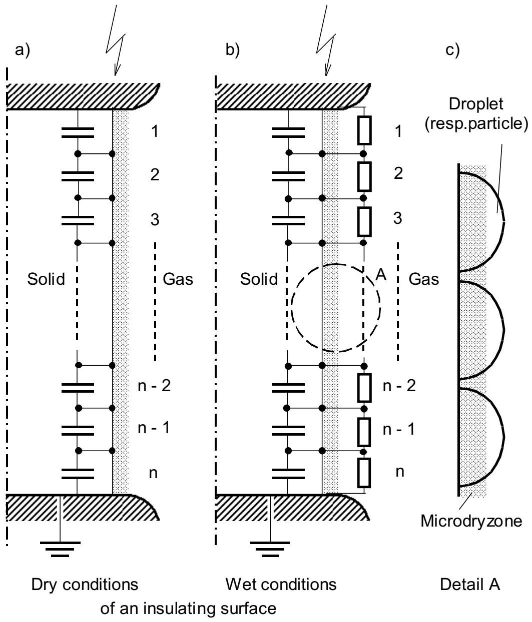

Fig. 1. Modelling of an insulating surface (after [7]).a) dry and clean conditions b) wet and/or contaminated conditions c) details of a wet hydrophobic and/or contaminated surface (droplets, resp. conducting particles)

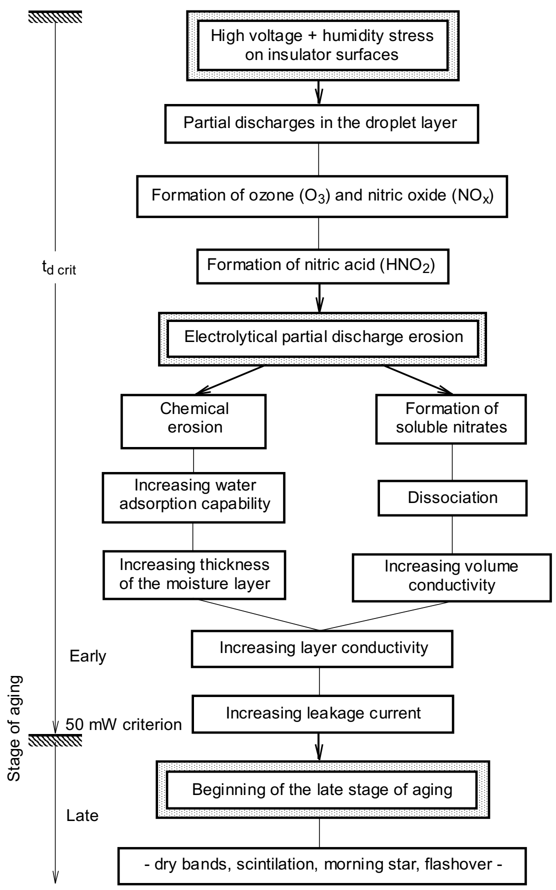

Fig. 2. Details of the surface ageing mechanisms of AIS indoor insulation at severe climatic service conditions (after [7]).

silicones [8–10]. If, however, the local electric stress becomes greater than a critical value (we will subsequently refer to as overstress), localized PD may start which in turn may lead to ultimate failure. The stages leading to the ultimate failure may vary, depending on the particular characteristics of the insulation system involved. In Fig. 1, a modelling of an insulator surface under dry conditions and wet/contaminated conditions is presented, where, in the former case the solid dielectric can be represented with a chain of capacitors and in the latter case it can be represented with a chain of capacitors and resistors in parallel representing the superposition of relevant ohmic and capacitive components of the electric field [7].

In the case of high pressure SF_6/solid insulation, the electric stress is very high and local high overstress will result to a "spontaneous" flashover without any intermediate stages of ageing [11]. For moderate pressure SF_6/solid insulation, however, local electric overstressing will lead to "electro-chemical surface erosion" because of the attack of SF_6 by-products [12]. Such by-products, combined with humidity, increase the surface conductivity and are chemically aggressive. Evidently, a low dew point is of critical importance for the lifetime of such an insulation [13]. It is thus clear that whereas in high pressure SF_6/solid insulation deteriorating surface mechanisms are not a prerequisite for the ultimate failure, in moderate SF_6/solid insulation applications a certain surface deterioration is a "sine qua non" situation in order to have a flashover. The time interval during which the solid surface deteriorates is called "early stage of ageing" [5, 7]. It is clear by now that together with appropriate computational techniques [14], among others more thorough knowledge of the "early stage of ageing" helps us to better study solid/gas insulation systems and to possibly take measures for the prolongation of the lifetime of such systems.

Indoor insulation systems, on the other hand, are subjected to relatively high electric stresses, certainly lower than those of the GIS but higher than those of outdoor insulation [7]. An "early stage of ageing" as well as a "late stage of ageing" have been already established [7]. Details of the surface ageing mechanisms of AIS indoor insulation at severe climatic conditions are shown in Fig. 2 [7]. It is obvious from Fig. 2 that not only the sort of pollution and the presence of humidity but also the insulator material plays a dominant role in determining the duration of the "early stage of ageing". Fillers may influence the electrical behaviour of the insulator material, *eg* cycloaliphatic epoxy resins containing alumina or dolomite type filler have a higher thermal coefficient of expansion than bisphenol epoxy resins having the same filler type [15]. Coating the insulators with silicone or hydrocarbon greases may also alter the surface behaviour of the insulator [3, 16–19].

It is remarkable that the importance of the "early stage of ageing" has not attracted the attention of the majority of researchers. The combination of high voltage and moist layers on the surface of an insulator may locally distort the electric field and generate PD. By collision mechanism highly reactive radicals may be formed, particularly ozone. Nitrous gases may result, as a consequence of ozone oxidation of the nitrogen in atmospheric air. Nitric acid will subsequently be formed [20]. The described process is already a pollution phenomenon. We thus see that the insulator surface is attacked by a combination of electrical and physico-chemical stresses resulting in a phenomenon called "electrolytic partial discharge erosion" [8]. This phenomenon may increase the layer conductivity via two possible mechanisms: a) by chemical attack and subsequent erosion, the surface roughness increases with the result that the surface becomes more hydrophilic. The surface is able to absorb more water and a decrease of the surface resistivity must be expected, and b) the formation of soluble nitrates increases the volume conductivity of the surface layer which in turn results in an increasing layer conductivity [7, 21]. The aforementioned process is a self contamination process. Indoor insulation is characterized by the "early stage of ageing" which is determined by relatively low layer conductivities and low energy surface discharges. Further reports on this do not mention any appreciable thermal effects due to the surface discharges [22]. In outdoor insulation, a similar mechanism was proposed, where the importance of the hydroxyl radical (OH), the ozonaled atmosphere as well as that of the small magnitude discharges, has been emphasized [23]. This validates the point of view, namely, that there is a parallel between indoor and outdoor insulation ageing phenomena. It should be noted, however, that the above is not a definite conclusion but rather an indication as to the possible parallelism between the two types of insulation, the reason being that no systematic studies have been carried out on the "early stage of ageing" especially for the outdoor insulation. Obviously, more research has to be done in this direction.

An increasing layer conductivity will lead to an increased leakage current and a worse flashover performance [24–26]. The transition from the "early stage of ageing" to a "late stage of ageing" is characterized by the transition of the low energy PD to "mini"-arcs. A certain threshold in terms of the energy of surface PD exists, beyond which we have the onset of the "late stage of ageing" [7, 27–29].

Figure 2 shows that the "early stage of ageing" is much longer than the "late stage of ageing". This means that the "early stage of ageing" is of great significance in trying to detect the initial deterioration of the insulating system. The distinction between the two aforementioned stages has also been observed for outdoor insulation, where it was noted that the "early stage of ageing" is characterized by uniform erosion of the insulator surface and does not lead to defects that would disqualify the insulation system [29]. The "late stage of ageing", according to [30], is characterized by a strong increase of leakage currents and intense damaging processes which are manifested as cracking, pitting, erosion etc. Such damages are sufficient to render the insulating system useless. The same conclusion was also reached in [31], where it was pointed out that the "early stage of ageing" is characterized by a polluting process on the insulator surface whereas the "late stage of ageing" presents a change of colour of the surface as well as microcracks.

It is true that there is not much information on the distinction between the "early" and "late" stages of ageing in both indoor and outdoor insulation. It is also true that this distinction may offer considerable help for these technologies. This distinction may even imply that to test an insulating system up to breakdown takes an unnecessarily long time since it extends the test to the stage of intense damaging. Because of the self contamination phenomenon — already described — which cannot be avoided in either indoor or outdoor insulation, it is evident that some parallel exists, as far as ageing is concerned, between these two types of insulation [32]. The elongation of the testing time up to the phase of intensive destruction is, according to [30], " . . . of no interest and even inadmissible from the user's point of view and introduces a wide scatter of data on ageing time and leakage currents". For the reasons given above, a test criterion should focus on the "early stage of ageing". Low energy surface discharges starting at water droplets are at the beginning of the ageing process.

4 MODELLING OF THE FLASHOVER MECHANISM

Regarding modelling of the flashover mechanism in indoor and/or outdoor insulation the above considerations should be taken into account. Perhaps too little attention has been given to the modelling of the "early stage of ageing", which is so vital in the further development of the surface phenomena which may finally lead to flashover. Until now much attention has been given to the formation of dry zones and the ensuing consequences [33–36]. It is our opinion that more attention should be given to the modelling of the early phenomena since from these phenomena a flashover may result [37]. The mechanisms leading to PD at water droplets on the insulator surface should be incorporated into the modelling of flashover phenomena. This by itself is a challenging task. The diagnostic methods used for the detection of the "early stage of ageing" phenomena may indeed contribute to such modelling [38, 39] as well as experience accumulated by surface phenomena in dielectric barrier discharges (DBD) in air in the presence of water vapour [40], where it was pointed out that water vapour introduces a discontinuity in the discharge behaviour in the form of mean current and temperature variations.

5 CONCLUSIONS

This work has as objective to show that there may be a common ground regarding the "early stage of ageing" in both indoor and outdoor insulation and to review work done precisely in this area up to now. Despite differences in external influences between indoor and outdoor applications, there are strong indications that ageing starts from light contamination of the insulator surface and low energy discharges. This stage of ageing was rather overlooked until now by the majority of researchers although it may offer much valuable information about the behaviour and/or suitability of various materials. Selfcontamination processes which are at the root of the "early stage of ageing" should be more thoroughly studied.

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