Partial discharge inception voltage and magnitude in polymeric cables under AC and DC voltage supply

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ABSTRACT

The ratio between partial discharge inception voltage, PDIV, under AC and DC voltage supply is estimated in the paper by an analytical model. Despite the simplifying assumptions, the experimental results confirm that the PDIV in DC can be much higher than in AC, for the same defect, especially at room temperature. However, depending on material conductivity and the rate of variation of conductivity with temperature, the PDIV in DC can become lower than that in AC, at least for the typical XLPE materials used from HV AC and DC cables. Hence, PD can incept and extinct during operation as a function of cable loading, posing reliability problems for a cable insulation system that have to be taken care both at the design and at the commissioning stage. Regarding PD amplitude, this paper shows that the delay time distribution of firing electrons is the main cause of the difference between PD amplitude values measured in DC and AC. Also, the effect of the different PDIV under DC and AC can induce wrong speculations once PD measurements are performed at the same peak voltage in AC and DC.

KEYWORDS

Partial Discharge Inception Voltage, PDIV, modelling.

INTRODUCTION

DC power cables are taking an increasing share of R&D projects, due to the growing need of transmission on long distances, the diffusion of renewable generation, as well as the increasing reliability and decreasing losses of converters. Cable insulation is mostly polymeric and solid, even if solutions involving polymeric tapes, paper and oil are proposed. One of the most important aging factors in AC are partial discharges, PD, which can incept in insulation defects (cavities or interfaces), and bring insulation to breakdown in times much shorter than those expected. Partial discharges may play a non-negligible role also in DC accelerated aging, despite their much smaller repetition rate when compared to AC. This would indicate that the life reduction that PD can cause under AC supply could be significantly lower than under DC conditions [1].

Due to the lack of confidence in insulation behavior under DC and in DC PD measurement techniques, DC cables are tested mostly under AC, which may be not appropriate for at least two reasons.

One is that defects which can incept PD under DC voltage may not be active under AC, and vice versa. This is due to the fact that, depending on the temperature gradient established across insulation, the so-called field inversion can occur in DC, and the highest field intensity can be found near the outer semicon, while that in AC is always maximum close to the inner semicon.

The second reason is that the partial discharge inception voltage can be drastically different from AC to DC, and it will also depend on temperature, that is, on cable loading [2]. This is due to the fact that the DC field in insulation will be distributed according to conductivity, while the AC field will be a function of permittivity instead. Considering the strong, exponential, dependence of conductivity on temperature in solid and liquid insulation (but not in gas filling defects), PDIV in DC can be much lower than in AC when a cable is loaded only partially, while the opposite might occur at full load.

Eventually, there are contrasting indications in literature about the expected charge amplitude of the PD comparing DC to AC [3].

This paper has the purpose to illuminate such shadows, focusing on the difference of PDIV and PD amplitude between DC and AC. It shows analytically the expected relationship between PDIVAC and PDIVDC as a function of temperature, comparing theoretical and experimental results of PD measurements on insulation models endowed with artificial defects.

PARTIAL DISCHARGE INCEPTION AND AMPLITUDE

Partial discharges (PD) in DC and AC occur under the probability of the presence of an electric field in an insulation defect (cavity, interface) exceeding the inception field, conditioned by the availability of a firing electron [4, 5]:

$$Pr((E_c > E_i)|F) = \frac{Pr((E_c > E_i) \cdot F)}{Pr(F)} \qquad (1)$$

being F the event of firing electron availability and Pr its probability, E_c the field in the defect (cavity), E_i is the PD inception field (peak value), having approximate expression (for air in a spherical defect of radius r), [6]:

$$E_i = 25.2p\left(1 + \frac{8.6}{\sqrt{2pr}}\right) \quad \left[\frac{V}{m}\right] \qquad (2)$$

where p represents the gas pressure inside the cavity. This can be adapted to a cylindrical cavity replacing r with h_c. The probability of having a firing electron available can be derived approximately from [7]:

$$h_1 = N_{SC}(t)\nu_0 \exp\left(-\frac{\Psi - \sqrt{e\frac{|E_i(t)|}{4\pi\varepsilon_0}}}{KT}\right) \qquad (3)$$

being h_1 the hazard rate of electron detrapping from insulation/defect interface and $N_{SC}(t)$ the interface charge that can be detrapped at time t. The terms e, ν_0, K, ε_0, T and Ψ are the electron charge, the base phonon frequency, the Boltzmann constant, the vacuum permittivity,