

## **Feasibility of Determining Margin of Remaining Life Using Void Content**

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### **ABSTRACT**

Research to date indicates that void content growth in electrical insulation occurs both as a function of partial discharge (for high voltage conditions) and from oxygen exposure alone under low and medium voltage conditions. Thus it seems reasonable that a diagnostic tool could be developed for predicting the degree of aging and the amount of remaining life in electrical cable based on measurements of void content (size and density). In this paper, we investigate the feasibility of such a tool using basic models of void development.

### **INTRODUCTION**

Several years of cumulative research into the aging of electrical insulation have shown that discharges in voids within a solid dielectric material are associated with the degradation and eventual failure of the material. Also, some evidence exists that increasing void content leads to weakening of the polymer structure. These voids, often called cavities, can originate during the manufacturing process or as a result of subsequent environmental and operational stresses. Several attempts have been made to correlate partial discharge (PD), chemical property, or mechanical property measurements to margin of remaining life.<sup>[1]</sup> Although these methods are useful for determining current operability of a dielectric, no method has successfully been developed to estimate remaining life.

The methodology proposed here is based on the measurement of the solid dielectric material's internal void content (i.e. void size and density). The technique relates void content to either (1) the material's proximity for partial discharge breakdown or (2) proximity to unacceptable mechanical property deterioration. Development of an appropriate void growth model and knowledge of void content parameters at predetermined failure criteria should allow estimation of remaining life. Successful completion of this project will ultimately result in an innovative, *in situ* method of providing an accurate indication of remaining cable insulation life.

### **METHODOLOGY**

Research has shown that voids grow in size and number when polymeric insulation, such as crosslinked polyethylene (XLPE) or ethylene propylene rubber (EPR), is exposed to thermal stress.<sup>[2]</sup> As the void size increases with age, the equivalent remaining insulation thickness reduces to a point where breakdown can occur.

Using the ideal gas law, the rate of increase in the volume occupied by the gaseous by-products of various aging-related chemical reactions will be directly proportional to the gas production rate, which is constant for a given temperature. Thus, the void volume at time,  $t$ , is

$$V(t) = V_o + Kt \quad (1)$$

Modeling the voids as spherical in shape, i.e.  $V_{\text{void}} = (4/3)\pi r^3$ , and knowing the initial and final void content parameters for a know period of aging, one can calculate the rate constant, K,

$$K = \frac{4/3\pi[(r^3 n)_{\text{final}} - (r^3 n)_{\text{initial}}]}{t} \quad (2)$$

where      n = total number of voids  
               r = void radius  
               t = elapsed aging time

Once K is known, the end of life void content criteria can be substituted for V(t) in equation (1) and subsequently solved to determine the time to end of life.

For some preliminary experimental void content data, we know that two samples of crosslinked polyethylene (XLPE) insulation from a cable removed after 20 years of normal operation had average void sizes on the order of 6.5 and 10  $\mu\text{m}$ , respectively.<sup>[2]</sup> The initial estimate of remaining life for the two samples is summarized in Table I below. The end of life (EOL) criteria were conservatively assumed to be 0.1% and 5% void volume.

**Table I.** Estimated Margin of Remaining Life

initial void size ( $\mu\text{m}$ )	initial $\rho_{\text{voids}}$ <sup>[3]</sup> (voids/ $\text{cm}^3$ )	20 year void size ( $\mu\text{m}$ )	20 year $\rho_{\text{voids}}$ (voids/ $\text{cm}^3$ )	$t_{\text{EOL}}$ (yrs) 0.1% $V_{\text{void}}$	$t_{\text{EOL}}$ (yrs) 5% $V_{\text{void}}$
1	$1 \times 10^5$	6.5	$1 \times 10^6$	140	7000
5	$1 \times 10^5$	10	$5 \times 10^5$	78	4000

## RESULTS/CONCLUSIONS

From the simplistic model described here, it can be seen that void size is proportional to the cubic root of elapsed time, which perhaps explains the long life, in general, of electric cable insulation. Additionally, it is noted that current imaging technologies are certainly capable of imaging voids of the size of interest for this methodology, although, finding a portable imaging technique may prove a challenge. Thus, from the preliminary data, it appears that a remaining life estimation based on void content measurement is feasible.

## REFERENCES

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