High Frequency Voltage Stress

Presented by: Flore Chiang
Date: March 30, 2012
2.10.1.1 Frequency

The insulation requirements given in 2.10 are for frequencies up to 30 kHz. It is permitted to use the same requirements for insulation operating at frequencies over 30 kHz until additional data is available.

10 Insulation requirements

The insulation requirements given in this standard are for frequencies up to 30 kHz. It is permitted to use the same requirements for insulation operating at frequencies over 30 kHz until additional data are available.

Now the additional data is available!
ground rules:

1. intro to PD.
2. experimental results.
3. comparison with current practice.
4. why different?
5. how air and solid dielectrics behave under high frequency stress?
Any type of periodic voltages with a fundamental frequency ($f_0$) above 30 kHz and up to 10 MHz

Key phenomenon = partial discharge (PD)

Its deteriorating effect is aggravated roughly in proportionally to the frequency
partial discharge (PD)
is a localized discharge within a solid or fluid dielectric system, restricted to only a part of dielectric material thus *only partially bridging the electrodes*, and is typically observed:

- in cavities, voids (bubbles) or gaps;
- between interfaces of different dielectric properties;
- at sharp electrode edges or protrusions.
Electric arc video
Townsend regions

normal glow

abnormal glow

glow-to-arc transition

breakdown voltage

I

V

nA

µA

mA

A

kA

glow discharge

dark discharge

background

saturation

corona

non-thermal

thermal

V

I

breakdown voltage

Townsend regions

normal glow

abnormal glow

glow-to-arc transition

I

V

nA

µA

mA

A

kA

glow discharge

dark discharge

background

saturation

corona

non-thermal

thermal
Slow motion video of lightning

© Tom A. Warner
ztresearch.com
field homogeneity

inhomogeneous field (point-to-plane) .................. Case A
homogeneous field (plane-to-plane) ................. ....Case B
approximately homogeneous field

- when the radius of curvature of the conductive parts is equal or greater than 20% of the associated clearance.
breakdown voltage \( (U_b) \) is frequency-dependent.

\( U_b \) degrades at 900 kHz, i.e., critical frequency.

worst-case scenario at 2.5 MHz, i.e., \( f_{(\text{min})} \)

\(~80\%\) retention rate

little effect on small clearances.
inhomogeneous field distribution

- the corona discharge phenomenon in inhomogeneous fields (point-to-plane) is much more intense than homogeneous (plane-to-plane) that can be observed by naked eye.
- the worst-case $U_b$ is about 50% of that at power frequency.
electrical breakdown in gases, i.e., clearances typically takes more than 100 μs to develop.

- **power frequency (10 ms):**
  - a.c. (peak) and d.c. are virtually identical (98.77%).

- **high frequencies (16.7 μs):**
  - insufficient time to constitute complete breakdown.
if the clearances are large or at high frequencies, the ions might get trapped, resulting in the gradient distortion and consequent field strength weakening.
figure C.3 — breakdown at high frequency, solid insulation; \( d = 0.75 \) mm; comparison on short-time breakdown field strength \( E_b \):  

- 50/60 Hz = 1  
- 1 MHz = 0.66  
- 100 MHz = 0.013  

The bottom has not yet been reached!?
solid insulation

• compared to air insulation, solid insulation provides at least a ten-fold increase in electric strength.

• however, in practice, a PD can occur in embedded voids or air gaps in solid dielectrics at a PD-inception voltage far below its breakdown voltage, reducing its voltage withstand ability, and likely resulting in the complete destruction of most solid dielectrics.
modeling a gas-filled void

\[ C = \varepsilon_r \varepsilon_0 \frac{A}{d} \]

- \( \varepsilon_r (\text{air}) = 1.0006; \)
- \( \varepsilon_r (\text{PC, polycarbonate}) = 2.3; \)
- \( \varepsilon_r (\text{FR-4}) = 4.4; \)

\( C_{(\text{remainder})} \gg C_{(\text{void})} \)

\( C_{(\text{void})} \gg C_{(\text{series})} \)

for any dielectric of the same size:

\[ V_{(\text{void})} = \varepsilon_r \cdot V_{(\text{dielectric})} \]

\[ V_{(\text{void})} = V \frac{C_{(\text{series})}}{C_{(\text{series})} + C_{(\text{void})}} = V \frac{1}{1 + \frac{1}{\varepsilon_r} \left( \frac{d}{t} - 1 \right)} \]
void-to-tree transition
Vicious Circle

1. Change in Parameters
2. Partial Discharge
3. Insulation Damage
4. Change in Dielectric Properties

The cycle starts with an initial change in parameters, leading to partial discharge, which then causes insulation damage. This damage further changes the dielectric properties, completing the cycle.
CREEPAGE DISTANCES
the experiment
Figure B.3 — Breakdown Voltage ($U_b$)

$U_b$ is less relevant to frequency factor

larger creepage distances do not add to the breakdown voltage, $U_b$
<table>
<thead>
<tr>
<th>Voltage $U_{\text{peak}}$ (kV)</th>
<th>Creepage distance $d$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>for $30 , \text{kHz} &lt; f \leq 100 , \text{kHz}$</td>
</tr>
<tr>
<td>0,1</td>
<td>0,167</td>
</tr>
<tr>
<td>0,2</td>
<td>0,042</td>
</tr>
<tr>
<td>0,3</td>
<td>0,083</td>
</tr>
<tr>
<td>0,4</td>
<td>0,125</td>
</tr>
<tr>
<td>0,5</td>
<td>0,183</td>
</tr>
<tr>
<td>0,6</td>
<td>0,267</td>
</tr>
<tr>
<td>0,7</td>
<td>0,358</td>
</tr>
<tr>
<td>0,8</td>
<td>0,45</td>
</tr>
<tr>
<td>0,9</td>
<td>0,525</td>
</tr>
<tr>
<td>1</td>
<td>0,60</td>
</tr>
<tr>
<td>1,1</td>
<td>0,683</td>
</tr>
<tr>
<td>1,2</td>
<td>0,85</td>
</tr>
<tr>
<td>1,3</td>
<td>1,20</td>
</tr>
<tr>
<td>1,4</td>
<td>1,65</td>
</tr>
<tr>
<td>1,5</td>
<td>2,30</td>
</tr>
<tr>
<td>1,6</td>
<td>3,15</td>
</tr>
<tr>
<td>1,7</td>
<td>4,40</td>
</tr>
<tr>
<td>1,8</td>
<td>6,10</td>
</tr>
</tbody>
</table>

**Larger Creepage Distances**

---

*Note: Additional information not included in this table.*
surface breakdown, i.e., creepage distances

unlike clearances, creepage distances and solid insulation are **NOT** replenishable — permanent damage such as puncture or carbonized tracking, is likely.

- in this sense, clearances are less vulnerable to PD.
please humor me while I speculate...

what does it mean by saying “creepage distances must be equal to or greater than clearances?”

geometry?

however, from this aspect it is difficult to understand what is the relationship between CL and CR.
I would say when we’re talking about the creepage distances we have to keep in mind that we’re talking about clearances as well.
how creepage distances and clearances interact with each other?
Change in Parameters → Partial Discharge → Insulation Damage → Change in Dielectric Properties → Change in Parameters
謝謝大家的時間！