Dielectric Response Measurements Using DC Voltage

Jean-François DRAPEAU
Researcher
Expertise Équipement électriques
IREQ

ICC Spring 2011 - St Pete
Education Session

2011-05-25
OUTLINE

- Introduction
- DC charging & discharging current components
- DC Leakage Current Measurement Technique
- Converting DC current values to loss spectral data - Hamon approximation
- Time Domain Spectroscopy
- VLF Hamon Approximation Method
INTRODUCTION

- It is possible to perform cable system diagnostic using DC supply sequences
- Diagnostic information will come from the measured current
- 3 methods:
  - DC leakage current measurement
  - Time Domain Spectroscopy (TDS)
  - VLF Hamon approximation
Charging current in a dielectric has 3 components:

\[ i_{pol}(t) = i_{cap}(t) + i_{abs}(t) + i_{qc}(t) \]

1. **Capacitive charging current**
   \[ i_{cap} = \varepsilon_\infty C_0 U_0 \delta(t) = K_1 e^{-t/\tau} \]

2. **Absorption (or Polarization) current**
   \[ i_{abs} = C_0 U_0 f(t) = K_2 t^{-n} \quad --> \text{associated to dielectric loss} \]

3. **Quasi-conduction (or Conduction) current**
   \[ i_{qc} = \frac{\sigma}{\varepsilon_0} C_0 U_0 = \text{constant value} \quad --> \text{associated to local weakness or defect} \]

Diagnostic issues:

- *Constant* value
- *Local weakness* or defect
DC CHARGING & DISCHARGING CURRENT COMPONENTS

Charging current in a dielectric has 3 components:

Linear Graph

\[ I_{\text{total}} = I_{\text{cap}} + I_{\text{abs}} + I_{\text{qc}} \]

\[ I_{\text{cap}} = K \cdot e^{-t/\tau} \approx I_{\text{tot}} \]

\[ I_{\text{abs}} = A \cdot t^{-n} \]
Charging current in a dielectric has 3 components:

Log-Log Graph

\[ I_{\text{total}} = I_{\text{cap}} + I_{\text{abs}} + I_{\text{qc}} \]

\[ I_{\text{cap}} = K_1 e^{t/\tau} \]

\[ I_{\text{abs}} = A t^{-n} \]

\[ I_{\text{qc}} = \text{constant} \]
**DC CHARGING & DISCHARGING CURRENT COMPONENTS**

**Charging current vs discharging current:**

\[ i_{pol}(t) = i_{cap}(t) + i_{abs}(t) + i_{qc}(t) \]

\[ i_{dépol}(t) = -i_{cap}(t) - i_{abs}(t) \]

--> For the discharging current, since the test sample is not energized anymore, the "quasi-conduction" (or conduction) component is absent.
DC LEAKAGE CURRENT MEASUREMENT

TECHNIQUE

METHOD

DC Leakage Current Measurement
Voltage Application Protocol

About 2 X peak value of rated line-to-ground voltage
DC Leakage Current Measurement Technique

**Method**

- DC current is measured during each step and during the hold phase

- Interpretation guide:

<table>
<thead>
<tr>
<th>Observed Characteristic</th>
<th>Judgment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leakage Current changes with time during test</td>
<td>No signs of deterioration: Current tends to decrease.</td>
</tr>
<tr>
<td>Rate of Change of current changes during test</td>
<td>Middle signs of deterioration: Current tends to decrease.</td>
</tr>
<tr>
<td>Leakage Current (relative to reference cable)</td>
<td>Marked signs of deterioration: Current tends to increase.</td>
</tr>
</tbody>
</table>

Ref.: CDFI Phase 1 Final Report, Neetrac
Hamon approximation:

- This is a "point-to-point" transformation
- For each current value acquisition $i_{pol}(t)$ taken at time $t$, we can use the formula:

$$tg \delta (f) = \frac{i(t) \times t}{0.63 \times C' \times U_0}$$

where $f = 0.1 / t$

$C'$ = capacitance
$U_0$ = voltage
TIME DOMAIN SPECTROSCOPY (TDS)

TDS principle for measuring dielectric loss

- The charging (polarization) current is measured during the application of a DC voltage step.
- The discharging (depolarization) current is measured when the DC supply is turned off, and the sample is grounded.
- These two currents can be converted into two dielectric loss components, using the Hamon approximation.

\[
\tan \delta \approx \frac{i x t}{0.628 x V x C}
\]

DC charge-discharge sequence
TIME DOMAIN SPECTROSCOPY (TDS)

IREQ's TDS system

<table>
<thead>
<tr>
<th>CONFIGURATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grounded</td>
</tr>
<tr>
<td>Pol</td>
</tr>
<tr>
<td>Multimeter</td>
</tr>
<tr>
<td>Sensitivity</td>
</tr>
<tr>
<td>$-10 \times 10^{-3}$ A</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EXPERIMENTAL PROCEDURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC Voltage</td>
</tr>
<tr>
<td>kV</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>$V_1 - V_2 - V_3$</td>
</tr>
</tbody>
</table>
TIME DOMAIN SPECTROSCOPY (TDS)

TDS principle for measuring dielectric loss

- Example of current measurement

![Graph showing TDS measurement](image_url)
TIME DOMAIN SPECTROSCOPY (TDS)

TDS principle for measuring dielectric loss

- Application of the Hamon approximation
In this case, the Hamon approximation is used for a situation where the test sample is energized with a VLF Cosine Rectangular wave:

VLF HAMON APPROXIMATION METHOD

Picture of the system:

Observations:

- Provides dielectric loss in polarization regime only
- Voltage steps correspond to $2 \times V_{\text{max}}$
- The upper bound of available $\tan \delta$ spectrum is set by the charging time of 0.3s
  
  \[
  \text{VLF}(0.1\text{Hz}) \quad \rightarrow \quad f_{\text{max}} = 0.33 \text{ Hz}
  \]

- The lower bound of available $\tan \delta$ spectrum is function of the VLF frequency:
  
  \[
  \begin{align*}
  \text{VLF}(0.1\text{Hz}) \quad &\rightarrow \quad f_{\text{min}} = 0.02 \text{ Hz} \\
  \text{VLF}(0.01\text{Hz}) \quad &\rightarrow \quad f_{\text{min}} = 0.002 \text{ Hz}
  \end{align*}
  \]
Thank you for your attention!