On-line Insulation condition monitoring of End-point Bonding cables

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INTRODUCTIONS
The increasing use of cables in power systems has been driven by the growing importance of electrical cables. The unpredictability of cable faults has led to sudden blackouts and increased pressure on utility companies. Therefore, the on-line insulation condition monitoring has become an urgent need for utilities. This work presents a new solution to achieve this goal based on power disturbances, in contrast to the status that a reliable online program that has not yet appeared.

CHALLENGES
From a conventional view, the preferred on-line method will be to translate the mature off-line method — Very-low Frequency Tanδ Measurement to on-line. However, there are too many practical obstacles when apply it on-line, including:

- Additional very-low frequency source will bring an unexpected interference to power systems;
- GPS synchronization with very high precision is essential but unachievable and costly.

This demand roots in the running condition of power cables, in contrast to the test condition of open circuit under off-line experiments.

NEW SOLUTION BASED ON POWER DISTURBANCES

Power disturbances

- Natural and frequent in power systems
- The magnitudes and distortions are distinct
- Abundant information in the transient waveform

Basic idea
The on-line insulation condition monitoring is implemented by analyzing the change trend of insulation parameters. The insulation parameters are estimated from the transients under each power disturbance event. The key part is the design of estimation model.

Design of estimation model

\[ J(c_r) = \left( \frac{z_s + z_c(e^{j2\pi f} + 1) + R_p(e^{j2\pi f} - 1) + Z_{load}(e^{j2\pi f} - 1)}{z_c(e^{j2\pi f} + 1) + R_p(e^{j2\pi f} - 1) + Z_{load}e^{j2\pi f}} \right) - \left( \frac{I_1(f)}{I_2(f)} \right) \]

In this model, \( z_s \) and \( z_c \) are impedance per unit of cable core and sheath, respectively; \( R_p \) is the grounding resistance; \( f \) is the variable containing the insulation parameters \( c_r \) (relative complex permittivity).

The principle of the design of estimation model is making full use of amplitude spectrum. By this way, the power disturbances can be utilized to realize the monitoring with less hardware requirements, which benefit the on-line application. This estimation model is established on the analysis of cable model. A frequency-dependent distribution cable model is adopt, and the cable parameters as shown in the equation have the frequency dependent characters.

ADVANTAGES FOR ON-LINE APPLICATION

- No additional interference to systems
- No need of GPS synchronization & phase angle
- Achievable monitor device — PQM

SIMULATION VERIFICATION

- the transient waveforms and amplitude spectrums:

To validate the advantage of the proposed method that no need of signal GPS synchronization, an intentional time-delay (5ms) is set between the sampling Window 1 and Window 2, the insulation parameters estimated by the proposed method is:

Estimation error

<table>
<thead>
<tr>
<th>Cable conditions</th>
<th>Power disturbances</th>
<th>Estimation error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacitor switching</td>
<td>1.16%</td>
<td>1.24%</td>
</tr>
<tr>
<td>No-load line switching</td>
<td>0.62%</td>
<td>0.85%</td>
</tr>
<tr>
<td>Grounding fault</td>
<td>0.54%</td>
<td>0.05%</td>
</tr>
<tr>
<td>Little aging</td>
<td>0.05%</td>
<td>0.07%</td>
</tr>
<tr>
<td>Aging</td>
<td>0.05%</td>
<td>0.07%</td>
</tr>
</tbody>
</table>

CONCLUSIONS

A new application of power disturbances is explored to diagnose the insulation condition of end-point bonding cables on-line. The method is developed in frequency domain, which utilizes amplitude spectrums of the transients from PQM to estimate the insulation parameters. This method can do not rely on GPS synchronization and has no interface to power systems. The effectiveness of the proposed method is verified through a 5ms delay between two GPS devices. The estimation results, available measure requirements, and widely installed PQM all exhibit the prospect of on-line application of the proposed method in the future smart grid.