Development of 100 kV AC High Voltage Measurement System

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Background

NIMT has only one national AC high voltage measurement system. This system has been sent periodically for calibration to make an international traceability.

- The systematic verification of AC high voltage measurement system cannot be performed.

- The calibration service for customers has been delayed during the external calibration period.

Additional 100 kV AC high voltage measurement system
Content

Background
High Voltage Measurement
Metrological Traceability
Design
Fabrication
Evaluation
Conclusion
High Voltage Measurement

Measuring System (MS) is used to perform high voltage measurement. It consists of:
1. a converting device
2. a transmission system and
3. a measuring instrument

\[ \frac{V_{LV}}{V_{HV}} = \frac{C_{HV}}{C_{LV} + C_{HV}} \]

Scale Factor

\[ \text{Scale Factor} = \frac{C_{LV} + C_{HV}}{C_{HV}} = 1 + \left( \frac{C_{LV}}{C_{HV}} \right) \]
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Metrological Traceability (at low voltage)

High Voltage ($V_{HV}$)

$V_{LV}/V_{HV} = C_{HV}/(C_{LV} + C_{HV})$

Scale Factor = $(C_{LV} + C_{HV})/C_{HV}$

= $1 + (C_{LV}/C_{HV})$

*without effect of a measuring cable, DVM

HV-side capacitors ($C_{HV}$)

LV-side capacitor ($C_{LV}$)

Low voltage measurement (Capacitor, DVM)
Due to Voltage Dependence of capacitors, Stray capacitance etc.

- **Inter-comparison**
- **Calibration (Comparison Measurement)**
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Design

(1) Rated Voltage = 100 kV
   ► National Standard, and UUCs

(2) Type = Capacitive Voltage Divider
   ► Practical application for AC High Voltage measurement

(3) Construction = Serial-connected Capacitor design
   ► Simplicity, and Cost

(4) HV-side capacitor = total 400 pF
   ► Effect of Stray Capacitance

(5) Nominal Scale Factor = 1000 :1
   ► Dynamic Range of voltage to be measured

(6) Digital multi-meter = 6 ½ digit multi-meter
   ► Measurement uncertainty less than 0.5%
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Fabrication (Low Voltage – Side)

► 4 of 0.1 pF are parallel-connected  
(Total = 0.4 μF)

► Spark gap for protection against breakdown
Fabrication (High Voltage – Side)

- 250 of 0.1 pF are serial-connected (Total = 400 pF)
  - VISHAY MKP 1845: 0.1 pF (700 Vac)
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Comparison measurement (Calibration)

High voltage is applied to both, the reference measuring system and the unit under calibration (UUC), while the output of both measuring system are simultaneously measured and compared to scale factor of the UUC.

\[
\text{Scale Factor}_{\text{UUC}} = \text{Scale Factor}_{\text{Standard}} \times \left( \frac{V_s}{V_x} \right)
\]
Scale Factor

### Table

<table>
<thead>
<tr>
<th>Applied Voltage (kV)</th>
<th>Scale Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1018.0</td>
</tr>
<tr>
<td>20</td>
<td>1018.1</td>
</tr>
<tr>
<td>30</td>
<td>1018.2</td>
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<tr>
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<tr>
<td>90</td>
<td>1018.2</td>
</tr>
<tr>
<td>100</td>
<td>1018.0</td>
</tr>
</tbody>
</table>

1010 (Calculated value)
# Linearity

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<th>Applied Voltage (kV)</th>
<th>Scale Factor</th>
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</thead>
<tbody>
<tr>
<td>10</td>
<td>1018.0</td>
</tr>
<tr>
<td>20</td>
<td>1018.1</td>
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<tr>
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<tr>
<td>90</td>
<td>1018.2</td>
</tr>
<tr>
<td>100</td>
<td>1018.0</td>
</tr>
<tr>
<td>average</td>
<td>1018.1</td>
</tr>
</tbody>
</table>

Standard Deviation/Average = 0.011 %
Stability

- Short-term stability (15 minutes) = 0.02 %
- Long-term stability (1-month) = 0.03 %
Temperature Dependence

Temperature Coefficient of Scale Factor ($\alpha_{\text{Scale Factor}}$) can be calculated from

$$\alpha_{\text{Scale Factor}} = \alpha_{\text{LV}} - \alpha_{\text{HV}}$$

where

Temperature Coefficient of low voltage – side capacitors ($\alpha_{\text{LV}}$), and
Temperature Coefficient of low voltage – side capacitors ($\alpha_{\text{HV}}$)
(246 ppm/°C and 235 ppm/°C respectively)

Hence,
Temperature Coefficient of Scale Factor = 11 ppm/°C
Proximity Effect

Max – Min = 0.5
= 0.05 %

100 kV high voltage source
# Uncertainty Budget

<table>
<thead>
<tr>
<th>Source of Uncertainty ((k = 1))</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncertainty from Standard</td>
<td>0.150</td>
</tr>
<tr>
<td>Uncertainty from Long-term stability of Standard</td>
<td>0.020</td>
</tr>
<tr>
<td>Uncertainty from Temperature of Standard</td>
<td>0.001</td>
</tr>
<tr>
<td>Uncertainty from Linearity of UUC</td>
<td>0.011</td>
</tr>
<tr>
<td>Uncertainty from Short-term stability of UUC</td>
<td>0.012</td>
</tr>
<tr>
<td>Uncertainty from Resolution of UUC</td>
<td>0.001</td>
</tr>
<tr>
<td>Uncertainty from Proximity Effect of UUC</td>
<td>0.029</td>
</tr>
<tr>
<td>Uncertainty from Repeatability of UUC</td>
<td>0.010</td>
</tr>
</tbody>
</table>

| Expanded Uncertainty \((k = 2)\)                               | 0.32 |
The 100 kV AC high voltage measurement system consists of a capacitive voltage divider with a 6 ½ digit multi-meter. 250 capacitor are serial-connected to form a high voltage arm of 400 pF. The low voltage arm consists of 4 of 0.1 pF connected in parallel. The calculated scale factor is 1010.

The fabricated measurement system was characterized by a comparison measurement. The scale factor is 1018, which agrees well with the calculated value. The measurement system was evaluated according to IEC 60060-2:2010 standard. The expanded uncertainty of 0.32 % was obtained.
Thank you for your attention
Stability

Scale Factor

0.5% / 4 Years

Time


1010.0
1011.0
1012.0
1013.0
1014.0
1015.0
1016.0
1017.0
1018.0
1019.0
1020.0