Measurement of High Voltage

Principles

High voltage can be measured in a variety of ways. Direct measurement of high voltage is possible up to about 200kV and several forms of voltmeters have been devised which can be connected directly across the test circuit. The spark over of sphere gaps and other gaps also are used especially in the calibration of meters in high voltage measurements.

Direct measurement of High Voltages

- Electrostatic voltmeters.
- Sphere gaps.

Measurement with sphere gaps

The sphere gap method of measuring high voltage is one of the most reliable methods and it is used as the standard method for calibration purposes.

In fact this method is used due to below reasons:

- Structure is easy.
- Accuracy is high enough.

In the measuring device, two metal spheres are used which are separated by a gas-gap. The potential difference between the spheres is increased until a spark passes between them. Whenever the spark is occurred, measured voltage is maximum voltage (Um). The breakdown strength depends on dimension of the spheres, electrode separation and a number of other factors.

\[ d \leq \frac{D}{2} \pm \%3 \]

- \( d \): electrode separation
- \( D \): spheres diameter
By precise experiments the breakdown voltage variation with gap spacing for different diameters and distances, have been calculated and represented in specific table (attached table). Electric potential, or voltage, is easily measured. This phenomenon can be used to map an electric field.

Standard sphere diameter (cm): 2-5-6.25-10-12.5-15-25-50-75-100-150-200

\[ D[mm] \geq U_{\text{max}}[kV] \]

For example: 130kV vs 13cm
But it is not standard electrode so 25cm should be used instead of it

Factors effecting measurement with sphere gaps

1. Structure of spheres (metal-good conductor-should stand applied voltage)
2. Surface of spheres should be clean and smooth (no dust and polish)
3. Electrode separation (d) should be adjustable with ±2% accuracy
4. Sphere configuration

5. Polarity of applied voltage

Horizontal

\[ 0.2D \geq d \text{ positive half cycle} \]

\[ 0.2D < d \text{ negative half cycle} \]

Vertical
6. Voltage frequency

![Diagram of voltage frequency]

\[ Xc = \frac{1}{j\omega Cs} = \frac{1}{j2\pi fCs} \]

7. Objects around spheres

![Diagram of objects around spheres]

\[ r = 7D - 4D \]

Not to distort field distance

8. Series damping resistor

![Diagram of series damping resistor]

\[ I_s = \frac{U}{Xc} \]

9. Ambient conditions (temperature & pressure)

The breakdown voltages are presented in a chart with respect to electrode gap under standard conditions (760mmHg at 20˚c) therefore the measured breakdown voltage should be corrected according to experiment conditions.

\[ \delta = \frac{p[mmHg] \times [273 + 20]}{760[mmHg] \times [273 + t˚c]} \]

\[ \delta: \text{the air density correction factor} \]

\[ 1\text{mmHg} = 133.322\text{Pa} \quad \text{&} \quad 1\text{bar} = 10^5\text{Pa} \]

\[ U_b = \delta \times U_r \]

\[ U_b: \text{Breakdown voltage during exp.} \]

\[ U_r: \text{standard table} \]
- Boundary condition of $\delta$:

$$\begin{align*}
\text{If } 0.95 < \delta < 1.05 & \quad \Rightarrow \quad \delta = \delta \\
\text{If } 0.95 > \delta \text{ or } 1.05 < \delta & \quad \Rightarrow \quad \delta = f(\delta)
\end{align*}$$

This means that $f(\delta)$ should be used instead of $\delta$ in above equation.

<table>
<thead>
<tr>
<th>$\delta$</th>
<th>0.7</th>
<th>0.75</th>
<th>0.8</th>
<th>0.85</th>
<th>0.9</th>
<th>1</th>
<th>1.1</th>
<th>1.15</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f(\delta)$</td>
<td>0.72</td>
<td>0.77</td>
<td>0.82</td>
<td>0.86</td>
<td>0.91</td>
<td>1</td>
<td>1.09</td>
<td>1.13</td>
</tr>
</tbody>
</table>

10. Humidity
   Humidity has an effect on breakdown voltage.

$$U_b = \frac{\delta}{k} \cdot U_n$$

from the chart

11. Ultraviolet lighting

Ionization creates a least resistance path for the flashover.

Experiment

1. $d$ (electrode gap) is constant and $U$ (applied voltage) is variable.
2. $U$ (applied voltage) is constant and $d$ (electrode gap) is variable.

Each time there is a breakdown, the circuit is closed and the experiment should start over.

In this experiment, we will measure flashover voltages for fixed electrode gaps. First; set the electrode gap to 2 cm, increase the voltage level until you here the breakdown. Repeat the experiment for the same conditions 5 times. Record the readings from the primary voltmeter and secondary voltmeter.

Do this experiment for $d = 2.0; 2.5; 3; 3.5$. 
Questions

1. Determine the flashover average voltages; give breakdown voltage for each electrode gap by using the chart.
   a. Assuming the secondary voltmeter is correct; determine the absolute and relative errors in sphere gap measurement.
   b. Assuming the sphere gap measurement is correct; determine the absolute and relative errors in secondary voltmeter measurement.
   c. The test transformer is 220 V/100000 V. Using this turns ratio and primary voltmeter readings, determine the flashover voltages. Assuming turns ratio is correct; determine the absolute and relative errors in sphere gap measurement.

2. It is needed to apply 70 kV (effective) to a high voltage support insulator in order to determine insulator’s withstand characteristics. Under the same ambient conditions as the question 1, determine the electrode separation and the voltage to be applied from the primary side of transformer in order to apply 70 kV (effective) to insulator.