Sample Calculations for Measurement Uncertainty in Electrical Testing
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1. INTRODUCTION

In the broad field of Electrical Engineering, various equipment and systems are used to cater to the application for Electrical power generation, transmission, distribution, control, instrumentation, Communication and domestic application. Each one of the products/equipment requires a wide variety of tests and hence a need of specialized testing facility.

The field of Electrical Testing covers tests of an essentially electrical nature performed on instruments, equipment, appliances, components and materials.

As per the requirements of clause 7.6 of ISO/IEC 17025: 2017, the testing laboratories are required to evaluate the Measurement Uncertainty.

When estimating the Measurement Uncertainty, all uncertainty components which are of importance in the given situation shall be taken into account, which shall include but not be limited to:

a. reference standards and reference materials with reported uncertainty in the calibration certificate(s)

b. method employed

c. equipment used with reported uncertainty in the calibration certificate(s)

d. environmental conditions

e. properties and condition of the item being tested

The testing laboratories shall identify all the components of uncertainty and make a reasonable estimation for all test parameters, and shall ensure that the form of reporting of the result does not give a wrong impression of the uncertainty. The degree of rigor needed in an estimation of Measurement Uncertainty depends on the requirements of test method, requirements of client and the existence of narrow limits on which decisions on conformance to a specification are based.

All laboratories will calculate the uncertainty of measurement at 95% confidence level.
2. **SCOPE**

As per the requirements of clause 7.6 of ISO/IEC 17025: 2017, the testing laboratories are required to evaluate the Measurement Uncertainty. This document guides the laboratory to evaluate the Measurement Uncertainty for Electrical Testing.

A few examples of Measurement Uncertainty in the field of Electrical Testing have been illustrated in this document.
Sample 1

UNCERTAINTY CALCULATION FOR VOLTAGE (at Power frequency)

Product : MCB, 32 A, 240/415V, Single pole
Test : Short circuit test of MCB
Equipment used : Digitizer with Amplifier
Range used for calibration : 62.5 - 1000 Volt
Accuracy : 0.16 % of Reading
Uncertainty of Digitizer with Amplifier from its calibration certificate : 0.281 %
Resolution : 0.0001 Volt

<table>
<thead>
<tr>
<th>Reading No.</th>
<th>Voltage (Volts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>250.2</td>
</tr>
<tr>
<td>2</td>
<td>250.3</td>
</tr>
<tr>
<td>3</td>
<td>250.1</td>
</tr>
<tr>
<td>4</td>
<td>250.2</td>
</tr>
<tr>
<td>5</td>
<td>250.3</td>
</tr>
</tbody>
</table>

Assuming contribution due to frequency is negligible

Type A Evaluation

Mean Rdg. (Volts) = \( \frac{R_1+R_2+R_3+R_4+R_5}{5} \) = 250.22 Volts
Standard deviation = 0.0836 Volts
Std. uncertainty \( U_r \) = 0.0374 Volts Standard Deviation/\( \sqrt{5} \)
Degree of freedom = \( V_1 = 5-1 = 4 \)
Std. uncertainty (% \( U_r \)) = 0.0149 % \( U_r \ast 100/ \text{Mean Reading} \)
Type B Evaluation

1. Uncertainty of Digitizer with Amplifier from its calibration certificate. The distribution is normal and the coverage factor for approximately 95% confidence level is 2

\[ U_1(\%) = \frac{A_1}{2} = \frac{0.281}{2} = 0.141 \% \]

\[ U_1 = 0.141 \times 250.22 \times 0.01 = 0.352 \text{ Volts} \]

Estimate = \[ 0.281 \times 250.22 \times 0.01 = 0.703 \text{ Volts} \]

Degree of freedom \( V_2 = \infty \)

2. Accuracy of Digitizer with Amplifier

\[ A_2 = 0.16 \% \text{ of reading} = 0.16 \times 250.22 \times 0.01 = 0.400 \text{ Volts} = \text{Estimate} \]

For rectangular distribution, the standard uncertainty \( U_2 = \frac{A_2}{\sqrt{3}} \)

\[ U_2 = 0.231 \text{ Volts} \]

\[ \% U_2 = 0.0924 \% \quad U_2 \times 100/ \text{Mean Reading} \]

Degree of freedom \( V_3 = \infty \)

3. Uncertainty due to resolution of display unit = \( U_3 \)

\[ A_3 = \frac{0.0001}{2} = 0.00005 \text{ Volts} = \text{Estimate} \]

For rectangular distribution, the standard uncertainty = \( U_3 = \frac{A_3}{\sqrt{3}} \)

\[ U_3 = 0.000028 \text{ Volts} \]

\[ \% U_3 = 0.0000115 \% \quad U_3 \times 100/ \text{Mean Reading} \]

Degree of freedom \( V_4 = \infty \)
Combined standard uncertainty ($U_c$)

\[ U_c = \sqrt{U_1^2 + U_2^2 + U_3^2 + U_4^2 + U_5^2} \]

$U_c = 0.423$ Volts

% $U_c = 0.169\% \quad U_c \times 100/\text{Mean Reading}$

Effective degrees of freedom ($v_{eff}$) =

\[ v_{eff} = \frac{(U_c)^4}{(U_1)^4 + (U_2)^4 + (U_3)^4 + (U_4)^4} \]

\[ \frac{(0.169)^4}{(0.0149)^4 + (0.141)^4 + (0.0924)^4 + (0.0000115)^4} \]

\[ v_{eff} = \frac{(0.169)^4}{(0.0149)^4} \]

\[ v_{eff} = \infty \]

Expanded Uncertainty at approximately 95% level of confidence, the coverage factor $k=2$, Thus

$U = k \times U_c = 2 \times 0.423$ Volts

$U = 0.85$ Volts

% $U = 0.34\% \quad U \times 100/\text{Mean Reading}$
### Uncertainty Budget

<table>
<thead>
<tr>
<th>Source of Uncertainty Xi</th>
<th>Estimates xi</th>
<th>Limits %</th>
<th>Probability Distribution Type A or B Factor</th>
<th>Standard Uncertainty (Volts)</th>
<th>Sensitivity Coefficient Cl</th>
<th>Uncertainty Contribution Ui (y)</th>
<th>Degree of freedom Vi</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
<tr>
<td>$U_1$</td>
<td>0.281</td>
<td></td>
<td>Normal type B – k=2</td>
<td>0.352</td>
<td>0.141</td>
<td>0.352</td>
<td>0.141</td>
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<tr>
<td>$U_2$</td>
<td>0.16</td>
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<td>Rectangular Type B sqrt(3)</td>
<td>0.231</td>
<td>0.0924</td>
<td>0.231</td>
<td>0.0924</td>
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<tr>
<td>$U_3$</td>
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<td>19</td>
<td>Rectangular Type B sqrt(3)</td>
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<td>0.0000115</td>
<td>0.000028</td>
<td>0.0000115</td>
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</tr>
<tr>
<td>Repeatability ($U_r$)</td>
<td>250.22</td>
<td>--</td>
<td>Normal Type A</td>
<td>0.0374</td>
<td>0.0149</td>
<td>0.0374</td>
<td>0.0149</td>
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<td></td>
</tr>
<tr>
<td>$U_c$</td>
<td></td>
<td></td>
<td></td>
<td>0.423</td>
<td>0.169</td>
<td>0.423</td>
<td>0.169</td>
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<tr>
<td>Expanded Uncertainty (U)</td>
<td></td>
<td></td>
<td></td>
<td>$k = 2$</td>
<td></td>
<td>0.85</td>
<td>0.34</td>
</tr>
</tbody>
</table>

### Reporting of results:

Voltage = 250.22 Volts ± 0.85 Volts
Sample 2

UNCERTAINTY CALCULATION FOR CURRENT (at power frequency)

Product : MCCB, 800 A, 415V, Four pole
Test : Short circuit test of MCCB
Equipment used :

1) Digitizer with Amplifier
Range used for calibration : 0.625 – 10 Volts
Accuracy : 0.19 % of Reading
Uncertainty of Digitizer with Amplifier from its calibration certificate : 0.281 %
Resolution : 0.0001 V

2) Shunt
Uncertainty of shunt (%) from its calibration certificate : 1.156

<table>
<thead>
<tr>
<th>Reading No.</th>
<th>Current (kAmp.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50.26</td>
</tr>
<tr>
<td>2</td>
<td>50.23</td>
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<tr>
<td>3</td>
<td>50.28</td>
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<tr>
<td>4</td>
<td>50.24</td>
</tr>
<tr>
<td>5</td>
<td>50.23</td>
</tr>
</tbody>
</table>

Assuming contribution due to frequency is negligible

Type A Evaluation
Mean Rdg. (kAmp.) = 50.248 (kAmp.) \( \frac{(R1+R2+R3+R4+R5)}{5} \)
Standard deviation = 0.0216 (kAmp.)
Std. uncertainty \( U_r \) = 0.00969 (kAmp.) Standard Deviation/ \( \sqrt{5} \)
Degree of freedom = \( V_1 = 5-1 = 4 \)
Std. uncertainty (% \( U_r \)) = 0.0193 % \( U_r \times 100/ \text{Mean Reading} \)
Type B Evaluation

1. Uncertainty of Digitizer with Amplifier from its calibration certificate. The distribution is normal and the coverage factor at approximately 95% confidence level is 2

\[ U_1(\%) = \frac{A_1}{2} = \frac{0.281}{2} = 0.141\% \]
\[ U_1 = 0.141 \times 50.248 \times 0.01 = 0.0708 \text{ kAmp.} \]

Estimate = 0.281 \times 50.248 \times 0.01 = 0.1412 \text{ kAmp.}

Degree of freedom \( V_2 = \infty \)

2. Digitizer with Amplifier Accuracy

\[ A_2 = 0.19\% \text{ of reading} = 0.19 \times 50.248 \times 0.01 = 0.09547 \text{ kAmp.} = \text{Estimate} \]

For rectangular distribution, the standard uncertainty = \( U_2 = \frac{A_2}{\sqrt{3}} \)

\[ U_2 = 0.0551 \text{ kAmp.} \]

\% \( U_2 = 0.109\% \)

\[ U_2 \times 100/ \text{Mean Reading} \]

Degree of freedom \( V_3 = \infty \)

3. Uncertainty due to resolution of display unit = \( U_3 \)

\[ A_3 = 0.0001/2 = 0.00005 \text{ kAmp.} = \text{Estimate} \]

For rectangular distribution, the standard uncertainty = \( U_3 = \frac{A_3}{\sqrt{3}} \)

\[ U_3 = 0.000028 \text{ kAmp.} \]

\% \( U_3 = 0.000057\% \)

\[ U_3 \times 100/ \text{Mean Reading} \]

Degree of freedom \( V_4 = \infty \)

4. Uncertainty of shunt from its calibration certificate. The distribution is normal and the coverage factor for approximately 95% confidence level is 2.

\[ U_4(\%) = \frac{A_4}{2} = \frac{1.156}{2} = 0.578\% \]
\[ U_4 = 0.578 \times 50.248 \times 0.01 = 0.290 \text{ kAmp.} \]

Estimate = 1.156 \times 50.248 \times 0.01 = 0.580 \text{ kAmp.}

Degree of freedom \( V_5 = \infty \)
Combined standard uncertainty (U_c)

\[ U_c = \sqrt{(U_1^* U_1) + (U_2^* U_2) + (U_3^* U_3) + (U_4^* U_4)} \]

\[ U_c = 0.310 \text{ kAmp.} \]

\[ \% U_c = 0.617 \% \quad U_c * 100/ \text{Mean Reading} \]

Effective degrees of freedom (\nu_eff) =

\[
\nu_{eff} = \frac{(U_1)^4}{V_2} + \frac{(U_2)^4}{V_3} + \frac{(U_3)^4}{V_4} + \frac{(U_4)^4}{V_5} + \frac{(U_r)^4}{V_1}
\]

\[
\nu_{eff} = \frac{(0.617)^4}{(0.0193)^4} + \frac{(0.141)^4}{(0.109)^4} + \frac{(0.109)^4}{(0.000057)^4} + \frac{(0.578)^4}{\infty}
\]

\[
\nu_{eff} = \frac{(0.617)^4}{(0.0193)^4} + 0
\]

\[ \nu_{eff} = 4178028 = \infty \]

Expanded Uncertainty for approximately 95 % level of confidence, the coverage factor k=2, Thus

\[ U = k * U_c = 2 * 0.310 \text{ kAmp.} \]

\[ U = 0.620 \text{ kAmp.} \]

\[ \% U = 1.234 \% \quad U * 100/ \text{Mean Reading} \]
### Uncertainty Budget

<table>
<thead>
<tr>
<th>Source of Uncertainty (X_i)</th>
<th>Estimates (x_i)</th>
<th>Limits (%)</th>
<th>Probability Distribution Type A or B Factor</th>
<th>Standard Uncertainty (Volts)</th>
<th>Sensitivity Coefficient (C_i)</th>
<th>Uncertainty Contribution (U_i(y))</th>
<th>Degree of freedom (V_i)</th>
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<tr>
<td>(U_1)</td>
<td>0.281</td>
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<td>Normal Type B</td>
<td>0.0708</td>
<td>0.141</td>
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<td>0.0708</td>
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<td>(U_2)</td>
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<td>0.0551</td>
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<tr>
<td>(U_3)</td>
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<td>Rectangular Type B sqrt(3)</td>
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<td>0.00057</td>
<td>1.0</td>
<td>0.000028</td>
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<tr>
<td>(U_4)</td>
<td>1.156</td>
<td></td>
<td>Normal Type B</td>
<td>0.2963</td>
<td>0.578</td>
<td>1.0</td>
<td>0.2963</td>
</tr>
<tr>
<td>(U_{\text{Repeatability}}) ((U_r))</td>
<td>50.248</td>
<td>--</td>
<td>Normal Type A</td>
<td>0.00969</td>
<td>0.0193</td>
<td>1.0</td>
<td>0.00969</td>
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<tr>
<td>(U_c)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expanded Uncertainty (U)</td>
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</tr>
</tbody>
</table>

### Reporting of results:

Current = 50.248 kAmp ± 0.620 kAmp.
Sample 3

UNCERTAINTY CALCULATION FOR POWER LOSS IN ENERGY METERS

Product: Static energy meter  
Test: Power loss measurement in Energy Meters  
Equipment used: Digital wattmeter  
Range: 20 Watts  
Accuracy: 0.5 % of Reading  
Uncertainty of watt meter from its calibration certificate: 0.0953 %  
Resolution: 0.01 Watts

<table>
<thead>
<tr>
<th>Reading No.</th>
<th>Power loss (Watt)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
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</tr>
<tr>
<td>2</td>
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<tr>
<td>3</td>
<td>0.68</td>
</tr>
<tr>
<td>4</td>
<td>0.68</td>
</tr>
<tr>
<td>5</td>
<td>0.68</td>
</tr>
</tbody>
</table>

Type A Evaluation

Mean Rdg.(Watt) = 0.678 Watt \((R1+R2+R3+R4+R5)/ 5\)

Standard deviation = 0.0044721 Watt

Std. uncertainty \(U_r\) = 0.002 Watt Standard Deviation/ \(\sqrt{5}\)

Degree of freedom = \(V_1 = 5-1 = 4\)

Std. uncertainty (% \(U_r\)) = 0.295 % \(U_r * 100/ \text{Mean Reading}\)
Type B Evaluation

1. Uncertainty of watt meter from its calibration certificate. The distribution is normal and the coverage factor for approximately 95% confidence level is 2
   \[ U_1(\%) = \frac{A_1}{2} = \frac{0.0953}{2} = 0.04765 \%
   \]
   \[ U_1 = 0.04765 \times 0.678 \times 0.01 = 0.323 \times 10^{-3} \text{ W}
   \]
   Degree of freedom \( V_2 = \infty \)

2. From watt meter specification (Accuracy)
   \[ A_2 = 0.5\% \text{ of reading} = 0.5 \times 0.678 / 100 = 0.00339 \text{ Watt}
   \]
   For rectangular distribution, the standard uncertainty \( = U_2 = A_2 / \sqrt{3} \)
   \[ U_2 = 0.00195 \text{ watt}
   \]
   \[ \% U_2 = 0.2876 \% \quad U_2 \times 100 / \text{Mean Reading}
   \]
   Degree of freedom \( V_3 = \infty \)

3. Uncertainty due to resolution of watt meter = \( U_3 \)
   \[ A_3 = 0.01 / 2 = 0.005 \text{ Watt}
   \]
   For rectangular distribution, the standard uncertainty \( = U_3 = A_3 / \sqrt{3} \)
   \[ U_3 = 0.002886 \text{ Watt}
   \]
   \[ \% U_3 = 0.4257 \% \quad U_3 \times 100 / \text{Mean Reading}
   \]
   Degree of freedom \( V_4 = \infty \)
Combined standard uncertainty ($U_c$)

$$U_c = \sqrt{U_r^2 + (U_1^2) + (U_2^2) + (U_3^2)} = 0.00402$$

$$\% U_c = 0.59 \%$$

Effective degrees of freedom ($\nu_{eff}$) =

$$\nu_{eff} = \frac{(U_c)^4}{(U_r)^4 + (U_1)^4 + (U_2)^4 + (U_3)^4}$$

$$\nu_{eff} = \frac{(0.59)^4}{(0.04765)^4 + (0.2876)^4 + (0.4257)^4 + (0.295)^4}$$

$$\nu_{eff} = 64$$

Expanded Uncertainty for approximately 95% level of confidence, the coverage factor $k=2$, Thus

$$U = k \cdot U_c = 2 \cdot 0.00402 = 0.008 \text{ W}$$

$$\% U = 1.18 \%$$

$U \times 100$/mean Reading
### Uncertainty Budget

<table>
<thead>
<tr>
<th>Source of Uncertainty Xi</th>
<th>Estimates xi</th>
<th>Limits %</th>
<th>Probability Distribution Type A or B Factor</th>
<th>Standard Uncertainty %</th>
<th>Sensitivity Coefficient Ci</th>
<th>Uncertainty Contribution U(y) %</th>
<th>Degree of freedom Vi</th>
</tr>
</thead>
<tbody>
<tr>
<td>U₁</td>
<td>0.0953</td>
<td></td>
<td>Normal type B – 2</td>
<td>0.04765</td>
<td>1.0</td>
<td>0.04765</td>
<td>infinity</td>
</tr>
<tr>
<td>U₂</td>
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<td>Rectangular Type B sqrt(3)</td>
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<td>U₃</td>
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<tr>
<td>Repeatability</td>
<td>0.678 W</td>
<td></td>
<td>Normal Type A</td>
<td>0.295</td>
<td>1.0</td>
<td>0.295</td>
<td>4</td>
</tr>
<tr>
<td>U₅ %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.59</td>
<td>64</td>
</tr>
<tr>
<td>Expanded Uncertainty</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.18</td>
<td>Infinity</td>
</tr>
</tbody>
</table>

### Reporting of results:

Power loss = 0.678 Watt ± 0.008 Watt
Sample 4

UNCERTAINTY CALCULATION FOR TRIPPING CHARACTERISTIC IN MCB

Product : MCB, 4 A
Test : Tripping characteristic at 2.55 ln
Standard used : 1) Digital time interval meter
Range used : 99.99 seconds
Accuracy : 0.5 % of Reading
Uncertainty of time interval meter from its calibration certificate : 0.015 %
Resolution : 0.01 seconds

2) Current transformer (CT)
Range used : 20/ 5 A
Accuracy : 0.2 % of Reading
Uncertainty of time interval meter from its calibration certificate : 0.092 %

3) Digital AC Ammeter
Range used : 0 -10 A
Accuracy : 0.5 % of Reading
Uncertainty of time interval meter from its calibration certificate : 0.0281 %
Resolution : 0.01 A

<table>
<thead>
<tr>
<th>Reading No.</th>
<th>Tripping time in seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18.01</td>
</tr>
<tr>
<td>2</td>
<td>18.26</td>
</tr>
<tr>
<td>3</td>
<td>18.76</td>
</tr>
<tr>
<td>4</td>
<td>18.68</td>
</tr>
<tr>
<td>5</td>
<td>18.16</td>
</tr>
</tbody>
</table>
**Type A Evaluation**

Mean Rdg.(seconds) = 18.374 seconds  
(R1+R2+R3+R4+R5)/ 5  

Standard deviation = 0.329 second  

Std. uncertainty \( U_r \) = 0.147 second  
Standard Deviation/ sqrt(5)  

Degree of freedom = \( V_1 = 5-1 = 4 \)  

Std. uncertainty (% \( U_r \)) = 0.801 %  
\( U_r \)*100/ Mean Reading  

**Type B Evaluation**

1. Uncertainty of time interval meter from its calibration certificate. The distribution is normal and the coverage factor for approximately 95% confidence level is 2  
   \( A_1 \) = 0.015 %  
   \( U_1(\%) \) = \( A_1/ 2= 0.015/ 2 \) = 0.0075 %  
   \( U_1 \) = 0.0075 \* 18.374 \* 0.01 = 0.0014 second  
   Degree of freedom \( V_2 = \) infinity  

2. From time interval Meter specification (Accuracy)  
   \( A_2 \) = 0.5% of reading = 0.5 \* 18.3740 \* 0.01 = 0.092 seconds  
   For rectangular distribution, the standard uncertainty = \( U_2 = A_2/\sqrt{3} \)  
   \( U_2 \) = 0.0531 second  
   \% \( U_2 \) = 0.289 %  
   \( U_2 \)* 100/ Mean Reading  
   Degree of freedom \( V_3 = \) infinity  

3. Uncertainty due to resolution of Meter = \( U_3 \)  
   \( A_3 \) = 0.01/ 2 = 0.005 seconds  
   For rectangular distribution, the standard uncertainty = \( U_3 = A_3/\sqrt{3} \)  
   \( U_3 \) = 0.0029 seconds  
   \% \( U_3 \) = 0.016 %  
   \( U_3 \)* 100/ Mean Reading  
   Degree of freedom \( V_4 = \) infinity
Uncertainty of CT from its calibration certificate. The distribution is normal and the coverage factor for approximately 95% confidence level is 1.96
\[ A_4 \quad = \quad 0.092 \% \]
\[ U_4(\%) \quad = \quad \frac{A_4}{2} \quad = \quad 0.092/2 \quad = \quad 0.046 \% \]
Degree of freedom \( V_5 \) = infinity

From CT specification (Accuracy)
\[ A_5 \quad = \quad 0.2\% \text{ of reading} \]
For rectangular distribution, the standard uncertainty = \[ U_5 = \frac{A_5}{\sqrt{3}} \]
\[ \% U_5 \quad = \quad 0.115 \% \]
Degree of freedom \( V_6 \) = infinity

5. Uncertainty of Ammeter from its calibration certificate. The distribution is normal and the coverage factor for approximately 95% confidence level is 1.96
\[ A_6 \quad = \quad 0.0281 \% \]
\[ U_6(\%) \quad = \quad \frac{A_6}{2} \quad = \quad 0.0281/2 \quad = \quad 0.141 \% \]
Degree of freedom \( V_7 \) = infinity

6. From Ammeter specification (Accuracy)
\[ A_7 \quad = \quad 0.5\% \text{ of reading} \]
For rectangular distribution, the standard uncertainty = \[ U_7 = \frac{A_7}{\sqrt{3}} \]
\[ \% U_7 \quad = \quad 0.289 \% \]
Degree of freedom \( V_8 \) = infinity

7. Uncertainty due to resolution of Meter = U8
\[ A_8 \quad = \quad 0.01/2 \quad = \quad 0.005 \]
For rectangular distribution, the standard uncertainty = \[ U_8 = \frac{A_8}{\sqrt{3}} \]
\[ \% U_8 \quad = \quad 0.005/\sqrt{3} \quad = \quad 0.016 \% \]
Degree of freedom \( V_9 \) = infinity
Combined standard uncertainty = $U_c$

\[
U_c = \sqrt{U_1^2 + U_2^2 + U_3^2 + U_4^2 + U_5^2 + U_6^2 + U_7^2 + U_8^2 + U_9^2}
\]

\[
\% U_c = \frac{U_c}{\text{Mean Reading}} 
\]

Effective degrees of freedom ($v_{eff}$) =

\[
v_{eff} = \frac{(U_c)^4}{(U_1)^4 + (U_2)^4 + (U_3)^4 + (U_4)^4 + (U_5)^4 + (U_6)^4 + (U_7)^4 + (U_8)^4 + (U_9)^4}
\]

\[
= \frac{(0.900)^4}{(0.801)^4 + (0.0075)^4 + (0.289)^4 + (0.016)^4 + (0.046)^4 + (0.115)^4 + (0.0141)^4 + (0.289)^4 + (0.016)^4 + (0.900)^4 + 0}
\]

\[
= \frac{(0.900)^4}{(0.801)^4 + (0.0075)^4 + (0.289)^4 + (0.016)^4 + (0.046)^4 + (0.115)^4 + (0.0141)^4 + (0.289)^4 + (0.016)^4 + (0.900)^4}
\]

\[
= 6.375
\]

Expanded Uncertainty for 95% level of confidence, the coverage factor $k=2.45$,

Thus $U = k \cdot U_c = 2.45 \cdot 0.900$

\[
\% U = 2.205\%
\]
### Uncertainty Budget

<table>
<thead>
<tr>
<th>Source of Uncertainty $X_i$</th>
<th>Estimates $x_i$</th>
<th>Limits %</th>
<th>Probability Distribution Type A or B Factor</th>
<th>Standard Uncertainty %</th>
<th>Sensit. Coefficient $C_i$</th>
<th>Uncertainty Contribution $U_i(y)$ %</th>
<th>Degree of freedom $V_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U_1$</td>
<td>0.015</td>
<td></td>
<td>Normal type $B - 2$</td>
<td>0.0075</td>
<td>1.0</td>
<td>0.0075</td>
<td>infinity</td>
</tr>
<tr>
<td>$U_2$</td>
<td>0.5</td>
<td></td>
<td>Rectangular Type B $\sqrt{3}$</td>
<td>0.289</td>
<td>1.0</td>
<td>0.289</td>
<td>Infinity</td>
</tr>
<tr>
<td>$U_3$</td>
<td>0.005</td>
<td></td>
<td>Rectangular Type B $\sqrt{3}$</td>
<td>0.016</td>
<td>1.0</td>
<td>0.016</td>
<td>Infinity</td>
</tr>
<tr>
<td>$U_4$</td>
<td>0.092</td>
<td></td>
<td>Normal type $B - 2$</td>
<td>0.046</td>
<td>1.0</td>
<td>0.0046</td>
<td>infinity</td>
</tr>
<tr>
<td>$U_5$</td>
<td>0.2</td>
<td></td>
<td>Rectangular Type B $\sqrt{3}$</td>
<td>0.115</td>
<td>1.0</td>
<td>0.0115</td>
<td>Infinity</td>
</tr>
<tr>
<td>$U_6$</td>
<td>0.0281</td>
<td></td>
<td>Normal type $B - 2$</td>
<td>0.0141</td>
<td>1.0</td>
<td>0.0141</td>
<td>infinity</td>
</tr>
<tr>
<td>$U_7$</td>
<td>0.5</td>
<td></td>
<td>Rectangular Type B $\sqrt{3}$</td>
<td>0.289</td>
<td>1.0</td>
<td>0.289</td>
<td>Infinity</td>
</tr>
<tr>
<td>$U_8$</td>
<td>0.5</td>
<td></td>
<td>Rectangular Type B $\sqrt{3}$</td>
<td>0.016</td>
<td>1.0</td>
<td>0.016</td>
<td>Infinity</td>
</tr>
<tr>
<td>$U_{9}$ (seconds)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.900</td>
<td>6.375</td>
</tr>
<tr>
<td>Expanded Uncertainty</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$k = 2.45$</td>
<td>Infinity</td>
</tr>
</tbody>
</table>

### Reporting of results:

Tripping time $= 18.374$ seconds $\pm 2.205\%$

$= 18.374$ seconds $\pm 0.405$ seconds
Sample 5

UNCERTAINTY CALCULATION FOR TRANSFORMER

Product: Distribution transformer
Test: Separate Source Voltage Withstand Test (Power Frequency Voltage Withstand Test)

Standards used:

1) Capacitive voltage Divider and peak voltmeter
   Range used for testing: 0-50 kV
   Accuracy: 0.03 % of FSD
   Uncertainty of Capacitive voltage Divider and peak voltmeter from its calibration certificate: 0.0443 %
   Resolution: 0.2 kV

2) Digital Stop watch
   Range used for testing: 0-99.99 seconds
   Accuracy: 0.02 % of RDG
   Uncertainty of Digital Stop watch from its calibration certificate: 0.0146 %
   Resolution: 0.0001 second

<table>
<thead>
<tr>
<th>Reading No.</th>
<th>Voltage (kV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28</td>
</tr>
<tr>
<td>2</td>
<td>28</td>
</tr>
<tr>
<td>3</td>
<td>28</td>
</tr>
<tr>
<td>4</td>
<td>28</td>
</tr>
<tr>
<td>5</td>
<td>28</td>
</tr>
</tbody>
</table>

Type A Evaluation

Mean Reading (kV.) = \frac{(R1+R2+R3+R4+R5)}{5} = 28 kV

Standard deviation = 0

Std. uncertainty U_1 = 0.0

Degree of freedom = V_1 = 5 – 1 = 4

Std. uncertainty (% U_1) = 0.0

U_r * 100/ Mean reading
Type B Evaluation

A. **Voltage Parameter**

1. Uncertainty of Capacitive voltage Divider and peak voltmeter from its calibration certificate.

\[ A_1 = 0.0443 \% \]

The distribution is normal and the coverage factor for approximately 95% confidence level is 2

\[ U_1(\%) = \frac{A_1}{2} = \frac{0.0443}{2} = 0.02215 \% \]

Estimate \[ = 0.0443 \times 28 \times 0.01 = 0.0124 \text{ kV} \]

Degree of freedom \( V_2 = \infty \)

2. Accuracy of Capacitive voltage Divider and peak voltmeter

\[ A_2 = 0.03\% \text{ of FSD} \]

\[ = 0.03 \times 50 \times 0.01 = 0.015 \text{ kV} \]

For rectangular distribution, the standard uncertainty \( U_2 = \frac{A_2}{\sqrt{3}} \)

\[ U_2 = 0.0086 \text{ kV} \]

\[ \% U_2 = \frac{U_2 \times 100}{\text{Mean Reading}} = \frac{0.0086 \times 100}{28} = 0.031 \% \]

Degree of freedom \( V_3 = \infty \)

3. Uncertainty due to resolution of Capacitive voltage Divider and peak voltmeter

\[ A_3 = \frac{0.2}{2} = 0.1 \text{ kV} = \text{Estimate} \]

\[ A_3(\%) = 0.1 \times \frac{100}{28} = 0.357 \% \]

For rectangular distribution, the standard uncertainty \( U_3 = \frac{A_3}{\sqrt{3}} \)

\[ U_3 = 0.0577 \text{ kV} \]

\[ \% U_3 = \frac{U_3 \times 100}{\text{Mean Reading}} = \frac{0.0577 \times 100}{28} = 0.206 \% \]
Combined standard uncertainty ($U_c$)

$$U_c = \sqrt{U_r^2 + U_1^2 + U_2^2 + U_3^2}$$

% $U_c = 0.21\%$.

Effective degrees of freedom ($v_{eff}$) =

$$v_{eff} = \frac{(U_r)^4}{(U_1)^4 + (U_2)^4 + (U_3)^4 + (U_4)^4}$$

$$v_{eff} = \infty$$

Expanded Uncertainty for approximately 95% level of confidence, the coverage factor $k=2$, Thus

$$U = k\cdot U_c = 2 \times 0.21\%$$

Total expanded uncertainty for voltage parameter % $U = 0.42\%$
Type B Evaluation

B. Time Parameter

1. Uncertainty of Digital Stop watch from its calibration certificate.
\[ \text{A}_1 = 0.0146\% \]

The distribution is normal and the coverage factor for approximately 95% confidence level is 2

\[ \text{U}_1(\%) = \frac{0.0146}{2} = 0.0073\% \]

Estimate = \(0.0146 \times 60 \times 0.01 = 0.00876\) sec

Degree of freedom \(V_2 = \infty\)

2. Accuracy of Digital Stop watch

\[ \text{A}_2 = 0.02\% \text{ of reading} \]

For rectangular distribution, the standard uncertainty = \(\text{U}_2 = \text{A}_2/\sqrt{3}\)

\[ \% \text{U}_2 = 0.0115\% \]

Estimate = \(0.02 \times 60 \times 0.01 = 0.012\) sec

Degree of freedom \(V_3 = \infty\)

3. Uncertainty due to resolution of Digital Stop watch

\[ \text{A}_3 = \frac{0.0001}{2} = 0.00005\text{ sec.} = \text{Estimate} \]

\[ \text{A}_3 = \frac{0.00005 \times 100}{60} = 0.000083\% \]

For rectangular distribution, the standard uncertainty = \(\text{U}_3 = \text{A}_3/\sqrt{3}\)

\[ \text{U}_3 = 0.0000288\text{ sec.} \]

\[ \% \text{U}_3 = \frac{\text{U}_3 \times 100}{\text{Mean Reading}} = 0.000048\% \]

Degree of freedom \(V_4 = \infty\)
Combined standard uncertainty ($U_c$)

$$U_c = \sqrt{U_r^2 + U_1^2 + U_2^2 + U_3^2}$$

% $U_c = 0.0137\%$.

Effective degrees of freedom ($v_{eff}$) =

$$v_{eff} = \frac{(U_c)^4}{(U_1)^4 + (U_2)^4 + (U_3)^4 + (U_r)^4 \frac{V_1}{V_1} \frac{V_2}{V_2} \frac{V_3}{V_3} \frac{V_4}{V_4}}$$

$v_{eff} = \infty$

Expanded Uncertainty for approximately 95% level of confidence, the coverage factor $k=2$, Thus

$$U = k \cdot U_c = 2 \cdot 0.0137\%$$

Total expanded uncertainty for time parameter % $U = 0.0275\%$.
Uncertainty Budget

A. VOLTAGE PARAMETER

<table>
<thead>
<tr>
<th>Source of uncertainty</th>
<th>Estimate</th>
<th>Limits %</th>
<th>Probability distribution</th>
<th>Divisor</th>
<th>std. uncert.</th>
<th>Sensitivity Coefficient</th>
<th>Uncertainty Contribution %</th>
<th>Degree of freedom</th>
</tr>
</thead>
<tbody>
<tr>
<td>( U_1 ) ('Uncertainty of CVD &amp; PVM)</td>
<td>0.04430</td>
<td>Normal</td>
<td>2</td>
<td>0.02215</td>
<td>1</td>
<td>0.02215</td>
<td>Infinity</td>
<td></td>
</tr>
<tr>
<td>( U_2 ) ('Accuracy of CVD &amp; PVM)</td>
<td>0.03% of FSD</td>
<td>Rectangular</td>
<td>1.73205</td>
<td>0.031</td>
<td>1</td>
<td>0.031</td>
<td>Infinity</td>
<td></td>
</tr>
<tr>
<td>( U_3 ) (Resolution of CVD &amp; PVM)</td>
<td>0.2 kV</td>
<td>0.357</td>
<td>Rectangular</td>
<td>1.73205</td>
<td>0.206</td>
<td>1</td>
<td>0.206</td>
<td>Infinity</td>
</tr>
<tr>
<td>( U_r ) (Type-A Repeatability)</td>
<td>28 kV</td>
<td>0.00000</td>
<td>Normal</td>
<td>1</td>
<td>0.0000</td>
<td>1</td>
<td>0.0000</td>
<td>4</td>
</tr>
</tbody>
</table>

Combined std. Uncertainty (%) | 0.21 | Infinity |

Expanded uncertainty (%) | \( k = 2 \) | 0.42 | Infinity |

Reporting of results:

Applied Voltage = 28 kV ± 0.42 %

\[ = 28 \text{ kV} \pm 0.1176 \text{ kV} \]

B. TIME PARAMETER

<table>
<thead>
<tr>
<th>Source of uncertainty</th>
<th>Estimate</th>
<th>Limits</th>
<th>Probability distribution</th>
<th>Divisor</th>
<th>std. uncert.</th>
<th>Sensitivity Coefficient</th>
<th>Uncertainty Contribution %</th>
<th>Degree of freedom</th>
</tr>
</thead>
<tbody>
<tr>
<td>( U_1 ) ('Uncertainty of Stop watch)</td>
<td>0.01460</td>
<td>Normal</td>
<td>2</td>
<td>0.0073</td>
<td>1</td>
<td>0.0073</td>
<td>Infinity</td>
<td></td>
</tr>
<tr>
<td>( U_2 ) ('Accuracy of stop watch)</td>
<td>0.02000</td>
<td>Rectangular</td>
<td>1.73205</td>
<td>0.0115</td>
<td>1</td>
<td>0.0115</td>
<td>Infinity</td>
<td></td>
</tr>
<tr>
<td>( U_3 ) (Resolution of stop watch)</td>
<td>0.0001 sec</td>
<td>0.000083</td>
<td>Rectangular</td>
<td>1.73205</td>
<td>0.000048</td>
<td>1</td>
<td>0.000048</td>
<td>Infinity</td>
</tr>
<tr>
<td>( U_r ) (Type-A Repeatability)</td>
<td>60 sec</td>
<td>0.00000</td>
<td>Normal</td>
<td>1.00000</td>
<td>0.0000</td>
<td>1</td>
<td>0.0000</td>
<td>4</td>
</tr>
</tbody>
</table>

Combined std. Uncertainty (%) | 0.137 | Infinity |

Expanded uncertainty (%) | \( k = 2 \) | 0.275 | Infinity |

Reporting of results:

Time of Voltage Application = 60 seconds ± 0.0275 %

\[ = 60 \text{ seconds} \pm 0.0165 \text{ seconds} \]
Sample 6

UNCERTAINTY CALCULATION FOR VOLTAGE FOR POWER MEASUREMENTS IN 3 PHASE INDUCTOR MOTOR

Product : 3 phase Induction motor
Test : Full load test
Equipment used : Wattmeter-3phase 3 wire
Current Transformer (a)
Current Transformer (b)
Accuracy : Wattmeter 0.5
Uncertainty from calibration report : Wattmeter 0.0953%
Current transformer (a) 0.092% (ratio error - 0.31%)
Current transformer (b) 0.092% (ratio error - 0.426%)
Resolution : Wattmeter 1 W
CT Ratio : 15/ 5 = 3
No. of Observation : 5

<table>
<thead>
<tr>
<th>Reading No.</th>
<th>Measured Power (Wattmeter rdg.)</th>
<th>Actual Power (=Wattmeter rdg * CT ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>W</td>
<td>W</td>
</tr>
<tr>
<td>1</td>
<td>3260 W</td>
<td>9780 W</td>
</tr>
<tr>
<td>2</td>
<td>3281 W</td>
<td>9843 W</td>
</tr>
<tr>
<td>3</td>
<td>3260 W</td>
<td>9780 W</td>
</tr>
<tr>
<td>4</td>
<td>3282 W</td>
<td>9846 W</td>
</tr>
<tr>
<td>5</td>
<td>3284 W</td>
<td>9852 W</td>
</tr>
</tbody>
</table>

Type A Evaluation

Mean Rdg. (Wattmeter rdg) = 3273.4 W \( (R1+R2+R3+R4+R5)/ 5 \)
Mean Rdg. (Actual Power) = 9820.2 W
Standard deviation = 36.84 W
Standard Uncertainty \( U_r \) = 16.475 W Standard Deviation/ sqrt(5)
Degree of freedom = \( V_1 = 5-1 = 4 \)
Std. uncertainty (% \( U_r \)) = 0.168 % \( U_r *100/ \text{Mean Reading} \)
Type B Evaluation

1. Uncertainty of Wattmeter from its calibration certificate. The distribution is normal and the coverage factor for approximately 95% confidence level is 2

\[ A_1 = 0.0953 \% \]

\[ U_1(\%) = A_1 / 2 = 0.0953 / 2 = 0.048 \% \]

\[ U_1 = 0.048 * 3273.4 * 0.01 = 1.571 \text{ W} \]

Estimate \[ = 0.0953 * 3273.4 * 0.01 = 3.12 \text{ W} \]

Degree of freedom \( V_2 = \text{infinity} \)

2. Accuracy of Wattmeter

\[ A_2 = 0.5 \% \]

For rectangular distribution, the standard uncertainty = \( U_2 = A_2 / \sqrt{3} \)

\[ U_2(\%) = 0.289 \% \]

\[ U_2 = 0.289 * 3273.4 * 0.01 = 9.46 \text{ W} \]

Estimate \[ = 0.5 * 3273.4 * 0.01 = 16.367 \text{ W} \]

Degree of freedom \( V_3 = \text{infinity} \)

3. Uncertainty due to resolution of Wattmeter = \( U_3 \)

\[ A_3 = 1 / 2 = 0.5 \text{ W} \]

For rectangular distribution, the standard uncertainty = \( U_3 = A_3 / \sqrt{3} \)

\[ U_3 = 0.289 \text{ W} \]

\[ U_3(\%) = 0.008 \% \]

Estimate \[ = 0.5 \text{ W} \]

Degree of freedom \( V_4 = \text{infinity} \)

4. Uncertainty of current transformer (a) from its calibration certificate. The distribution is normal and the coverage factor for approximately 95% confidence level is 2

\[ A_4 = 0.092 \% \]

\[ U_4(\%) = A_4 / 2 = 0.092 / 2 = 0.046 \% \]

Degree of freedom \( V_5 = \text{infinity} \)
5. Ratio error for current transformer (a) from its calibration certificate
   \[ A_5 = 0.31 \% \]
   For rectangular distribution, the standard uncertainty = \[ U_5 = A_5/\sqrt{3} \]
   \[ U_5 (\%) = 0.178 \% \]
   Degree of freedom \( V_6 = \infty \)

6. Uncertainty of current transformer (b) from its calibration certificate. The distribution is normal and the coverage factor for approximately 95% confidence level is 2
   \[ A_6 = 0.092 \% \]
   \[ U_6 (\%) = A_6/2 = 0.092/2 = 0.046 \% \]
   Degree of freedom \( V_7 = \infty \)

7. Ratio error for current transformer (b) from its calibration certificate.
   \[ A_7 = 0.426 \% \]
   For rectangular distribution, the standard uncertainty is \[ U_7 = A_7/\sqrt{3} \]
   \[ U_7 (\%) = 0.246 \]
   Degree of freedom \( V_8 = \infty \)
Combined standard uncertainty ($U_c$)

$$U_c = \sqrt{U_r^2 + U_1^2 + U_2^2 + U_3^2 + U_4^2 + U_5^2 + U_6^2 + U_7^2}$$

$$\% U_c = 0.459 \%$$

Effective degrees of freedom ($\nu_{eff}$)

$$\nu_{eff} = \frac{(U_c)^4}{(U_1)^4 + (U_2)^4 + (U_3)^4 + (U_4)^4 + (U_5)^4 + (U_6)^4 + (U_7)^4 + (U_r)^4}$$

$$\nu_{eff} = \frac{(0.459)^4}{(0.048)^4 + (0.289)^4 + (0.008)^4 + (0.046)^4 + (0.178)^4 + (0.046)^4 + (0.246)^4 + (0.168)^4}$$

$$\nu_{eff} = 222.9$$

Expanded Uncertainty for approximately 95% level of confidence, the coverage factor $k = 2$, Thus

$$U = k \cdot U_c = 2 \cdot 0.459$$

$$\% U = 0.918 \%$$
### Uncertainty Budget

<table>
<thead>
<tr>
<th>Source of Uncertainty XI</th>
<th>Estimates xi</th>
<th>Limits %</th>
<th>Probability Distribution Type A or B Factor</th>
<th>Standard Uncertainty U (xi) %</th>
<th>Sensitivity Coefficient Ci</th>
<th>Uncertainty Contribution Ui (y) Volts %</th>
<th>Degree of freedom Vi</th>
</tr>
</thead>
<tbody>
<tr>
<td>U₁</td>
<td>0.0953</td>
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<td>Normal Type B 2</td>
<td>0.048</td>
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<tr>
<td>U₂</td>
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<tr>
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<td>0.015</td>
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<td>U₄</td>
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<td>Normal Type B 2</td>
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<td>U₅</td>
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<tr>
<td>Expanded Uncertainty (U)</td>
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</tr>
</tbody>
</table>

#### Reporting of results:

Measured Power = 9820.2 W ± 0.918%

= 9820.2 W ± 90.1 W
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