NABL 174

National Accreditation Board for Testing and Calibration Laboratories (NABL)

Sample Calculations for Uncertainty of Measurement in Electrical Testing

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AMENDMENT SHEET

Sl no	Page No.	Clause No.	Date of Amendment	Amendment	Reasons	Signature QM	Signature Director
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

CONTENTS

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.

The Specific Criteria for Electrical Testing Laboratories (NABL 104) has been brought out which deals with the technical issues and serve the purpose of giving all the necessary action and guidelines for the preparation of application for NABL Accreditation by the laboratories and conducting assessment by the Technical Assessors.

As per the requirements of clause 5.4.6 of ISO/ IEC 17025: 2005, the testing laboratories are required to estimate the Uncertainty of Measurement.

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

This document is supplementary to “Specific Criteria for Electrical Testing Laboratories” (NABL 104). As per the requirements of clause 5.4.6 of ISO/ IEC 17025: 2005, the testing laboratories are required to estimate the Uncertainty of Measurement. This document guides the laboratory to estimate the Uncertainty of Measurement for Electrical Testing.

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

3. REFERENCES

1. ISO/ IEC 17025: 2005 - General Requirements for the Competence of Testing and Calibration Laboratories

2. NABL 104 - Specific Criteria for Electrical Testing Laboratories

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

Reading No.	Voltage (Volts)
1	250.2
2	250.3
3	250.1
4	250.2
5	250.3

Assuming contribution due to frequency is negligible

Type A Evaluation

Mean Rdg. (Volts) = 250.22 Volts (R1+R2+R3+R4+R5)/ 5

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 *100/ 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(%) = A_1/ 2 = 0.281/ 2 = 0.141 %

U_1 = 0.141 * 250.22 * 0.01 = 0.352 Volts

Estimate = 0.281* 250.22 * 0.01 = 0.703 Volts

Degree of freedom V_2 = infinity

2.

Accuracy of Digitizer with Amplifier

A_2 = 0.16 % of reading = 0.16 * 250.22 * 0.01 = 0.400 Volts = Estimate

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

U_2 = 0.231 Volts

% U_2 = 0.0924 % U_2 * 100/ Mean Reading

Degree of freedom V_3 = infinity

3.

Uncertainty due to resolution of display unit = U_3

A_3 = 0.0001/ 2 = 0.00005 Volts = Estimate

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

U_3 = 0.000028 Volts

% U_3 = 0.0000115 % U_3 * 100/ Mean Reading

Degree of freedom V_4 = infinity

Combined standard uncertainty (U_c)

U_c = sqrt($(U_r*U_r)+(U_1*U_1)+(U_2*U_2)+(U_3*U_3)$)

U_c = 0.423 Volts

% U_c = 0.169 % U_c * 100/ Mean Reading

Effective degrees of freedom (ν_{eff}) =

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

$$\nu_{eff} = \frac{(0.169)^4}{\frac{(0.0149)^4}{4} + \frac{(0.141)^4}{\infty} + \frac{(0.0924)^4}{\infty} + \frac{(0.0000115)^4}{\infty}}$$

$$\nu_{eff} = \frac{(0.169)^4}{\frac{(0.0149)^4}{4} + 0}$$

ν_{eff} = ∞

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

U = $k*U_c$ = 2 * 0.423 Volts

U = 0.85 Volts

% U = 0.34 % U * 100/ Mean Reading

Uncertainty Budget

Source of Uncert-ainty Xi	Estimates xi	Limits %	Probability Distribution Type A or B Factor	Standard Uncertainty (Volts)		Sensitivity Coefficient Ci	Uncertainty Contribution Ui (y)		Degree of freedom Vi
				Volts	%		Volts	%	
U_1		0.281	Normal type B – k=2	0.352	0.141	1.0	0.352	0.141	Infinity
U_2		0.16	Rectangular Type B sqrt(3)	0.231	0.0924	1.0	0.231	0.0924	Infinity
U_3		0.000019	Rectangular Type B sqrt(3)	0.000028	0.0000115	1.0	0.000028	0.0000115	Infinity
Repeata-bility (U_r)	250.22	--	Normal Type A	0.0374	0.0149	1.0	0.0374	0.0149	4
U_c				0.423	0.169		0.423	0.169	Infinity
Expanded Uncertainty (U)			k = 2				0.85	0.34	Infinity

Reporting of results:

Voltage = 250.22 $\pm$ 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

Reading No.	Current (kAmp.)
1	50.26
2	50.23
3	50.28
4	50.24
5	50.23

Assuming contribution due to frequency is negligible

Type A Evaluation

Mean Rdg. (kAmp.)	= 50.248 (kAmp.)	(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 *100/ 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(%) = A_1/ 2 = 0.281/2 = 0.141 %

U_1 = 0.141 * 50.248 * 0.01 = 0.0708 kAmp.

Estimate = 0.281 * 50.248 * 0.01 = 0.1412 kAmp.

Degree of freedom V_2 = infinity

2.

Digitizer with Amplifier Accuracy

A_2 = 0.19% of reading = 0.19 * 50.248 * 0.01 = 0.09547 kAmp. = Estimate

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

U_2 = 0.0551 kAmp.

% U_2 = 0.109 % U_2 * 100/ Mean Reading

Degree of freedom V_3 = infinity

3.

Uncertainty due to resolution of display unit = U_3

A_3 = 0.0001/ 2 = 0.00005 kAmp. = Estimate

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

U_3 = 0.000028 kAmp.

% U_3 = 0.000057 % U_3 * 100/ Mean Reading

Degree of freedom V_4 = infinity

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 (%) = A_4/ 2 = 1.156/ 2 = 0.578 %

U_4 = 0.578 * 50.248 * 0.01 = 0.290 kAmp.

Estimate = 1.156 * 50.248 * 0.01 = 0.580 kAmp.

Degree of freedom V_5 = infinity

Combined standard uncertainty (U_c)

U_c = sqrt(U_r*U_r)+(U_1*U_1)+(U_2*U_2)+(U_3*U_3))+(U_4*U_4)

U_c = 0.310 kAmp.

% U_c = 0.617 % U_c * 100/ Mean Reading

Effective degrees of freedom (ν_{eff}) =

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

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

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

ν_{eff} = 4178028 = ∞

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

U = k * U_c = 2 * 0.310 kAmp.

U = 0.620 kAmp.

% U = 1.234 % U * 100/ Mean Reading

Uncertainty Budget

Source of Uncert-ainty Xi	Estimates xi	Limits %	Probability Distribution Type A or B Factor	Standard Uncertainty (Volts)		Sensitivity Coefficient Ci	Uncertainty Contribution Ui (y)		Degree of freedom Vi
				kAmp.	%		kAmp.	%	
U_1		0.281	Normal Type B 2	0.0708	0.141	1.0	0.0708	0.141	Infinity
U_2		0.190	Rectangular Type B sqrt(3)	0.0551	0.109	1.0	0.0551	0.109	Infinity
U_3		0.00005	Rectangular Type B sqrt(3)	0.000028	0.000057	1.0	0.000028	0.000057	Infinity
U_4		1.156	Normal Type B 2	0.2963	0.578	1.0	0.2963	0.578	Infinity
Repeatabi-lity (U_r)	50.248	--	Normal Type A	0.00969	0.0193	1.0	0.00969	0.0193	4
U_c				0.310	0.617		0.310	0.617	Infinity
Expanded Uncerta-inty (U)			k = 2				0.620	1.234	Infinity

Reporting of results:

Current = 50.248 ± 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

Reading No.	Power loss (Watt)
1	0.67
2	0.68
3	0.68
4	0.68
5	0.68

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/ 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(%) = A_1/ 2 = 0.0953/2 = 0.04765 %

U_1 = 0.04765 * 0.678 * 0.01 = 0.323 * 10^{-3} W

Degree of freedom V_2 = infinity

2.

From watt meter specification (Accuracy)

A_2 = 0.5% of reading = 0.5 * 0.678/ 100 = 0.00339 Watt

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

U_2 = 0.00195 watt

% U_2 = 0.2876 % U_2 * 100/ Mean Reading

Degree of freedom V_3 = infinity

3.

Uncertainty due to resolution of watt meter = U_3

A_3 = 0.01/ 2 = 0.005 Watt

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

U_3 = 0.002886 Watt

% U_3 = 0.4257 % U_3 * 100/ Mean Reading

Degree of freedom V_4 = infinity

Combined standard uncertainty (U_c)

U_c = sqrt(U_r*U_r)+(U_1*U_1)+(U_2*U_2)+(U_3*U_3) = 0.00402

% U_c = 0.59 %

Effective degrees of freedom (ν_{eff}) =

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

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

ν_{eff} = 64

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

U = k*U_c = 2* 0.00402 = 0.008 W

% U = 1.18 % U* 100/mean Reading

Uncertainty Budget

Source of Uncertainty Xi	**Estimates xi**	**Limits %**	**Probability Distribution Type A or B Factor**	**Standard Uncertainty %**	**Sensitivity Coefficient Ci**	**Uncertainty Contribution Ui(y) %**	**Degree of freedom Vi**
U_1		0.0953	Normal type B – 2	0.04765	1.0	0.04765	infinity
U_2		0.5	Rectangular Type B sqrt(3)	0.2876	1.0	0.2876	Infinity
U_3		0.7373	Rectangular Type B sqrt(3)	0.4257	1.0	0.4257	Infinity
Repeatability	0.678 W		Normal Type A	0.295	1.0	0.295	4
U_c %						0.59	64
Expanded Uncertainty			k = 2			1.18	Infinity

Reporting of results:

Power loss = 0.678 $\pm$ 0.008 Watt

Sample 4

UNCERTAINTY CALCULATION
FOR TRIPPING CHARACTERISTIC IN MCB

Product	:	MCB, 4 A
Test	:	Tripping characteristic at 2.55 In
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

Reading No.	Tripping time in seconds
1	18.01
2	18.26
3	18.76
4	18.68
5	18.16

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

4.

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 = 0.092 %

U_4 (%) = A_4/ 2= 0.092/ 2 = 0.046 %

Degree of freedom V_5 = infinity

5.

From CT specification (Accuracy)

A_5 = 0.2% of reading

For rectangular distribution, the standard uncertainty = U_5 = A_5/ sqrt(3)

% U_5 = 0.115 %

Degree of freedom V_6 = infinity

6.

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 = 0.0281 %

U_6(%) = A_6/ 2 = 0.0281/ 2 = 0.141 %

Degree of freedom V_7 = infinity

7.

From Ammeter specification (Accuracy)

A_7 = 0.5% of reading

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

% U_7 = 0.289 %

Degree of freedom V_8 = infinity

8.

Uncertainty due to resolution of Meter = U_8

A_8 = 0.01/ 2 = 0.005

For rectangular distribution, the standard uncertainty = U_8 = A_8/ sqrt(3)

% U_8= 0.005/ sqrt(3)= 0.016 %

Degree of freedom V_9 = infinity

Combined standard uncertainty = U_c

U_c = sqrt$(U_r*U_r)+(U_1*U_1)+(U_2*U_2)+(U_3*U_3)+(U_4*U_4)+(U_5*U_5)+(U_6*U_6)+(U_7*U_7)+(U_8*U_8)$

% U_c = 0.900 % U_c * 100/ Mean Reading

Effective degrees of freedom (ν_{eff}) =

$$\nu_{eff} = \frac{(U_c)^4}{\frac{(U_r)^4}{V_1} + \frac{(U_1)^4}{V_2} + \frac{(U_2)^4}{V_3} + \frac{(U_3)^4}{V_4} + \frac{(U_4)^4}{V_5} + \frac{(U_5)^4}{V_6} + \frac{(U_6)^4}{V_7} + \frac{(U_7)^4}{V_8} + \frac{(U_8)^4}{V_9}}$$

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

$$= \frac{(0.900)^4}{\frac{(0.801)^4}{4} + 0}$$

= 6.375

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

Thus U = $k*U_c$ = 2.45*0.900

% U = 2.205 %

Uncertainty Budget

Source of Uncertainty Xi	Estimates xi.	Limits %	Probability Distribution Type A or B Factor	Standard Uncertainty %	Sensit. Coefficient Ci	Uncertainty Contribution Ui(y) %	Degree of freedom Vi
U_1		0.015	Normal type B – 2	0.0075	1.0	0.0075	infinity
U_2		0.5	Rectangular Type B sqrt(3)	0.289	1.0	0.289	Infinity
U_3		0.005	Rectangular Type B sqrt(3)	0.016	1.0	0.016	Infinity
U_4		0.092	Normal type B – 2	0.046	1.0	0.0046	infinity
U_5		0.2	Rectangular Type B sqrt(3)	0.115	1.0	0.0115	Infinity
U_6		0.0281	Normal type B – 2	0.0141	1.0	0.0141	infinity
U_7		0.5	Rectangular Type B sqrt(3)	0.289	1.0	0.289	Infinity
U_8		0.5	Rectangular Type B sqrt(3)	0.016	1.0	0.016	Infinity
Repeatability	18.374		Normal Type A	0.801	1.0	0.801	4
U_c (seconds)						0.900	6.375
Expanded Uncertainty			k = 2.45			2.205	Infinity

Reporting of results:

Tripping time = 18.374 seconds $\pm$ 2.205 %

= 18.374 $\pm$ 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

Reading No.	Voltage (kV)
1	28
2	28
3	28
4	28
5	28

Type A Evaluation

Mean Reading (kV.)	=	28 kV	(R1+R2+R3+R4+R5)/ 5
Standard deviation	=	0	
Std. uncertainty U_r	=	0.0	Standard Deviation/ sqrt(5)
Degree of freedom = V_1	=	5 – 1 = 4	
Std. uncertainty (% U_r)	=	0.0	U_r * 100/ Mean reading

Type B Evaluation

A. <u>Voltage Parameter</u>

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

$U_1(\%)$ = $A_1/ 2$ = 0.0443/ 2 = 0.02215 %

Estimate = 0.0443 * 28 * 0.01 = 0.0124 kV.

Degree of freedom V_2 = infinity

2.

Accuracy of Capacitive voltage Divider and peak voltmeter

A_2 = 0.03% of FSD

= 0.03 * 50 * 0.01 = 0.015 kV

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

U_2 = 0.0086 kV

% U_2 = U_2 * 100/ Mean Reading

= 0.0086 * 100/ 28 = 0.031 %

Degree of freedom V_3 = infinity

3.

Uncertainty due to resolution of Capacitive voltage Divider and peak voltmeter

A_3 = 0.2/ 2 = 0.1 kV = Estimate

$A_3(\%)$ = 0.1 * 100/ 28 = 0.357 %

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

U_3 = 0.0577 kV

% U_3 = U_3 * 100/ Mean Reading

= 0.0577 * 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 (ν_{eff}) =

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

ν_{eff} = infinity

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

$U = k*U_c = 2 * 0.21$ %

Total expanded uncertainty for voltage parameter % U = 0.42 %

Type B Evaluation

B. <u>Time Parameter</u>

1.

Uncertainty of Digital Stop watch from its calibration certificate.

A_1 = 0.0146 %

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

U_1(%) = 0.0146/ 2 = 0.0073 %

Estimate = 0.0146 * 60 * 0.01 = 0.00876 sec

Degree of freedom V_2 = infinity

2.

Accuracy of Digital Stop watch

A_2 = 0.02 % of reading

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

% U_2 = 0.0115 %

Estimate = 0.02 * 60 * 0.01 = 0.012 sec

Degree of freedom V_3 = infinity

3.

Uncertainty due to resolution of Digital Stop watch

A_3 = 0.0001/ 2 = 0.00005 sec. = Estimate

A_3 = 0.00005 * 100/ 60 = 0.000083 %

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

U_3 = 0.0000288 sec.

% U_3 = U_3 *100/ Mean Reading = 0.000048 %

Degree of freedom V_4 = infinity

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 (ν_{eff}) =

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

ν_{eff} = infinity

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

U = k * U_c = 2 * 0.0137 %

Total expanded uncertainty for time parameter % U = 0.0275 %

Uncertainty Budget

A. VOLTAGE PARAMETER

Source of uncertainty	Estimate	Limits %	Probability distribution	Divisor	std. uncert.	Sensitivity Coefficient	Uncertainty Contribution %	Degree of freedom
U_1 ('Uncertainty of CVD & PVM)		0.04430	Normal	2	0.02215	1	0.02215	Infinity
U_2 ('Accuracy of CVD & PVM)		0.03% of FSD	Rectangular	1.73205	0.031	1	0.031	Infinity
U_3 (Resolution of CVD & PVM)	0.2 kV	0.357	Rectangular	1.73205	0.206	1	0.206	Infinity
U_r (Type-A-Repeatability)	28 kV	0.00000	Normal	1	0.0000	1	0.0000	4
Combined std. Uncertainty (%)							0.21	Infinity
Expanded uncertainty (%)			k =	2			0.42	Infinity

Reporting of results:

Applied Voltage = 28 kV ± 0.42 %.

B. TIME PARAMETER

Source of uncertainty	Estimate	Limits	Probability distribution	Divisor	std. uncert.	Sensitivity Coefficient	Uncertainty Contribution %	Degree of freedom
U_1 ('Uncertainty of Stop watch)		0.01460	Normal	2	0.0073	1	0.0073	Infinity
U_2 ('Accuracy of stop watch)		0.02000	Rectangular	1.73205	0.0115	1	0.0115	Infinity
U_3 (Resolution of stop watch)	0.0001 sec	0.000083	Rectangular	1.73205	0.000048	1	0.000048	Infinity
U_r (Type-A-Repeatability)	60 sec	0.00000	Normal	1.00000	0.0000	1	0.0000	4
Combined std. Uncertainty (%)							0.0137	Infinity
Expanded uncertainty (%)			k =	2			0.0275	Infinity

Reporting of results:

Time of Voltage Application = 60 seconds ± 0.0275 %.

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 (2 wattmeter method) 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	

Reading No.	Measured Power (Wattmeter rdg.) W	Actual Power (=Wattmeter rdg * CT ratio) W
1	3260	9780
2	3281	9843
3	3260	9780
4	3282	9846
5	3284	9852

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/ 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 W

Estimate = 0.0953 * 3273.4 * 0.01 = 3.12 W

Degree of freedom V_2 = 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 W

Estimate = 0.5 * 3273.4 * 0.01 = 16.367 W

Degree of freedom V_3 = infinity

3.

Uncertainty due to resolution of Wattmeter = U_3

A_3 = 1/ 2 = 0.5 W

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

U_3 = 0.289 W

U_3 (%) = 0.008 %

Estimate = 0.5 W

Degree of freedom V_4 = 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 = 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 = infinity

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 = infinity

7.

Ratio error for current transformer (b) from its calibration certificate.

A_7 = 0.426 %

For rectangular distribution, the standard uncertainty is = $U_7 = A_7$/ sprt(3)

U_7 (%) = 0.246

Degree of freedom V_8 = infinity

Combined standard uncertainty (U_c)

U_c = sqrt(U_r*U_r + U_1*U_1 + U_2*U_2 + U_3*U_3 + U_4*U_4 + U_5*U_5 + U_6*U_6 + U_7*U_7)

% U_c = 0.459 %

Effective degrees of freedom (ν_{eff}) =

$$\nu_{eff} = \frac{(U_c)^4}{\frac{(U_1)^4}{V_2} + \frac{(U_2)^4}{V_3} + \frac{(U_3)^4}{V_4} + \frac{(U_4)^4}{V_5} + \frac{(U_5)^4}{V_6} + \frac{(U_6)^4}{V_7} + \frac{(U_7)^4}{V_8} + \frac{(U_r)^4}{V_1}}$$

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

ν_{eff} = 222.9

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

U = k*U_c = 2 * 0.459

% U = 0.918 %

Uncertainty Budget

Source of Uncertainty Xi	Estimates xi	Limits %	Probability Distribution Type A or B Factor	Standard Uncertainty U (xi) %	Sensitivity Coefficient Ci	Uncertainty Contribution Ui (y) Volts %	Degree of freedom Vi
U_1		0.0953	Normal Type B 2	0.048	1.0	0.048	Infinity
U_2		0.5	Rectangular Type B sqrt(3)	0.289	1.0	0.289	Infinity
U_3	0.03	0.015	Rectangular Type B sqrt(3)	0.008	1.0	0.008	Infinity
U_4		0.092	Normal Type B 2	0.046	1.0	0.046	Infinity
U_5		0.31	Rectangular Type B sqrt(3)	0.178	1.0	0.178	Infinity
U_6		0.092	Normal Type B 2	0.046	1.0	0.046	Infinity
U_7		0.426	Rectangular Type B sqrt(3)	0.246	1.0	0.246	Infinity
Repeatability (U_r)	9820.2	--	Normal Type A	0.168	1.0	0.168	4
U_c						0.459	222.9
Expanded Uncertainty (U)			k = 2			0.918	Infinity

Reporting of results:

Measured Power = 9820.2 W $\pm$ 0.918%

= 9820.2 $\pm$ 90.1W

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