ICSE 2009

PROCEEDINGS OF THE FIRST INTERNATIONAL CONFERENCE ON SCIENCE AND ENGINEERING

Volume - 1

Electronics
Electrical Power
Information Technology
Engineering Physics

Sedona Hotel, Yangon, Myanmar
December 4-5, 2009

PROCEEDINGS OF THE FIRST INTERNATIONAL CONFERENCE ON SCIENCE AND ENGINEERING

Volume - 1

Electronics
Electrical Power
Information Technology
Engineering Physics

Organized by
Ministry of Science and Technology

DECEMBER 4-5, 2009
SEDONA HOTEL, YANGON, MYANMAR

ELECTRICAL POWER ENGINEERING

Estimation of Uncertainty in Measurement of AC Power

Thida Swe
Electrical Power Department,
Technological University (Kyauksei)
Myanmar
thidaswekpg@gmail.com

***Abstract*— The problem on measurement of AC power in single-phase or three-phase networks is always very important. In this paper Test Method is to be applied to Unit Under Test (UUT) Meter which is compared by the known error of Standard Power Meter as reference. This method used to measure the error of UUT Meter. When estimating the uncertainty of measurement, all components which are of importance in the given situation shall be taken into account using appropriate methods of analysis. In this paper calibration procedure is provided for calibration process of single phase AC power meter using comparison method with its capability as declared. A method for calibration of AC power meter, measurement instruments used in the procedure, processing and presentation of the final results are presented as well.**

***Keywords*— measurement, AC power, uncertainty, calibration, procedures**

I. Introduction

The Watt–Hour training program was held for 6 weeks at NIMT, laboratory of AC Power Measurement. The program starts from January 11 until February 21 on 2009. It is organized by Japan International Cooperation Agency (JICA), Thailand International Development Cooperation Agency (TICA), and National Institute of Metrology of Thailand (NIMT). The training purpose is to transfer technology related to measurement standards to the third country of Asia-Pacific countries. The training program generally divide by two parts, at the first week of training was metrology orientation and ISO/IEC 17025 lecture plus basic uncertainty on measurement, and remain weeks for five weeks period is scheduled for specific needs in measurement standard in the fields of Watt-Hour. AC Power Measurement is one of ten laboratories or sections of Electrical Metrology Department in NIMT. During the training, calibration systems were calibrated one by one. In the last week, AC power meter calibration procedure using direct method and using comparison method were reported and interviewed one by one. In this paper, the calibration of digital power meter, Yokogawa WT2030 is calibrated with multi-product calibrator, Fluke 5500A.

II. Preliminary Operations

The equipments and the requirements that will be involved in the calibration process of an AC power meter on the calibration desk were prepared. The standard system (STD) and AC power meter (Unit Under Test/UUT) was arranged on its appropriate places. The entire procedure beginning calibration process was read carefully. All instruction for calibration in operation manual or instruction manual of standard equipment and unit under calibration was studied. Stabilize all equipments for appropriate times of individual equipment in the ambient temperature of 23 °C ± 2 °C and relative humidity of 50% RH ± 15% RH. The UUT line voltage was selected 220V or 230V and the proper power applied to the equipment was ensured. The UUT to line voltage was connected and was turned on. Warm up time 48 hours was allowed or following manufacturer's specification requirement. Twisted the current leads should be used in order to reduce their self inductance and stray capacitance.

TABLE I
EQUIPMENT ARRANGEMENT REQUIREMENTS

Nomenclature Characteristic	Requirement Specifications	Calibration Equipment
Calibrator	AC Power Range : 0.1 mW to 11Kw at 45 Hz to 65 Hz, PF = 1 Accuracy: ± 844 ppm to ± 1275 ppm Voltage Range : 33 mV to 1020 V Accuracy: ± 318 ppm to ± 578 ppm Current Range : 3.3 mA to 11 A Accuracy: ± 782 ppm to ± 1136 ppm Power Factor: 1 to 0, Lead and Lag Accuracy: 0.00% to 2.99% Frequency : 0.01 to 2000 MHz Accuracy : 25 ppm ± 1 mHz to 25 ppm ± 15 mHz	FLUKE, Model 5500A or equivalent

The wiring from Hi Voltage Input of Power Meter to Normal Hi of Calibrator and from Low COM of Power Meter to Normal LO of Calibrator was connected. The wiring from Hi Current Input of Power Meter to AUX HI of Calibrator and from Low COM of Power Meter to AUX LO of Calibrator was connected.

A. Calibration Process

The AC Voltage range, AC Current range, Channels of the AC Power Meter (UUC) that set range to be calibrated was pressed. (Power factor =1.0, (0 degree), Power factor = 0.5 lead (60 degree), 0.5 lag (-60 degree) and Power factor =0 lead (90 degree), 0 lag (-90 degree).The known value was applied required for calibrator by pressing OPR button from the calibrator. To set the ac power value on the calibrator, dial a number then ended with "V" as unit of voltage, dial next number then ended with "A" as unit of current, dial next number then ended with "Hz" as unit of frequency, then ENTER. To change the phase, push "WAVE MENUS" then "PHASE" then dial number and ENTER. After that push the "PREV MENU" button twice. Then OPERATE by pushing "OPR" button. Wait for UUC to stabilize for approximately 30 seconds. The UUC reading 5 times in calibration record is recorded then press STANDBY button on the calibrator. The calibration process was repeated for each value.

III. MATHEMATICAL MODEL

The UUC is connected directly to the calibrator as shown in Fig. 1. The mathematical model of the process is to calculate the error of the AC Power Meter (unit under test) as defined:

$$\Delta P = P_X - P_S \;\; \delta P_{Sacc} + \delta P_R$$

where:

ΔP = Error of the unit under test (UUT).

P_X = The indicated value of the unit under test (UUT).

P_S = The value of the standard ac power from the Calibrator (STD) that applied to unit under test (UUT).

δP_{Sac}= Influence of the measurement error due to the short-term stability and long term stability of the Calibrator's ac power value, and it represent by accuracy of calibrator.

δP_R = Influence of the finite resolution of unit under test.

$\Delta \overline{P}$ = Mean of five difference value between the unit under test and the calibrator.

$\overline{P}_X$ = Mean of five indicated values of unit under test.

A. Calibration result

The unit under calibration (UUC) is Power meter, calibrated by calibrator which specification is shown in Table I. According to Table I, various AC voltage range, various AC current range, various power factor and various frequency can be applied to the calibrator and then calibrated and recorded in excel and solved detail random uncertainty and systematic uncertainty in excel. In this paper, 600 W (300 V, 2 A, power factor 0.5 lead) and frequency of 50 Hz is calibrated as an example because the data can be applied within the limits as shown in Table I. That calibration system is connected as shown in Fig. 1. And then calibrated and recorded five times in Table II.

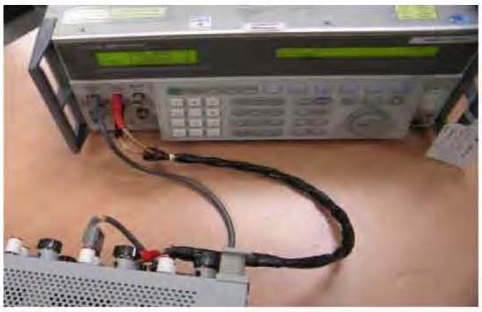

Fig. 1 Connection of Calibrator and Digital Wattmeter

Fig. 2 AC power Calibrations System for Digital Wattmeter

TABLE II
CALIBRATION RESULT

Applied Input (P_S)	UUC Reading (P_X)	ΔP
300.000 W	300.8 W	0.8 W
300.000 W	300.8 W	0.8 W
300.000 W	300.7 W	0.7 W
300.000 W	300.8 W	0.8 W
300.000 W	300.8W	0.8 W
= 300.000 W	=300.78 W	= 0.78 W

Fig. 3 shows the display of multi-product calibrator; Fluke 5500A at 300V, 2A, power factor 0.5 (lead) and frequency 50Hz. And Fig. 4 is the display of calibration result of digital power meter, Yokogawa WT 2030.

Fig. 3 Display of Multi-Product Calibrator, Fluke 5500A

Fig. 4 Calibration result of Digital Power Meter, Yokogawa WT 2030

B. Uncertainty Equation

The combined standard uncertainty is given by

$$u_c(\Delta P)=\sqrt{c_1^2u^2(P_X)+c_2^2u^2(P_S)+c_3^2u^2(\delta P_{Sacc})+c_4^2u^2(\delta P_R)}$$

Since it is evaluated by relative standard uncertainty, then the combined standard uncertainty is given by:

$$u_c(\Delta P)=\sqrt{u^2(P_X)+u^2(P_S)+u^2(\delta P_{Sacc})+u^2(\delta P_R)}$$

where:

$u(P_X)$ = The standard uncertainty from the indicated value of the unit under test

$u(P_S)$ = The standard uncertainty from the value of the standard ac power from the Calibrator

$u(\delta P_{Sacc})$ = The standard uncertainty due to shot-term and long-term stability of the Calibrator, represent by the accuracy of Calibrator

$u(\delta P_R)$ = The standard uncertainty due to finite resolution of the unit under test

IV. Calculation of Uncertainty Components

A. Type A Evaluation:

The best estimate of the measured power is given by arithmetic mean:

$$\overline{P_X}=\frac{1}{5}\sum_{X=1}^{5}P_X$$

=300.78 W

Standard deviation:

$$S(\overline{P}_X)=\sqrt{\frac{1}{5-1}\sum_{X=1}^{5}(P_X-\overline{P}_X)^2}=0.044722\text{ W}$$

Absolute standard uncertainty: $u(P_X)=\frac{S(\overline{P}_X)}{\sqrt{n}}$ =0.02 W

B. Type B Evaluation:

1. The value of the standard AC Power from the Calibrator u (P_S)

The calibration certificate issued for the Calibrator state that AC power is the 300W (600 VA, 300 V, 2 A and phase 60° by the Calibrator setting with the assigned expended uncertainty of measurement 0.0626W (k = 2). Thus, the assigned relative standard uncertainty of measurement $u_2(P_S)$ is 0.0313W and assumed a normal distribution.

Degree of freedom:

$$u_2=\infty$$

2. The standard uncertainty due to stability of the Calibrator u (δP_{Sacc})

Influence of the error of the measurement due to the short-term and long-term stability of the value of the AC power source. No correction is made for it. The manufacturer's specification gives the AC power value of the Calibrator accuracy at the 300 W (600 VA, 300 V, 2A and phase 60°) is 2.7711 and assumed rectangular distribution gives the assigned relative standard uncertainty $u_3(\delta P_{Sacc})$ is 1.5999 W.

Degree of freedom:

$$u_3=\infty$$

3. The Standard uncertainty due to finite resolution of the unit under calibration u (δP_R)

No correction made for the deviation of the finite resolution of the indicated of the unit under calibration. For unit under the calibration is wattmeter, the measurement range 600 VA (300 V, 2A), the unit under calibration has the digital resolution of 0.1 W. This assumed rectangular distribution gives the relative standard uncertainty $u_4(\delta P_R)$ =0.0289.

Degree of freedom:

$$u_4=\infty$$

C. Uncertainty Budget

Uncertainty budget for AC Power measurement at 300 W (600 VA, 300 V, 2A) power factor 0.5 Lead (phase = 60^0) at 50 Hz is shown as the following Table III and Table IV.

TABLE III
UNCERTAINTY BUDGET

Quantity	Estimation (Watt)	Standard Uncertainty	
		Relative	**Absolute**
X_i	x_i	$u(x_i)$	
P_X	300.78		0.02W
P_S	300.000		0.0313W
δP_{Sacc}	0		1.6W
δP_R	0		0.0289W
ΔP	**0.78**		

TABLE IV
UNCERTAINTY BUDGET

Prob. Dist.	Effective Degree of Freedom	Sen. Coeff.	Uncertainty contribution
			Relative Absolute
	(υ)	c_i	$u(y_i)$
Normal	4	1	0.02W
Normal	∞	-1	0.0313W
Rec	∞	-1	1.6W
Rec	∞	1	0.0289W
	∞		

D. Relative Combined Standard Uncertainty

$$u_c=\sqrt{u_{typeA}^2+u_{typeB}^2}$$

$$=1.601W$$

E. Effective Degree of Freedom

Since u_1, u_2 and u_3 are infinite, Effective degrees of freedom υ_{eff} =

$$v_{eff}=\frac{u_c^4(y)}{\sum_{i=1}^{n}\frac{u_i^4(y)}{v_i}}=\frac{u_c^4}{\frac{u_A^4}{n-1}+\frac{u_B^4}{\infty}}=\infty$$

F. Expanded Uncertainty

For $\upsilon_{eff} = \infty$, the coverage factor of the relative combined standard uncertainty (k) is equal to 2 at 95 % level confidence.

And the expanded uncertainty $U = k \times u_c$

$U = 2 \times (1.601) = 3.202$ W

G. Reporting Result

The reporting result of AC Power Measurement Accuracy Test at 50 Hz, Power factor 0.5 lead, (60 Degree) is as shown the following Table V.

TABLE V
REPORTING RESULT

Range	Applied Input	Error Reading	Relative Uncertainty
300 V,2.00A	300 V, 2.00 A, Ø =60° (600 VA, 300 W)	0.78 W	5.335 mW/VA

V. CONCLUSION

The reported expanded uncertainty of measurement is state as the standard uncertainty of measurement multiplied by the coverage factor k = 2 which has been derived from the assumed rectangular probability distribution for a coverage probability of 95%. The estimation of uncertainty in measurement of AC power on single phase or three phases is the important quality of the measurement of electrical standard.

A calibration laboratory, or a testing laboratory performing its own calibrations, shall have and apply a procedure to estimate the uncertainty of measurement for all calibrations and types of calibrations. The laboratory shall use appropriate methods and procedures for all tests and calibrations within its specification. We hope we can build good relation in the future. “One standard, one test, one certificate, accepted everywhere”.

ACKNOWLEDGMENT

Regards and Thanks are not enough to say to our lectures, experts, project committee of NIMT, also training program sponsor, JICA and TICA and some people that we can not mention one by one. Please accept my best sincere regards and thank for all that support our training before and during the course until finish. I would like to express my deeply grateful to Mr. Voraphol Phapukdee, Metrologist, Department of Electrical Metrology, DC/AC Power, National Institute of Metrology (Thailand), for his help and support during the training in Thailand. And then I would like to thank Dr. Sai Kyaw Naing Oo for his considerable support, suggestion and constructive advice.

REFERENCES

[1] ISO (BIPM, IEC, IFCC, IUPAC, IUPAP, OIML): 1993: Guide to the expression of uncertainty in measurement,(GUM), 2nd edition, Genève, 1993

[2] BSS 17371-95 "Static Electricity Meters (electronic). Technical requirements and testing methods.

[3] BSS 17397-98 “Metrology. Dictionary of the basic and comon terms in metrology”

[4] BSS ISO IEC 17025 “General requirements for competence of testing and calibration laboratories”

[5] BSS ISO 1000 “Units SI and recommendations for application of divisible and other units”

[6] EA, publication EA-4/02 “Expression of the Uncertainty of Measurement and Calibration”

[7] www.trs-rentelco.com/Model/FLU_**5500A**.aspx - Operator Manual FLUKE 5500A