Precision Power Calibration System (PPCS) A Primary Standard of AC Power & Energy Traceable to base Units

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***Abstract*— This paper is related to the establishment of a Primary Standard of AC Power & Energy. This is traceable to Voltage, resistance (current in effect) and time. Two digitalized AC signals are generated one for voltage and the other for current. The signals are converted in analog signals by D/A converters. The voltage signal is amplified and applied to device under calibration (DUC) and for measurement, applied to a step down transformer, which is at same level when it was generated. The current amplifier generates the test currents which is given to the DUC and also to a current transformer (CT). The secondary side of the CT is burdened with a shunt and again brought at the level when it was generated. The two signals are measured by a Digital Multi-Meter (DMM) by a single clock signal. Then the two signals, are compared through DMM. The phase between voltage and current is applied by time delay.**

***Index Terms*—Primary Standard, Voltage , Current, Power Factor.**

I. INTRODUCTION

The present paper is about the establishment of Precision Power Calibration System (PPCS) at National Physical Laboratory India (NPLI) . The system is traceable to base units and is suitable for the measurement of active, reactive and apparent powers at any power Factors (PF) [1]. It makes use of digital signal synthesis and discrete Fourier Transform evaluation based on single master clock. The system not only measures power at power frequencies (45 to 65 Hz) but can also measure at 400 Hz [2] Communication with the PC is handled with bi-directional transfer of 8-bit wide data word that can be transmitted individually as ASCII character or in a block. The communication module has two 8 bit wide bus system for this purpose.

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II. OPERATING PRINCIPLE

The Primary standard of AC Power has been established in NPL India for last one year. It works on the principle that a two channel AC source generates sinusoidal voltages in digital form and converted to analog signal by D/A converter and the phase is introduced by time delay. Any phase difference +180º to -180º can be introduced and corrected if there is difference in the applied and measured value. One signal is for voltage and other for current. [3]

The voltage signal is amplified to different values and the voltage amplifier supplies the voltage to the device under calibration (DUC) and in parallel to the voltage transformer [1]. The secondary side of the transformer is connected to DMM through a signal switch. The other signal is amplified by a trans-conductance amplifier and test current is generated to different values, which is applied to the DUC and the primary side of a precision current transformer (CT). The secondary side of this CT side of a Current Transformer (CT). The secondary side of this CT is burdened with AC shunt. The voltage drop across the shunt is measured by DMM through signal switch. The two signals are compared with generated voltages and the error is calculated.

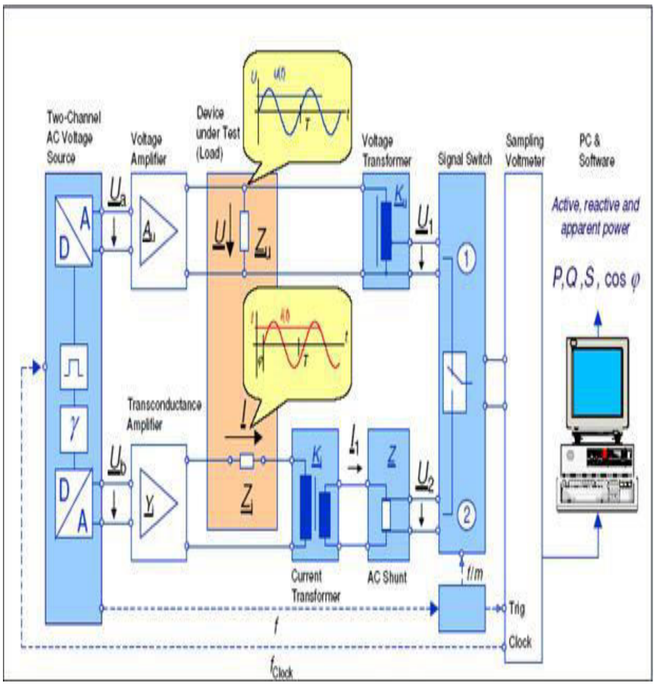

Fig. 1 Schematic diagram and working principle of Primary Power Calibration System (PPCS)

Fig. 2 Calibration of MSB 100 by PPCS Set-up

Synchronizing errors are eliminated [4] because of single clock signal used for generation as well as for measurement of both signals and also by the use of single voltmeter for measurement of all the voltage signals. The clock generator module generates a frequency-programmable output pulse that is based on an internal quartz oscillator (10 MHz) or an externally provided pulse signal at the clock input terminal.

The measurement uncertainties are in the range of ± 10ppm to ± 40ppm at k=2. The system is traceable to DC voltage, resistance and time.

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The active reactive and apparent powers are calculated by software and compared with the measured values from Device under calibration

The digital-analogue-converter slide-in modules convert the system pulse of the scanning volt meter (10 MHz) into two digitally synthesised, synchronous, sinus-shaped alternating , one for voltage at 6V and other for current at 1 V. The output voltages are galvanic ally separated. The programmable pre-divider and the option of determining the number of sampling points facilitates programming of almost any output frequency.

The Output currents from 0.1 A to 100 A are generated. Current range settings are at 0,1 A – 0,25 A – 0,5 A – 1 A – 2,5 A – 5 A – 10 A – 25A-50A-100A

Voltage ranges are 60-120-240-480 V

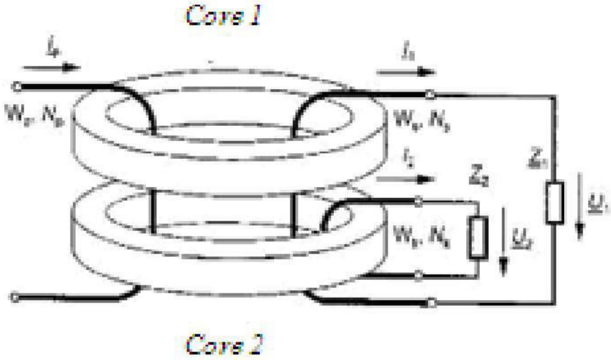

Fig. 3 Two step current transformer

Fig. 3 shows the structure of a two-step current transformer. It consists of two ring cores made of highly permeable, magnetically soft material: the main core (Core 1) and the compensation core (Core 2). They are provided with a primary coil W_P (number of turns N_P), a secondary coil (W_S, N_S) and a compensation coil (W_K, N_K). The primary and secondary coils envelop both cores, while the compensation coil only envelops the compensation core.The primary current $\underline{I}_P$ creates the secondary current $\underline{I}_1$ and the compensation current $\underline{I}_2$ through the impedances $\underline{Z}_1$ and $\underline{Z}_2$. This two-step arrangement ensures that the magnetization current, which is required for the magnetization of the main core (the primary cause of the inappropriate performance of one-step current transformers), is also magnetizing the compensation core and creating the compensation current $\underline{I}_2$. When the secondary and the compensation coil have the same number of turns ($N_S = N_K$), the compensation current $\underline{I}_2$ becomes nearly as large as the magnetization current required for the magnetization of the main core. If one adds $\underline{I}_1$ and $\underline{I}_2$ in a suitable manner and forms the quotient of the added currents ($\underline{I}_1 + \underline{I}_2$) and the primary current IP, the ideal conversion performance of a two-step current transformer results, which only depends ratio $K_{ni} = N_S/N_P$:

$$\frac{\underline{I}_1 + \underline{I}_2}{\underline{I}_P} = \frac{1}{K_{ni}} \cdot (1 + \underline{\varepsilon}_i)$$

Values of approx. 1 x 10^{-6} or 1µrad in phase can be achieved for the complex measuring error $\underline{\varepsilon}_i$ (with real part α_i and imaginary part β_i). When two resistors with the same nominal value R_N are used for the impedances $\underline{Z}_1$ and $\underline{Z}_2$ and the output voltage $\underline{U}_a$ is calculated as the total of the voltages $\underline{U}_1$ und $\underline{U}_2$, the following complex conversion K_{ju} results for the current/voltage transformer

$$K_{ju} = \frac{\underline{U}_a}{\underline{I}_P} = \frac{\underline{U}_1 + \underline{U}_2}{\underline{I}_P} = \frac{\left[(\underline{I}_1 \cdot \underline{Z}_1) + (\underline{I}_2 \cdot \underline{Z}_2)\right]}{\underline{I}_P} \approx \frac{R_N}{K_{ni}} = \frac{N_P}{N_S} \cdot R_n$$

In this idealized case, the properties of the current/voltage transformer only depend on R_n and the ratio of the numbers of turns N_P / N_S.

contribution Xi	value contribution	relative meas. Ur u(Xi) in 10 E - 06	sensitivity coefficient	Variance (ci*u(Xi)E-02 in E-12	weight %	power at 0.8PF
rms voltage U1	6V	1	1	1	8.8888889	
rms voltage U2	1V	2	1	4	35.555556	
Voltage Tx Fu	6V/120V=0.05	2	1	4	35.555556	
Current Tx Fi	1V/5A=0.2ohm	1.5	1	2.25	20	
with Ac shunt			Σ (var)	11.25	100	
Active power	P=480W	Relative Ur (TypeB)	in E-06	3.354101966		
0.8lead	Type A	all at k=1	ppm	1.7		
Type-A Standard Uncertanty (in ppm)						1.7
Combined Uncertanty (Uc) in ppm						3.7603191
Effective Degrees of Freedom (Using Welsch-Satterthwaite Formula)						215.44958
Coverage Factor (k) (From Students' t distribution)						2
Expanded Uncertanty (in ppm) at k=2						7.5206383
wrt app		PF	0.8			6.0165106
Date:	03.02.2015	2	(Note: MS-Excel is used for Evaluation of Uncertainty)			

Table 1 Measurement Uncertainty (Type A & Type B) for the PPCS at 120.0 Volts, 5A & 0.8 lead Power factor.

III. RESULTS:

Using the PPCS for the calibration of the national Standard of India COM 3000 at 120V/5A and 0.8c (lead) Power Factor Table 1 shows the results of uncertainties. Type A uncertainty as 1.7 * 10^{-6} while The Type B uncertainties include the uncertainties of the measurement of two rms voltages 6 V and 1V by the digital multi-meter and those of the voltage and current transformers which have been calibrated at these points. The sensitivity coefficient has been taken as 1.0. Variance is taken as the square of the multiplication of sensitivity coefficient and uncertainty at k=1. The weight of each uncertainty contribution is the % of that contributing factor with respect to the total variance. Finally variance is added and square root is taken to find the total type B uncertainty We can calculate the total uncertainty and taking 1* 10^{-6} as 1 ppm (part per million)

total uncertainty = $\sqrt{(\text{Type A})^2 + (\text{Type B})^2}$ = = $\sqrt{(1.7)^2 + (3.354)^2}$ = 3.76 ppm at k=1

As the degree of freedom is very high, we can take k as 2 and then expanded uncertainty would be 4.1*2= 7.52 ppm

COM3000 and MSB100A are the national reference standards with NPLI having highest metrological properties as low drift and low temperature coefficient. MSB 100A was calibrated

and low temperature coefficient. MSB 100A was calibrated by NIST USA 2009 at lower power factors. The same was calibrated by NPLI in 2012 and 2014 using the PPCS in different ranges (V x I) and power factors (PF). Tables 2 & 3 compare the values of MSB 100A in 2012 & in 2014 while table 4 & 5 compare at lower power factors from NIST, USA and NPLI and the values found are very close.

The difference in errors may be due to the drift of the instrument. Uncertainties in results in 2012 are as per our CMCs in BIPM website while in 2014 they are very less owing to the establishment of PPCS at NPLI Error in power is given as x ppm & uncertainty as ux ppm (k=1). [4 & 5]

Range	P F	Year	xi (ppm)	Ux (ppm)
120V/ 5A	1.0	2012	-100.0	25
		2014	-118.0	10
	0.5i	2012	-62.0	25
		2014	-67.0	10
	0.5c	2012	-22.0	25
		2014	-24.0	10

Table 2 Comparison of results of MSB 100A by NPLI For UPF and 0.5i/c PF at 120V/5A

Range	P F	Year	xi (ppm)	Ux (ppm)
240V/10A	1.0	2012	-86.0	25
		2014	-90.0	10
	0.5i	2012	-49.0	25
		2014	-54.0	10
	0.5c	2012	+23.0	25
		2014	+23.0	10

Table 3 Comparison of results of MSB 100A by NPLI For UPF and 0.5i/c PF at 240V/10A

Range	PF	NMI	Year	xi (ppm)	Ux (ppm)
120V/ 5A	0.01i	NIST	2009	-15.0	15
		NPLI	2012	-20.0	35
		NPLI	2014	-13.0	15
	0.01c	NIST	2009	-19.1	15
		NPLI	2012	-22.0	35
		NPLI	2014	-33.0	15

Table 4 Comparison of results of MSB100A by NPL and NIST for 0.01 (i/c) PF at 120V/5A

Range	PF	NMI	Year	xi (ppm)	Ux (ppm)
240V/ 10A	0.1i	NIST	2009	-20.8	15
		NPLI	2012	-23.0	35
		NPLI	2014	-36.0	15
	0.1c	NIST	2009	-25.0	15
		NPLI	2012	-21.0	35
		NPLI	2014	-22.0	15

Table 5. Comparison of results of MSB100A by NPLI and NIST for 0.1 (i/c) PF at 240V/10A

IV. CONCLUSION:

The traceability of PPCS is achieved by the RMS voltmeter and AC Shunt with small and well known frequency characteristic which are calibrated against the national standards and the errors whatever be are incorporated in the software. The reduction of measurement uncertainty is achieved by the use of single clock signal for the generation and measurement of the signals. Use of single voltmeter reduces synchronization errors and unavoidable differences between the sampling voltmeters.

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