비동기 샘플링에 의한 전력과 에너지 측정 기준시스템

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Electrical Power and Energy Reference Measurement System with Asynchronous Sampling

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Abstract - A digital sampling algorithm that uses a two high resolution integrating Voltmeters which are synchronized by Phase Lock Loop (PLL) time clock for accurately measuring the parameters, active and reactive power, for sinusoidal power measurements is presented. The PLL technique provides high precision measurements, root mean square (rms), phase and complex voltage ratio, of the AC signal. The system has been designed to be used at the Korean Research Institute of Standards and Science (KRISS) as a reference power standard for electrical power calibrations. The test results have shown that the accuracy of the measurements is better than 10 μW/VA and the level of uncertainty is valid for the power factor range zero to 1 for both lead and lag conditions. The system is fully automated and allows power measurements and calibration of high precision wattmeters and power calibrators at the main power frequencies 50 and 60 Hz.

1. Introduction

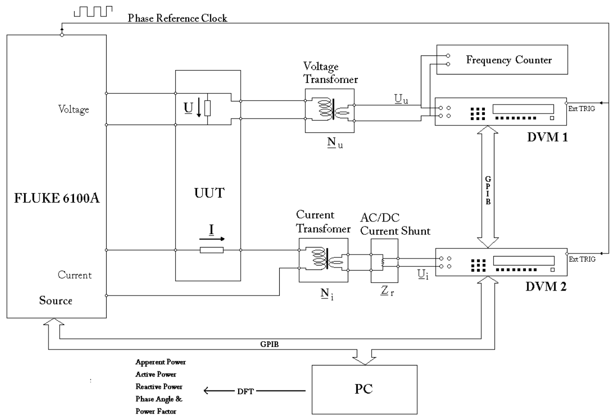
Precise power measurement is very important in the area of energy maintenance to reduce the power loss that directly affects to the economy of any country. All industries try to minimize power losses, while they maintaining their traceability of power measurement. Therefore, the capabilities of power testing and calibration have grown and the demand on National Metrology Institutes (NMI) to provide such services has increased. In order to response to changing needs of the power measurement industries, KRISS has to improve the level of uncertainty 10 ppm or better as done by other NMI's. The important factors of the power standards are determination of active power, apparent power and power factor which minimizes the reactive power and the errors of those factors should be minimized for power standard and its precise measurement.

The existing traceability maintenance system at KRISS based on the power comparator method which uses the thermal converters (TC) and the uncertainty of the system is more than 20 μW/VA. Therefore, the power standards laboratory of KRISS began research and development work of the sampling system based reference power standard to fulfill the requirement. The sampling technique, dual channel method successfully used in [1] and [2] or single channel as used in [3], was employed by few NMIs recently. The analog to digital converters (ADC) are more important when the sampling technique is being employed and more details can be found in [1] and [2]. The precision measurement of alternating (ac) signals by digital sampling can be best accomplished with the use of a phase-lock loop (PLL) [4]. However, most of the dual channel sampling technique not included the PLL synchronization clock. Furthermore, the technique used Master-Slave triggering sequence of the Digital Voltmeters (DVM) with fixed time delay when the voltage signals were sampled. In this study, another possibility of synchronization the two DVM using PLL time clock instead of Master Slave method is considered. More details will be discussed in the layout. The proposed method although operates at power line frequency 60 Hz, it can be used as a reference standard with the frequency rage of 20 to 100 Hz precisely.

2. Theory

2.1 Layout

The measuring system of the reference power standard at KRISS is represented schematically in Fig. 1. The system mainly consists of power source and two sampling DVMs measured the output voltages of voltage transformer and AC/DC current shunt.

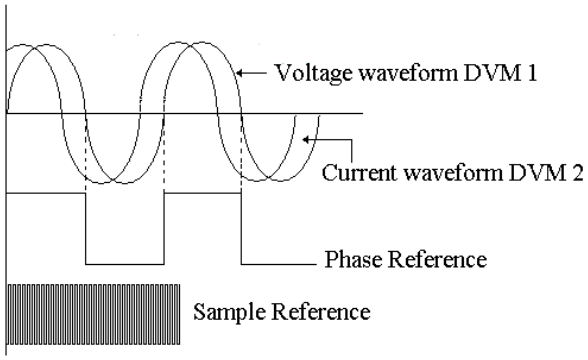


<Fig 1> Layout of the KRISS Reference Power Standard

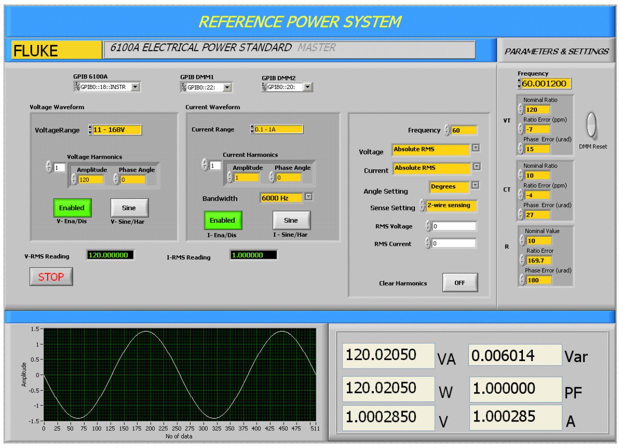
The source, Fluke 6100A, generates the ac voltage and current at the same frequency variable in amplitude and with the phase difference 0 to 180 degree. The voltage output $\underline{U}$ directly connected to the potential transformer (PT), up to 220 V, and parallel to the instrument to be calibrated (UUT). The current output $\underline{I}$ is supplied to the UUT and also to the primary of a current transformer (CT) up to 50 A, specially developed at the laboratory. The secondary of the CT connected to the AC-DC current shunt, and the nominal value of the outputs voltages, $\underline{U}_u$ and $\underline{U}_i$, are 1 V. The both voltages are directly connected to the sampling voltmeters, DVM 1 and DVM 2, operate as a waveform aquisition system, controlled by a computer with an IEEE.488 interface.

The timing clock, generated by source, of the data acquisition system is controlled by the programme and connected to the external trigger input of the both DVMs. The sample and phase reference are provided by the source, Fluke 6100A, and can be controled by the GPIB commands. The Fig. 2 shows the relationship between reference signal and analog output.

The sample reference only appears when the positive zero crossing of the phase reference signal on the GPIB "ON" condition and triggers he both DVMs to start sampling the waveforms data, phase locked to the master clock of the source. In this synchronization technique not appears time delay, however, a small jitter between two DVMs and can be corrected through the programme. The both channels take 256 samples per cycle yielding 2560 samples out of ten cycles and averaged to obtain good results.



<Fig 2> Synchronization pattern of the DVMs.



<Fig 3> Screen Printout of the developed software

2.2 Analysis

The FFT function is used to calculate discrete Fourier transform (DFT) for each sample to calculate the power parameters and all of the process is controled by the developed sophisticated software. The rms value of the waveform can be calculated as follows

$$rms = \sqrt{V_{DC}^2 + \frac{1}{2}\frac{Sin(\pi.f.T_a)}{\pi.f.T_a}\{(DFTRe)^2 + (DFTIm)^2\}} \qquad (1)$$

Where T_a is aperture of the DVM and f is frequency of the input signal.

The Voltage $\underline{U}$ current $\underline{I}$ and phase angle between them are the interest quantities that calculate active and reactive power. The quantities can be expressed in terms of $\underline{U}_u$ and $\underline{U}_i$ combining with voltage transformer (VT) ratio $\underline{N}_u$, CT gain ratio $\underline{N}_i$ and AC-DC current shunt resister impedance $\underline{Z}r$, as shown in Fig. 1. After digitizing the analog input voltages of the DAQ may be expressed as complex numbers since the FFT calculate real and imaginary parts of the DFT for fundamental and its harmonics. Therefore, $\underline{U}_u$ and $\underline{U}_i$ are complex numbers and U_u is rms amplitude of the voltage input. The VT, CT shunt resistor parameters are also complex numbers since they can be express using their relative ratio and phase errors. Then the main power parameters of the input signals may be written as follow:

the active power is

$$P = \frac{1}{4}U_u^2 Re\,\underline{Y} \qquad (2)$$

and the reactive power is

$$Q = \frac{1}{4}U_u^2 Im\,\underline{Y} \qquad (3)$$

where

$$\underline{Y} = \left\{\left(\underline{N}_u + \frac{\underline{N}_i}{\underline{Z}_r}\frac{\underline{U}_i}{\underline{U}_u}\right)^2 - \left(\underline{N}_u - \frac{\underline{N}_i}{\underline{Z}_r}\frac{\underline{U}_i}{\underline{U}_u}\right)^2\right\}$$

The sophisticated algorithm was developed using LabView, and the screen printout is shown in Fig.3, The software calculates all power parameters and display.

3. Results

High precision power meters like RD33 product of Radian Co., MSB 100 from Rotek were calibrated using develop reference system. The input voltages are 120 V and 240 V. The current range is 1 A to 50A. The calibration were carried out for the power factors 1, 0.5 lead and 0.5 lag. The results were agree within the specifications of the power meters.

The uncertainty of the reference power measurement system is within the 10 μW/VA. The uncertainty mainly depend on the calibration uncertainty of Current transformer (CT), Voltage transformer (VT), Current Shunt , AC-DC transfer uncertainty and phase error of the system. The DFT calculates the AC-DC error and phase error of the system and both are within the 3 ppm. The achievement of the 10 ppm uncertainty of the power measurement is in higher level with compare to other NMI's. The uncertainty can be reduced further improving the uncertainty of CT and VT. This needs to be developed and considered as future plan.

4. Conclusion

The application of the sampling technique that utilizes the DVMs has allowed to design a system for the measurements of electrical power for power frequencies having relative uncertainties lower than 10 μW/VA. for power factor 0 to 1 both lead and lagging conditions. The system is now used at KRISS as a primary standard for the precision measurement of electrical power. The improvement of VT and CT accuracy and their calibration uncertainties, the level of uncertainty of the system bound to be significantly reduced.

References

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