2009년도 대한전기학회 하계학술대회 논문집 2009. 7. 14 - 17

디지털 샘플링 방법을 사용한 교류전압과 전류의

위제싱허, 박영태,
한국표준과학연구원,

Traceable AC Voltage and Current Measurements Using Digital Sampling Technique

W.M.S. Wijesinghe, Young Tae Park
Korea Research Institute of Standards and Science

Abstract - The traceability maintenance system for the AC voltage and current has been developed at the frequency range of 20 Hz to 100 Hz without using any compensation technique which is used at thermal converter (TC) ac-dc transfer system at low frequencies. The system uses a digital voltmeter (DVM) as a data acquisition system of the input waveform and stored data in memory. The developed algorithm acquires and processes the sampling data to calculate the root mean square (rms) value of the input voltage of DVM which operates at DC 10 V range for better accuracy. The best uncertainty of the AC voltage measurements is 3 μV/V within the frequency range. The best uncertainty of the AC current measurements is better than the 5 μA/A and mainly depend on the current to voltage converter, ac-dc current shunt or Current Transformer (CT), used for the measurement

1. Introduction

The traceability measurements of AC quantities are generally established by thermal converters (TC) which produces the same thermal effect for the same quantity of AC and DC voltages. However, the accuracy of the ac-dc transfer measurements limit at low frequencies due to low thermal inertia of the thermal converters. Consequently, a error compensation method has to be used to obtain correct value. The most precise methode to determine the rms value of an ac voltage is the ac-dc transfer with a Multijunction Thermal converters (MJTC). It is known that the ac-dc transfer difference together with its uncertainty increases below 100 Hz. It can be evaluated with an uncertainty of 0.5 ppm down to 10 Hz [1]. However the fabrication of MJTC is difficult and not available in commercially. Therefore, simple and alternative technique need to be developed for traceability maintenance of ac quantities.

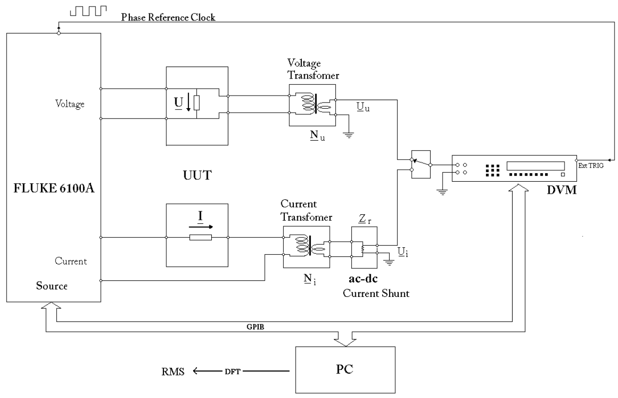
Another approach to determine the rms value of ac voltage is the sampling technique with a analog to digital converter (ADC). The precision of the sampling method depends on the choice of the ADC and usually high precision digital voltmeter (DVM), HP-3458A, is used for this purpose. More details can be found in [2,3]. In the past, several laboratories initiated research and development of sampling technique appling the digital voltmeter and one of the first important contribution was Swerlein's algorithm [4]. The data processing in the algorithm was in time domain and it has been exhaustively tested [5]. The extension version of the Swerlein's algorithm [6] processed the sapling data in frequency domain and obtained the results within the level of uncertainty 2.5 ppm. The Fourier coefficients of the waveform model equation used in the algorithm [6] were evaluated by the least-squares procedures based on the minimization technique. The data processing time is more longer in least-squares methode. Furthermore, the total number of harmonics being considered for the calculation of rms limited to eleven or less in most application. In this study Fast Fourier Transform (FFT) method is considered to calculate Discrete Fourier Transform (DFT) minimizing the data processing time.

2. Theory

2.1 Layout

The traceable ac voltage and current measuring system is shown in Fig. 1. it mainly consists of voltage and current source and the data aquisition system. The measurement parameter either current or voltage can be selected through the channel selector connected to the DVM.

The source generates the ac voltage or current at the same frequency. The voltage channel $\underline{U}$ directly connected to the potential transformer (PT), up to 220 V, and parallel to the instrument to be calibrated (UUT). The output of the PT $\underline{U}_u$ connected to the channel selector.



<Fig 1> Layout of the measuring system

The current output $\underline{I}$ is supplied to the UUT and also to the primary of a current transformer (CT) up to 50 A, 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 connected to the sampling voltmeter by channel selector. DVM operate as a waveform aquisition system, controlled by a computer with an IEEE.488 interface.

2.2 Signal Processing

A software program drives the acquisition system. At each measurement point, the setting of all instrument of the system are preliminarily established. The other information required by the instruments such as address, range and the information, no. of samples, sampling frequency, aperture time etc, about measurement are set before run the program. Then the program controls the acquisition of the series of samples from the DVM, and the resulting data are stored in the memory of the computer. Subsequently, a series of samples is processed to compute the amplitude of the voltage or current. The data calculation option, voltage or current measurements, can be controlled changing the mode of the programme.

In the data reconstruction procedure, the signal of the voltage is assumed to be represented as Fourier function of time by the following model:

$$V(t)= \sum_{n=0}^{N-1} V_{cn} cos(2\pi nft) + \sum_{n=0}^{N-1} V_{sn} sin(2\pi nft) \qquad (1)$$

where V_{cn} and V_{sn} are the amplitudes of the cosine and sine n^{th} harmonics component of the voltage waveform and f is the frequency of the fundamental. The parameters are unknown and are computed up to the oder of harmonics N-1 from the acquired samples by a propper algorithm which calculates the DFTs of the waveform mentioned below:

$$V_{cn} = \frac{2}{N}\sum_{k=0}^{N-1} V(t_k)cos(2\pi nft_k) \tag{2}$$

$$V_{sn} = \frac{2}{N}\sum_{k=0}^{N-1} V(t_k)sin(2\pi nft_k) \tag{3}$$

As mentioned above to solve the equations (2) and (3) can be solved using FFT algorithm. The program calculate DFT for each samples and then apply frequency correction factor of the ADC. The frequency correction for n^{th} harmonics is:

$$K_n = \frac{\pi.n.f.T_a}{sin(\pi.n.f.T_a)} \tag{4}$$

Where T_a is aperture of the DVM. Then the rms value of the input signal can be written as

$$rms = K_g\sqrt{V_0^2 + \frac{1}{2}\sum_{n}^{M} K_n(V_{cn}^2 + V_{sn}^2)} \tag{5}$$

where K_g is DC gain correction of the DVM and M is the total number of harmonics.

The DVM always operates in 10 V range and the voltages below 10 V can measure directly without PT and calculates according to equation (5). The voltage between 10 and 220 computes as follows:

$$U_{rms} = N_{nu}(1+\alpha_u)U_{u-rms} \tag{6}$$

where N_{nu} is the nominal ratio of the PT and α_u is the ratio error of the PT.

The ac current is determined by the following equation:

$$I_{rms} = \frac{N_{ni}(1+\alpha_i)}{R_n(1+\alpha_r)}U_{i-rms} \tag{7}$$

Where

N_{ni} - nominal ratio of the CT

α_i - ratio error of the CT

R_n - nominal resistance of the ac-dc shunt

α_r - relative ratio error of the ac-dc shunt

3. Evaluation of Results

The measurements were done on DC mode, therefore the results traceable to DC voltage that is best accuracy can be archived for ac quantities. Either current or voltage measurements, the final waveform acquired by DVM is 1 V voltage signal. Therefore, error evaluation of 1 V should be evaluated at first. Considering 1 V signal the main uncertainties contribution to the final value are DVM DC uncertainty and the sampling uncertainty. The first is within 0.5 ppm and the second is depend on several factors of ADC. They are bandwidth, noise, amplitude correction of frequency and computation of DFTs. The details uncertainty analysis shows that the best uncertainty is within 3 ppm for 1 V measurement. In addition, PT ratio error uncertainty take into account at high voltage measurement and it is better than 10 μV/V with the developed system.

The uncertainty of the CT ratio error and the ac-dc shunt resistor ratio error are the main factors of current measurements. Those factors are not very high values and it was found to be 5 μA/A best uncertainty for current measurement. The values mentioned above are valid for withing the frequency range of 20 Hz to 100 Hz.

4. Conclusion

The developed system shows that the ac quantities can be measured using digital sampling technique. Furthermore, the method provides high accurate results and shows that alternative option for MJTC within the above mentioned level of uncertainties. Further improvements are possible with high precision CT and PT. Also the results can be used within the low frequency range without any compensation. The results were evaluated using MJTC and agreed within the level of uncertainties. The measurements are traceable to DC voltage standard since the DVM operates at DC mode. The system is fully automatic and final results display on the screen and test instrument directly compares with the values given by the programme. The operation and maintenance of the system very easy compare to MJTC system.

References

[1] M. Klonz, " AC-DC transfer difference of the PTB multijunction thermal converter in the frequency range from 10 Hz to 100 kHz, " IEEE Trans. Instrument Measurements, Vol. IM-36, pp. 320-329, June 1987.

[2] U. Pogliano, " Use of integrative analog-to-digital converters for high precision measurement of electric power," *IEEE Trans. Instrument Meas., vol 50, no. 5, pp 1315-1318, Oct 2001.*

[3] Endre Toth, A. M. R. Franco and R.M. Debatin, " Power and Energy Referance System, Applying dual-Channel sampling", *IEEE Trans. Instr. Meas., vol. 54, no 1 Feb. 2005.*

[4] R. L. Swerlein, " A 10 ppm Accurate Digital ac Measurement Algorithm", *Hewlett- Packard internal publication, Aug. 1991.*

[5] M. Kampik, H. Laiz, and M. Klonz, " Comparison of three accurate methods to measure AC voltage at low frequencies." *IEEE Trans. Instum. Mea., Vol. IM-49, pp. 429-433, Apr. 2000.*

[6] Gregory A. Kyriazis, " Extension of Swerlen's Algorithm for AC Voltage Measurement in the Frequency Domain," *IEEE Trans. Instum. Mea., Vol. IM-52,No. 2, pp. 367-370, Apr. 2003.*