Accuracy Verification of Simplified Error Correction Method in Digital Electricity Meters

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Abstract. *There are practically four main error sources in digital sampling electricity meters: errors of analogue input circuits, errors of the sampling process, errors of analogue-to-digital (A/D) conversion and errors of digital calculations. Brief description of correction of these errors is given. Very often it is not possible to make correction of every sample. Then, only the final calculated values are corrected and, thus, additional errors are introduced. MATLAB environment was used to find out the errors of such simplified calculations of the active power and the rms value of the voltage in case of harmonic and nonharmonic voltages and currents.*

Keywords: Digital Electricity Meter, Error Correction, MATLAB

1. Introduction

Basic instruments for the most accurate measurement of electric power and energy are static digital electricity meters. They use digital multiplication of voltage and current samples, [1], [2], received from one A/D converter with multiplexed inputs, [3], or they may use separate A/D converter for each input signal, [4]. The advantages of such instruments are obvious: high accuracy, short- and long-term stability, complex net parameters measurements, possibility of remote automated data processing, auto-calibration, self-test and many other functions resulting from the microprocessor-based digital system possibilities. Nowadays, digital signal processors make it also possible to measure reactive and apparent power, phase shift, power factor and frequency spectra of the power network signals.

Very important characteristic of electricity meters is their accuracy. It depends on the accuracy of analogue input circuits, the accuracy of the sampling process itself, [5], the accuracy of A/D conversion and the accuracy of digital calculations. There are many methods of error correction in digital electricity meters, [6]. Most of these methods use software correction based on calibration process, in which calibration constants are obtained. In the electricity meters usually voltage calibration, current calibration and parasitic phase shift correction are necessary. Every voltage and current range is calibrated separately. Calibration process is usually carried out using harmonic waveforms but there are also attempts to evaluate electricity meters accuracy under nonharmonic conditions [7], [8].

2. Error Correction in Digital Electricity Meters

The measurement errors caused by the analogue input circuits can be simply eliminated in the digital signal processing. The main problem is the stability of the parameters of these analogue parts. The analogue input circuits must be constructed using highly stable components.

The sampling of a real waveform usually approximates the waveform by a staircase or a piecewise linear function. For the sake of calculation simplicity, mainly staircase approximation is used. In symmetrical signals the errors of sampling in one quarter of period are partly compensated in another quarter.

Usually, synchronized or approximately synchronized sampling is used, [5]. Approximately synchronized sampling with starting point in the instant of zero crossing of the sampled signal is the usual case. Better accuracy can be achieved if the sampling starts in the instant of crossing the rms value of the sampled signal, [9]. It is difficult to realize in a three-phase system or if there is a phase shift between the voltage and the current. If the number of samples used in a summation interval is sufficiently high, then the error of sampling is low.

Because of errors caused by time delay between the multiplied voltage and current samples, A/D converter with multiplexed inputs is not used in precise instruments. Low-resolution A/D converters (low number of bits) cause unacceptable quantisation errors. Precise instruments use sigma-delta A/D converters with high resolution (over 16 bits) and high sampling rate (tens kSPS). All the measured quantities are then calculated during one period but, usually, the results are averaged again during longer summation intervals to get higher accuracy.

To find out the error of calculation when only the final calculated values were corrected, simplified calculations of the active power, P, and the rms value of the voltage, V, were compared with the calculations where every sample was corrected, [10], [11], [12], [13]. The selected correction function was a linear function of the type $y = ax + b$, where the constant a represents the gain error and the constant b is the offset error. All the calculations were carried out by MATLAB. In case of **harmonic signals** 1000 samples of the voltage and current per period were calculated using the equations

$$u_i = a_1 V_m \sin(\frac{2\pi i}{1000}) + b_1 \quad (1)$$

$$i_i = a_2 I_m \sin(\frac{2\pi i}{1000}) + b_2 \quad (2)$$

where i = 1, 2, ..., 1000. For simplicity, the values V_m and I_m were set to unity.

The following equations show the correct use of the correction function (every sample corrected) (the current calculation is not shown, because it is similar to voltage calculation)

$$V_1 = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{1}{a_1}v_i - \frac{b_1}{a_1}\right)^2} \quad (3)$$

$$P_1 = \frac{1}{N}\sum_{i=1}^{N}\left[\left(\frac{1}{a_1}v_i - \frac{b_1}{a_1}\right)\left(\frac{1}{a_2}i_i - \frac{b_2}{a_2}\right)\right] \quad (4)$$

The simplified calculations of the corrected values (the final calculated values corrected) are given by the equations

$$V_2 = \frac{1}{a_1}\sqrt{\frac{1}{N}\sum_{i=1}^{N} v_i^2 - b_1^2} \quad (5)$$

$$P_2 = \frac{1}{a_1 a_2}\frac{1}{N}\sum_{i=1}^{N} v_i i_i - \frac{b_1 b_2}{a_1 a_2} \quad (6)$$

The differences of the corresponding values are the calculation errors given by equations

$$\delta_u = \frac{V_2 - V_1}{V_1} \times 100 \quad (7)$$

$$\delta_P = \frac{P_2 - P_1}{P_1} \times 100 \quad (8)$$

The errors δ_u and δ_P were plotted for different values of the coefficients a_1, a_2 (gain) and b_1, b_2 (offset). The offset is relative, referenced to the amplitude V_m or I_m. The results show that the relative errors of such simplified calculations are negligible, on the level of calculation errors of MATLAB (approximately 10^{-15}). They are small enough to use simplified calculations instead of much more complicated and time-consummating exact calculations.

To investigate the situation, when the current has a **phase shift** towards the voltage, the current samples were calculated using the equation

$$i_i = a_2 I_m \sin(\frac{2\pi i}{1000} + \varphi) + b_2 \tag{9}$$

with phase shifts φ = 30°, 60° (very often used) and 72° (2π/5 rad). The powers were calculated using equations (4) and (6) and the error δ_P was again calculated using equation (8). The results from MATLAB (for the phase shift φ = 72°) show that the relative error of such simplified calculation is of the order of tens ppm and is again negligible. But this error increases with increasing phase shift because of the decreasing value of the power factor cosφ and hence, the decreasing value of the calculated power.

In case of **nonharmonic signals** 1024 samples of the voltage and the current per period were calculated in MATLAB using the equations of the desired waveforms. The amplitudes V_m and I_m were set to unity. First, both signals, v_i and i_i, are equal. In this case the rms value differs from the power only in the fact that the rms value is calculated as the square root of the mean value of the sum of samples. The properties of the rms value error are similar as that of the power error, so, the results of the power will be given only.

Very often a half-wave rectified signal is used. Only the first four harmonics were used and the phase shifts π/6 in the second harmonic, π/5 in the fourth harmonic and π/7 in the sixth harmonic were added. The error of such simplified power calculation is relatively high, of the order of tenth %, what is unacceptable for precise instruments. MATLAB calculations show that this error is nearly equal even without phase shifts and with up to ten harmonics used.

Another test signal was the sine wave signal with uniformly distributed random noise superimposed on it. The errors of the simplified power calculation for the noise amplitudes 0 %, 10 % and 20 % of the amplitude of the sine wave signal were in the range ±10 ppm but they differed for different shapes of the generated noise signal.

The relative errors of the simplified calculations of power for a triangle wave signal with only the first ten harmonics used were on the level of calculation errors (approximately 10^{-15}). Similar errors were achieved for a square wave signal with only the first ten harmonics used.

The calculated relative error of the power for the square wave signal with the added phase shifts π/3 in the third harmonic and π/5 in the fifth harmonic was of the order of 1 ppm.

In real conditions, the voltage waveform in a power network is nearly harmonic, but the current waveform is distorted, [14]. Such situation has been also investigated. The MATLAB results show that these errors are a bit lower (from 20 % to 30 %) than corresponding power errors with both, voltage and current signals equally distorted. The only difference is the half-wave rectified signal where these errors are approximately half.

3. Conclusions

Brief description of the four main error sources and the error correction is given. In case if only the final calculated values are corrected, additional errors are introduced. MATLAB environment was used to find out the errors of such simplified calculations of the active power P in case of harmonic and nonharmonic voltages and currents. If both signals are equal, then these errors are negligible for harmonic signals and for noisy signals. In case of nonharmonic signals the error of the half-wave rectified signal is relatively high, of the order of tenth %. It is caused by nonsymmetry of such signal. From calculations it can be seen that it is not important how much the signal is distorted. Only the symmetry of the signal round some vertical axes is of the great importance. If the voltage waveform is harmonic and the current waveform is distorted, then these errors are a bit lower (from 20 % to 30 %) than corresponding errors with both, voltage and current signals equally distorted. The only difference is the half-wave rectified signal where these errors are approximately half.

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