Digital Power and Energy Measurement

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Abstract *A brief description of the designed digital sampling electricity meter based on the modern Texas Instruments TMS320C6711 DSP is given. The electricity meter measures basic electric network parameters such as rms values of voltages and currents, powers, energy, power factor and net frequency. A brief discussion of measurement accuracy and error correction is also given.*

1. Introduction

Basic instruments for the most accurate measurement of electric power and energy are 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, autocalibration, selftest and many other functions resulting from the microprocessor-based digital system possibilities. With today‘s high computing power of digital signal processors it is also simple to measure the reactive power, apparent power, phase shift, power factor and the frequency spectrum of the power network signals.

Very important characteristic of electricity meters is their accuracy. It depends on the accuracy of the analogue input circuits, the accuracy of the sampling process itself, [5], the accuracy of A/D conversion and the accuracy of digital calculations. In digital sampling electricity meters the measurement error can be simply eliminated in the digital signal processing. In this case the main problem is the stability of the parameters of these parts which handle the measured signals. The analogue input circuits must be constructed using highly stable components. A/D conversion with multiplexed inputs of A/D converter must use one of the known methods of compensation of errors caused by time delay between the multiplied voltage and current samples, [6]. Better way is to use separate A/D converter for each input signal. There are many methods of error correction in digital electricity meters, [7]. Most of these methods use software correction based on calibration process.

Digital electricity meters have different measurement and communication possibilities and different prices. The accuracy of the best instruments is of the order 0.01 %.

2. Electricity meter description

The proposed instrument is able to measure all basic three-phase net parameters (rms values of voltages and currents, active, reactive and apparent power, power factor, frequency and energy delivered into the load). It can calculate the frequency spectra using FFT.

Block diagram of the proposed instrument for power and energy measurement (PEM 6711) is in Fig.1, [8]. Analogue part contains circuits for sensing and conditioning of the net voltages and currents. A block of six A/D converters digitises the signals from the analogue part. The DSP part with the Texas Instruments TMS320C6711 processor makes necessary calculations and signal processing in digital form. It also contains software for three-phase signal generation with the output through a D/A converters block and a frequency output with the frequency proportional to the measured power.

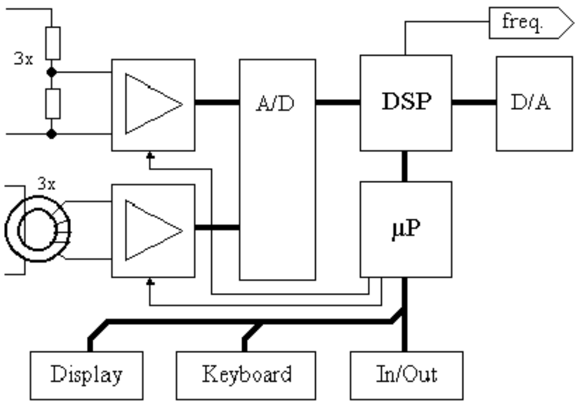

Fig. 1. Block diagram of the designed electricity meter.

Microcontroller board with the Texas Instruments TMS320F243 processor controls the operation of the device. It controls some circuits of the analogue part, displays the results and enables communication with other instruments via infrared or RS 485 interfaces. For presentation of time and frequency characteristics, graphical LCD display with the resolution 240x128 dots is used.

3. Error corrections in electricity meters

To increase the accuracy of the electricity meter a few precautions must be done. First of all the start of sampling must be synchronised with the input signal. Simple and often used method is to start sampling in the instant of zero crossing of the input voltage or current. 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. The best accuracy, from this point of view, needs synchronization of the sampling frequency with the frequency of the input signal, [2].

The sampling of the real waveform usually approximates the waveform by a staircase or a piecewise linear function. The rms value and the power are calculated in staircase approximation by, [10],

$$U = \sqrt{\frac{1}{N}\sum_{i=0}^{N-1} u_i^2}\ , \qquad P = \frac{1}{N}\sum_{i=0}^{N-1} u_i i_i\ , \tag{1}$$

and in piecewise linear approximation by

$$U = \sqrt{\frac{1}{3N}\sum_{i=0}^{N-1}\left(u_i^2 + u_i u_{i+1} + u_{i+1}^2\right)},\quad P = \sqrt{\frac{1}{3N}\sum_{i=0}^{N-1}\left[u_i i_i + \frac{1}{2}\left(u_{i+1} i_i + u_i i_{i+1}\right) + u_{i+1} i_{i+1}\right]} \tag{2}$$

The approximation increases the error of measurement but because of the symmetry of sine and cosine functions this error may be small. The error increases if the waveform is distorted.

The number of samples, *N*, used to get the average value with the desired accuracy must be sufficiently high, [5]. That means high sampling rate or long averaging time. High sampling rate makes it possible to average the samples with good accuracy even during one period of the net signal. It is then possible to register even short transitions in power consumption and to change the frequency output after every period of the net signal.

Usually, the input signal conditioning circuits are not adjusted very accurately. Even very fast DSP is not able to make corrections of every sample (for the three-phase system six samples must be corrected per one sampling period and all other calculations and operations must be also done). One possible way to overcome this problem is in [11]. Of course, it is possible to use lower sampling rate to extend the time period between two neighbouring samples but with the consequences following from the notes mentioned above.

One serious problem to be solved for accurate power calculation is the calibration process itself. In electricity meters, three values must be calibrated: voltage U, current I and parasitic phase shift φ_p between U and I. The best way is to carry out the calibration process automatically, using a computer. The computer controls a signal source (sets the desired measured values), reads the necessary values from the calibrated and reference instrument in the same instant, calculates the calibration constants and stores them in the memory of the calibrated instrument. Manufacturers of electricity meters usually have such possibility.

The designed instrument contains an algorithm for voltage calibration using the least squares method. The current calibration can be done using the same algorithm but usually the measured current is not stable. In this case it is necessary to synchronise the measuring time period of the calibrated and the reference instrument or to use mean values. It is also possible to use frequency output of the instrument with the output frequency proportional to the apparent or active power. The frequency proportional to the measured power is compared with the correct value in the precise reference comparator. In this way, the calculated apparent power, S_i, is compared with the correct power value, S. As the voltage is correct (calibrated already) the mean value of the apparent power relative error is the same as the mean value of the current relative error. These errors in a few points over the calibrated current range can be used to calibrate the current by the least squares method.

In the case of the frequency output based on the active power such current calibration procedure must be repeated because of its slight dependence on the phase shift correction. A method was carried out to calculate the current and the phase shift at the same time. The measured powers, P_i, $P_{i\varphi}$, for two different phase shifts, 0, φ, are compared with the correct values, P, P_φ, respectively, using the frequency output of the instrument. The mean values of the relative errors, δ, δ_φ, yield the mean values of the calculated powers

$$P_i = P(1+\frac{\delta}{100}), \qquad P_{i\varphi} = P_\varphi(1+\frac{\delta_\varphi}{100}). \tag{3}$$

The equations to be solved to get the mean values of the measured current and parasitic phase shift are

$$P_i = UI\cos(\varphi_p), \qquad P_{i\varphi} = UI\cos(\varphi+\varphi_p) \tag{4}$$

Using mathematical formula for the cosine of the sum of two phase angles, [12], and taking into account that φ_p is a small phase shift it is possible to simplify this equations. The simplest solution follows from the well known fact that if x is small then $\sin(x) = x$ [rad] and $\cos(x) = 1$

$$I = \frac{1}{U}\frac{2P_i^3 \sin^2(\varphi)}{2P_i^2 \sin^2(\varphi) - [P_i \cos(\varphi) - P_{i\varphi}]^2}, \qquad \varphi_p = \frac{P_i \cos(\varphi) - P_{i\varphi}}{P_i \sin(\varphi)}. \tag{5}$$

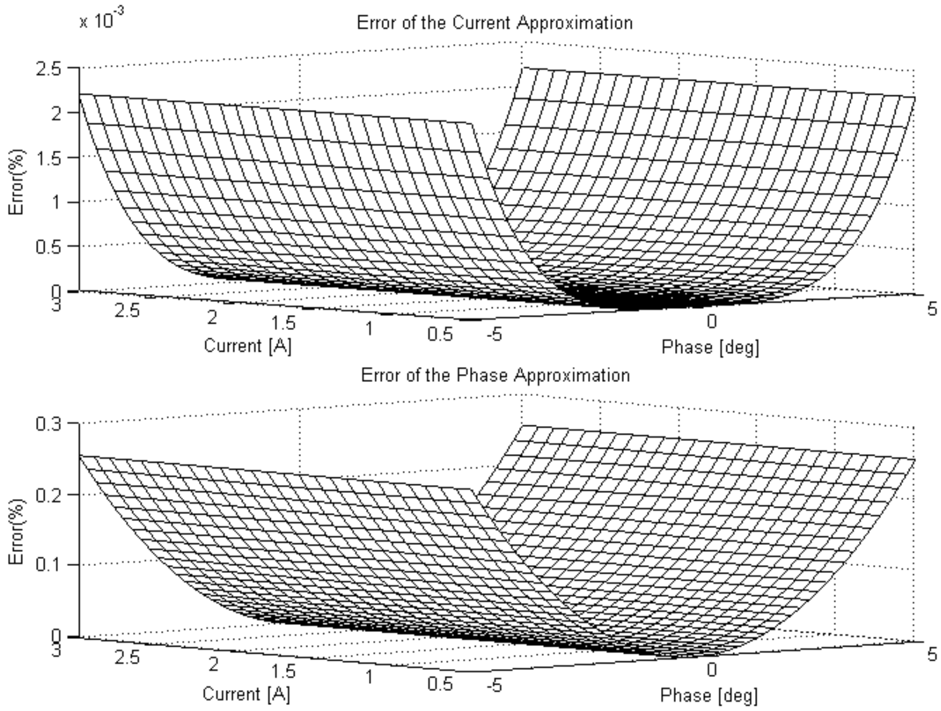

Fig. 2. Error of the approximate current and phase shift correction.

For phase shifts φ_p up to 5° the error of this solution is of the order of tenth per cent as shown in Fig. 2. Here, for starting values of I and φ_p the exact values of powers P_i and P_φ are calculated from equations (4), the values of I and φ_p are calculated again from equations (5) and compared with the starting values. The values U = 100 V and φ = 60° were used.

4. Conclusions

Brief description of the designed digital electricity meter is given. The analogue part of the instrument consists of the signal sensing and conditioning circuits for the three voltage and current channels. The digital part contains the microcontroller board with the connected keyboard, graphical LCD display, infrared and RS 485 interface, the DSP board for the necessary calculations and the separate A/D converters for every voltage and current signals. Modern Texas Instruments TMS320F243 processor and TMS320C6711 DSP were used to get a powerful measuring system. Error sources and error correction are briefly mentioned. Simple current and phase shift calibration algorithm was designed to overcome the problems with the instability of the measured current. The resulting errors of simplified calculations are plotted in Fig. 2 and show the accuracy of the order of tenth per cent.

Acknowledgement

This work is supported by the Slovak grant agency GAT under the grant No. 102/VTP/2000.

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