21st IMEKO TC4 International Symposium and
19th International Workshop on ADC Modelling and Testing
Understanding the World through Electrical and Electronic Measurement
Budapest, Hungary, September 7-9, 2016

Stochastic Measurement of Reactive Power Using a Two-Bit A/D Converter

Platon Sovilj[1], Bojan Vujicic[1], Aleksandar Radonjic[2], Dragan Pejic[1], Vladimir Vujicic[2]

[1]*Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia, platon@uns.ac.rs*
[2]*Institute of Technical Sciences, The Serbian Academy of Sciences and Arts, Belgrade, Serbia*

***Abstract* – In this paper we propose a new method for measurement of reactive power. The proposed method is based on stochastic digital measurement approach and discrete Fourier transform. The validity of the method is verified by numerous simulations. Besides this, it is shown that the proposed method is simple, robust and reliable, which makes it very suitable for practical implementation.**

***Keywords* – Reactive power, stochastic A/D conversion, Fourier coefficients.**

I. INTRODUCTION

Uncompenzated reactive power (RP) causes majority of losses in transmission and distribution systems. The most significant harmonic component of RP is that on fundamental frequency. Until the end of the last century, when a public power distribution network (PDN) was almost purely sinusoidal, RP on fundamental frequency is calculated from the expression

$$Q=\sqrt{S^2-P^2}=\sqrt{\left(\frac{U\cdot I}{2}\right)^2-\left(\frac{U\cdot I}{2}\cdot cos\varphi\right)^2} \quad (1)$$

where U and I respectively denote the voltage and the current amplitude, while φ represents the phase difference between these values. However, when the voltage and current become very complex quantities (having many harmonic components) the expression (1) became useless. Because of this, it was needed to develop new techniques for measuring RP. One of the first approaches was based on wavelet transform (WT) [1]. The key idea behind [1] was to use WT and digital phase-shift networks (DPSNs). Although this approach was very effective, it is was also complicated and quite expensive. As an alternative to this method, the authors of [2] proposed an approach based on Fourier transform (FT). Unlike [1], this method allowed the evaluation of RP without using DPSNs. However, to do that it was necessary to perform a large number of complex operations. Finally, the most popular approach for measuring RP is based on Walsh functions (WFs) [3], [4], [5]. This approach is faster than [1], [2] since it does not require the phase shift between the voltage and current. In addition, it is known that WFs have only two values, +1 and -1, over the normalized period. As a result, the multiplication of the signal by corresponding order WF is performed simply by alteration of sign of the signal from +1 to -1. In this paper we propose a similar but even more simpler approach.

II. DESCRIPTION OF THE METHOD

Stochastic digital measurement method (SDMM) [6], [7], [8], [9], [10] is characterized by simple hardware and high measurement speed. In this paper, SDMM is used to measure Fourier coefficients needed for calculation of RP. For instance, if a_1 and b_1 are the sine and cosine fundamental voltage coefficients, and if c_1 and d_1 are the sine and cosine fundamental current coefficients, then the value of RP on the fundamental frequency Q_1 is given by

$$Q_1=\frac{a_1\cdot d_1-b_1\cdot c_1}{2} \quad (2)$$

Using the same analogy we can compute, for instance, the value of RP at triple fundamental frequency

$$Q_3=\frac{a_3\cdot d_3-b_3\cdot c_3}{2} \quad (3)$$

From the above it is easy to see that the value of RP on the desired frequency can be computed by measuring only four Fourier coefficients. On Fig. 1. it is shown how to measure one Fourier coefficient. It should be noted that samples of dithered signal f_1 (t) (the voltage or current) are two-bit as well as samples of the dithered base function f_2 (t) ($f_2(t)$ $= cos(i\omega t)$ or $f_2(t) = sin(i\omega t)$), which are stored in memory. In one measurement period T there is N samples of the input signal f_1 (t), so the value of measured coefficient, say a_1, is given by

$$a_1=\frac{2\cdot <\text{Counter}\,1>}{<\text{Counter}\,2>} \quad (4)$$

Finally, it should be noted that the total RP, on first m harmonic frequencies [11], can be computed using

$$Q=\frac{1}{2}\sum_{i=1}^{m}((a_ic_i+b_id_i)\cdot cos(-i\frac{\pi}{2})+ \\ +(b_ic_i-a_id_i)\cdot sin(-i\frac{\pi}{2})) \quad (5)$$

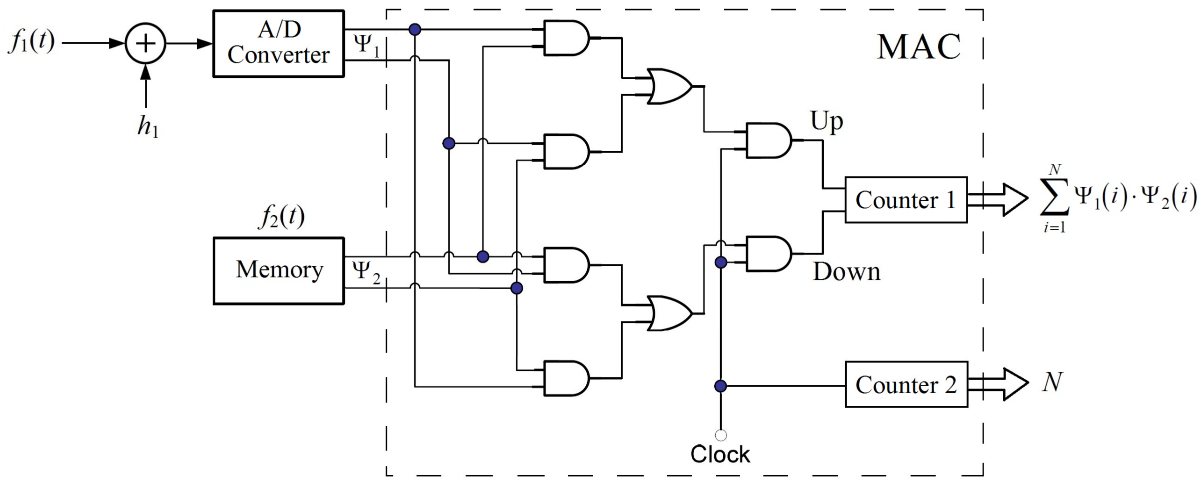

Fig. 1. Stochastic digital measurement of one Fourier coefficient.

III. VERIFICATION OF THE METHOD THROUGH SIMULATIONS

In order to evaluate the performance and accuracy of the proposed method, extensive simulations have been performed. The sampling frequency is set to f_s = 12 MHz, whereas the simulation time is equal to T = 1.28 s. The input signals have the following waveforms (Fig. 2):

$$u(t) = \frac{U_m}{2}\cdot sin(100\pi t) + \frac{U_m}{2}\cdot sin(300\pi t) \tag{6}$$

$$i(t) = \frac{I_m}{2}\cdot sin(100\pi t + \frac{\pi}{6}) + \frac{I_m}{2}\cdot sin(300\pi t + \frac{\pi}{9}) \tag{7}$$

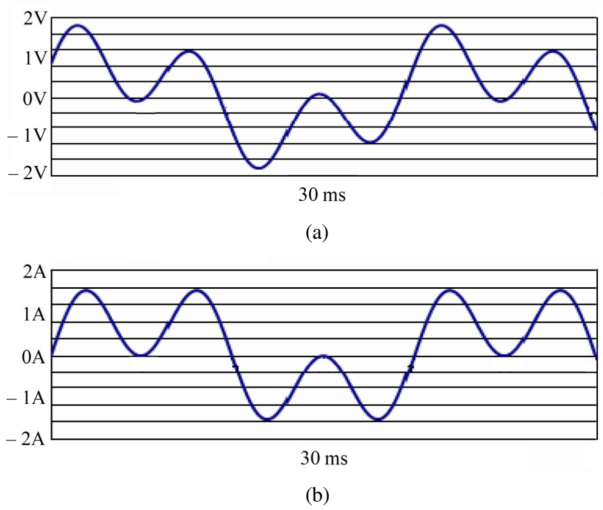

Fig. 2. Simulated signal waveforms: (a) voltage and (b) current.

On the basis of these parameters, we performed three series of 300 measurements (Fig. 3). The results of simulations are shown in Tables 1, 2 and 3.

Table 1. The results of simulations for f_s = 12 MHz U_m = 2V, I_m = 2A, $\varphi = \pi/6$ and T = 1.28s.

Series	$\bar{Q}_1$ [VAr]	σ_1 [VAr]	Γ_1 [%]
1	- 0.25001	0.00030	0.120
2	- 0.25000	0.00031	0.124
3	- 0.24999	0.00030	0.120

Table 2. The results of simulations for f_s = 12 MHz U_m = 2V, I_m = 2A, $\varphi = \pi/9$ and T = 1.28s.

Series	$\bar{Q}_3$ [VAr]	σ_3 [VAr]	Γ_3 [%]
1	- 0.17101	0.00030	0.175
2	- 0.17101	0.00030	0.175
3	- 0.17102	0.00031	0.181

Table 3. The results of simulations for f_s = 12 MHz U_m = 2V, I_m = 2A, $Q = Q_1 + Q_3$ and T = 1.28s.

Series	$\bar{Q}$ [VAr]	σ [VAr]	Γ [%]
1	- 0.42101	0.00023	0.055
2	- 0.42101	0.00018	0.043
3	- 0.42100	0.00020	0.047

IV. DISCUSSION

From Table 1 one can see that the standard deviation in statistical sample of 300 measurements is equal to $\sigma_1 \approx$ 0.0003 (VAr). Since the measurement result contains random error, the sum of 4 consecutive measurements (based on central limit theorem) is 2 times more accurate, the sum of 16 consecutive measurements is 4 times more accurate and so on (the same applies to the value of the relative error Γ_1). The results given in Table 2 are closely similar to those given in Table 1. In this case the standard deviation is also equal to $\sigma_1 \approx$ 0.0003 (VAr), whereas the

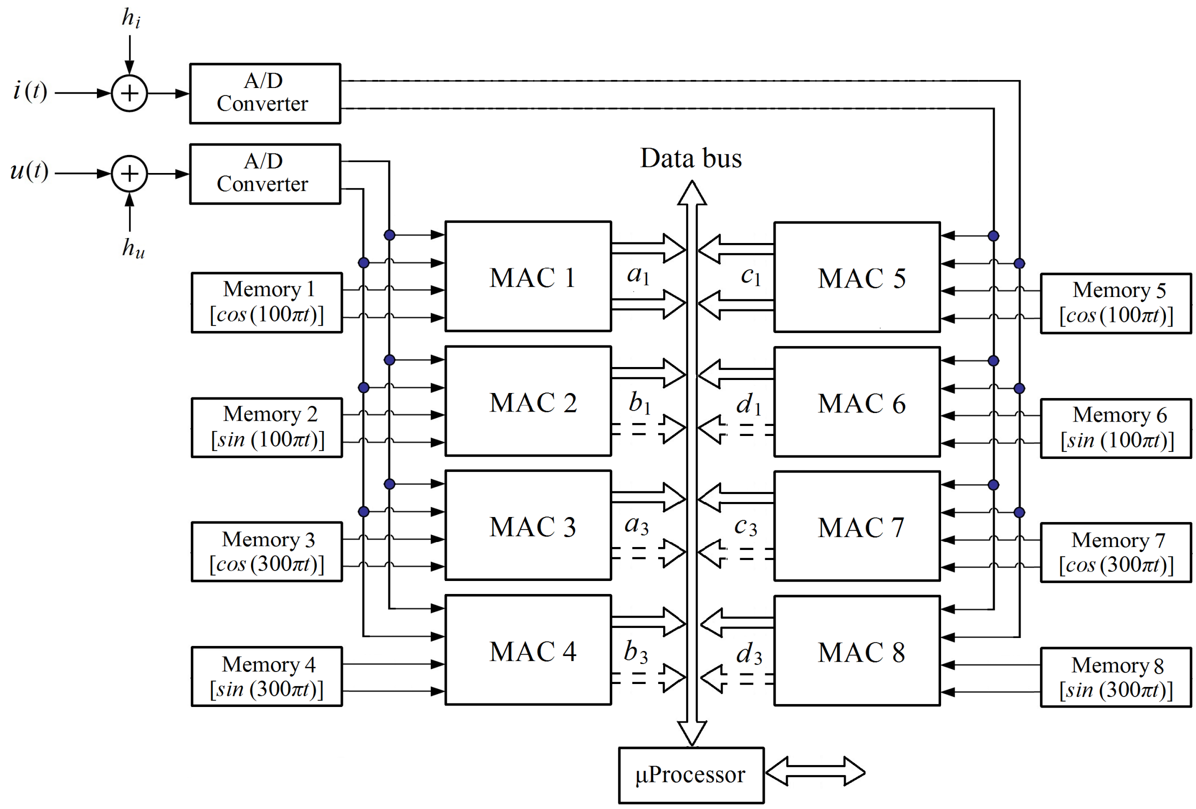

Fig. 3. Simulated hardware for measurement of reactive power.

relative error is slightly higher than in the previous case. The reason for this is that the measured quantity Q_3 is somewhat smaller Q_1. On the other hand, from Table 3 one can observe that the relative error of the measurement of total RP is more than twice as lower as that of individual RPs. This fact can be explained by the central limit theorem, since $\sigma_1 \approx \sigma_3 \approx \sqrt{2}\cdot\sigma$. This is quite logical considering that the values Q_1 and Q_3 are measured independently from each other.

V. CONCLUDING REMARKS

Based on the theory presented in Section 2 one can conclude that the proposed method is much simpler than those described in [1], [2], [3], [4], [5]. The addition and subtraction, the only operations used in the method, are reduced to up and down counting, respectively (Fig. 1). The reason is the use of two-bit A/D converter and two-bit base functions from the memory. This means that the instrument, based on the proposed method, would be very simple, and consequently, highly robust and reliable.

The validity of the method is verified by simulations. They have shown that RP on the desired (fundamental) frequency can be measured with accuracy better than 0.025%. On the other hand, since individual RPs are mutually independent, total RP can be measured at least 2 times more accurately. All these facts suggest that the proposed method is highly suitable for practical implementation, especially in devices such as VAr-hour meters.

REFERENCES

[1] W. Yoon and M. J. Devaney, "Reactive Power Measurement using the Wavelet Transform," IEEE Trans. Instrumentation and Measurement, vol. 49. no 2, pp. 246-252, Apr. 2000.

[2] S. Smith and M. J. Devaney, "Fourier based Three Phase Power Metering System," Proc. IEEE Instrumentation and Measurement Technology Conference (IMTC 2000), pp. 30-35, May 2000.

[3] A. Brandolini, A. Gandelli, and F. Veroni, "Energy Meter Testing based on Walsh Transform Algorithms", Proc. IEEE Instrumentation and Measurement Technology Conference (IMTC 1994), pp. 1317-1320, May 1994.

[4] A. N. Abiyev and K. Dimililer, "Reactive Power Measurement in Sinusoidal and Nonsinusoidal Conditions by Use of the Walsh Functions, ," Proc. IEEE Instrumentation and Measurement Technology Conference (IMTC 2008), pp. 89-94, May 2008.

[5] A.N. Abiyev, "A New Electronic Reactive Power Meter based on Walsh Transform Algorithms", Proc. IEEE/PES Transmission and Distribution Conference and Exposition, pp. 1-7, Apr. 2008.

[6] B. Santrac et al., "A Novel Method for Stochastic Measurement of Harmonics at Low Signal-to-Noise Ratio," IEEE Trans. Instrumentation and Measurement, vol. 58, no. 10, pp. 3434–3441, Oct. 2009.

[7] V. Pjevalica and V. Vujicic, "Further Generalization of the Low-Frequency True-RMS Instrument," IEEE Trans. Instrumentation and Measurement, vol. 59, no. 3, pp. 736-744, Mar. 2010.

[8] P. Sovilj, S. Milovancev and V. Vujicic, "Digital Stochastic Measurement of a Nonstationary Signal with an Example of EEG Signal Measurement," IEEE Trans. Instrumentation and Measurement, vol. 60, no. 9, pp. 3230-3232, Sep. 2010.

[9] A. Radonjic, P. Sovilj and V. Vujicic: "Measurement Uncertanity Bounds of DSM Method", Proc. IEEE Conference on Precision Electromagnetic Measurements (CPEM 2012), pp. 572-573, July 2012.

[10] A. Radonjic, P. Sovilj and V.Vujicic, "Stochastic Measurement of Power Grid Frequency using a Two-bit A/D Converter", IEEE Trans. Instrumentation and Measurement, vol. 63, no. 1, pp. 56-62, Jan. 2014

[11] V. Vujicic et al., "Concept of Stochastic Measurements in the Fourier Domain", Proc. 16th IEEE International Conference on Harmonics and Quality of Power, pp. 288-292, May 2014.