A different approach to electrical energy consumption monitoring

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Keywords

Sensor, Measurement, Energy system management, Diagnostics, Current sensor

Abstract

A different approach to electrical energy/power calculation by means of summing of non-even time current samples over short time periods are described in to the article.

Introduction

It's overall accepted that energy consumption calculations are based on instant power values, especially if consumer generate non-sinusoidal current form. Usually instant current and voltage readings - ADC (Analog to Digital Converter) readings - and following multiplication are used to calculate instant power and average consumed power or energy [1], [2]. Non-sinusoidal current forms are generated by consumers equipped with simple rectifier-capacitor input. Moreover, power factor is remarkably lower than 1, because power factor correction must be applied for devices with installed power more then 75W.

Other method are voltage and current values averaging via multi-order delta-sigma modulation and the following multiplication [3].

Electrical energy measuring/monitoring device installation near every consumer are expensive. Several methods are proposed to lower costs, for example [4], [5], in order to achieve widespread electrical energy measuring/monitoring devices installations.

Electrical safety during metering is very important. Here the main problematic question is voltage sensor isolation from power line. Isolation transformers, for example [6] are more heavy and bigger sized compared to Hall current sensors, even current transformers available today [7], [8]. Due to mentioned, many energy metering solutions implement non-isolated voltage measuring by simple resistive voltage dividers and calculation (micro-controller) circuits.

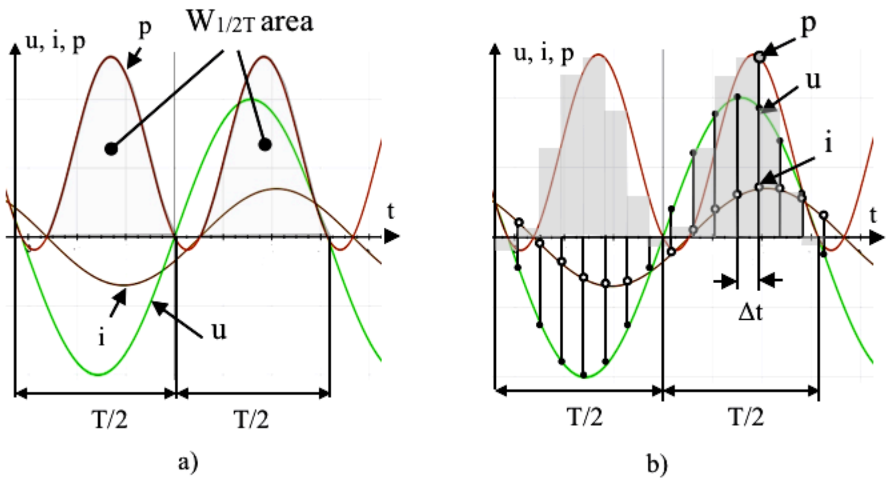
Below are described a different approach to electrical energy metering in order to simplify measurement device as well as achieve necessary safety conditions.

Non-even sampling energy consumption measuring method

As known, AC active energy usually are defined as integral value of instant value p over 1/2T or area W1/2T (Fig.1a). Simultaneous readings of instant voltage and current values u, i allow to calculate instant power value p with the sampling rate of $1/\Delta t$ and energy w over time period Δt (Fig.1b). Sampling rate must be at least 4,2 KHz or 42 samples per 1/2T (EN 61000-3-2 [9], Nyquist frequency).

Sampling allow to substitute area W1/2T, representing energy during 1/2T, with sum of smaller areas (Fig.1c) (1), assuming that i, u are constant during Δt:

$$W_{1/2T} \simeq \sum_{0}^{T/2} p\Delta t = \sum_{0}^{T/2} ui\Delta t, \qquad (1)$$



a) i, u, p graph and energy area $W_{1/2T}$, **b)** $W_{1/2T}$ substitution with sum of ***uiΔt***

Fig.1. AC instant voltage **u**, current **i** and power **p** graphs and half-period active energy area $W_{1/2T}$

Described rectangle approximation are widely used today in electrical power/energy metering devices. The main design problem for known devices are electrical isolation to achieve necessary safety and input signal noise reduction.

Micro-controller ADC's work only with positive input voltage in range 0...+3,3V or 0...+5V, depending from micro-controller. So, DC component - a half of ADC reference voltage - must be added to the sensing signal. Typically this is done by adding resistor divider.

In oder to simplify electrical power/energy, different approach are proposed.

Here, instead of voltage readings via transformer, voltage divider etc., mains voltage are converted to frequency by voltage-to-frequency (U ➔ f) converter and output frequency are proportional to input voltage.

Voltage-frequency converter output signal (pulses) are transferred through isolating optocoupler and used as micro-controller's ADC strobe signal. Strobe signal frequency determine current sampling intervals Δt (Fig.2).

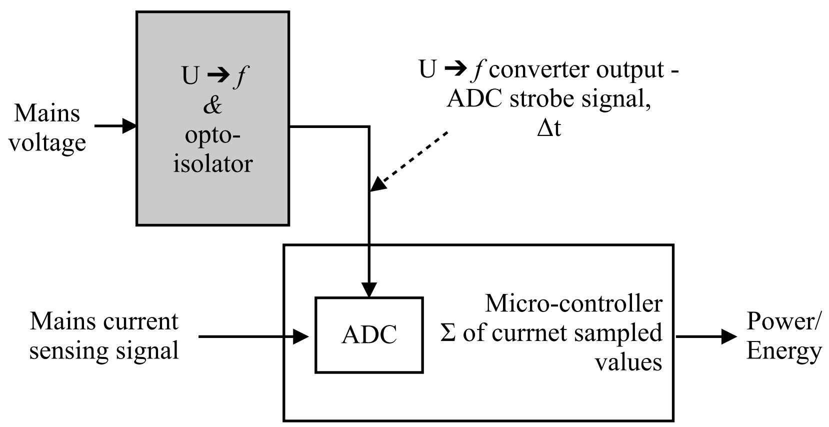


Fig.2. Power/Energy measurement block diagram, containing voltage - frequency converter

For sinusoidal voltage (mains) Δt changes also are sinusoidal as are shown on Fig. 3.

Voltage-frequency transfer ***K*** function (2) must be linear:

$$f_{osc} = K \times u, \quad \text{or} \quad \frac{1}{T_{osc}} = K \times u, \tag{2}$$

In this case, as mentioned above, $T_{osc} = \Delta t$ thus expression (1) can be re-written, including (2):

$$W_{1/2T} \simeq \sum_{0}^{T/2} p\Delta t = \sum_{0}^{T/2} ui\Delta t = \sum_{0}^{T/2} \frac{1}{KT_{osc}} i\Delta t = \sum_{0}^{T} \frac{1}{K} i = \frac{1}{K} \sum_{0}^{T/2} i, \tag{3}$$

According to expression (3), electrical energy during 1/2T or T are proportional to the sum of current samples over 1/2T or T accordingly, if sampling rate are modulated by applied voltage.

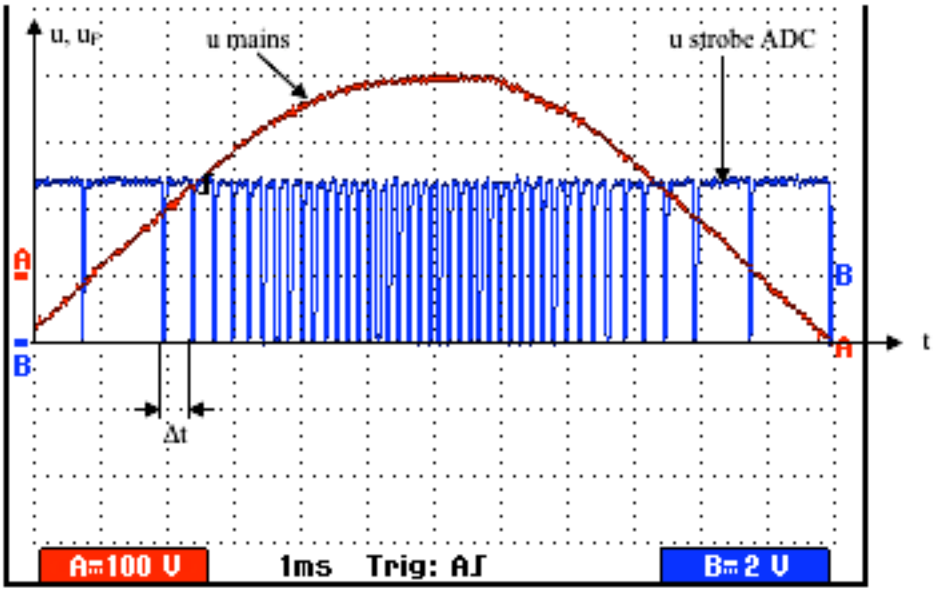


Fig.3. Voltage-frequency converter output signal **B** v.s. input voltage **A**.

Experimental devices and results

Several versions of the energy metering devices, based on described above method, was tested (Fig.4).

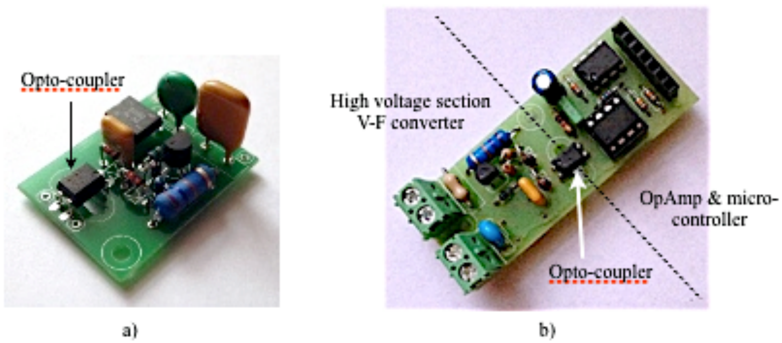


Fig.4. Energy metering devices prototypes: a) simple voltage-frequency converter module, b) with integrated voltage-frequency converter, current transformer operational amplifier and ATtiny85 micr-controller

The main difference between tested devices was applied micro-controller: 8-bit AVR micro-controllers, 16MHz clock ATmega328 or 8MHz clock ATtiny85 [10], or 32-bit 72 MHz clock STM32 ARM Cortex micro-controller [11]. Clock frequency determine ADC conversion speed, thus determine highest applicable output frequency for voltage-frequency converter. Mentioned is important only for ARM micro-controllers.

Triac based voltage regulator was applied as variable load. Typical load voltage and current waveforms are shown on Fig.5. Such triac phase regulation allow to regulate voltage on the resistive load, generate current harmonics as well as change power factor. In the same time, resulting current form cause errors when triac are OFF in case of low-cost current transformer [12].

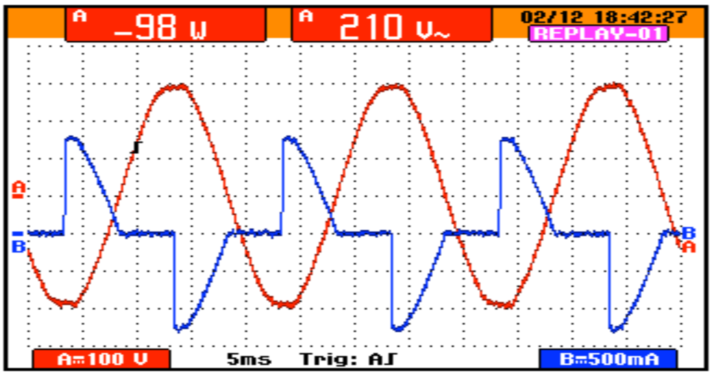


Fig.5. Mains voltage **A** and regulated resistive load current **B**

Metering module (for example - shown on Fig.4b.) direct output (sum of ADC readings) are shown on Fig.6. Each bar represent sum of current ADC readings, non-even sampled according to mains voltage value, over 1 sec.

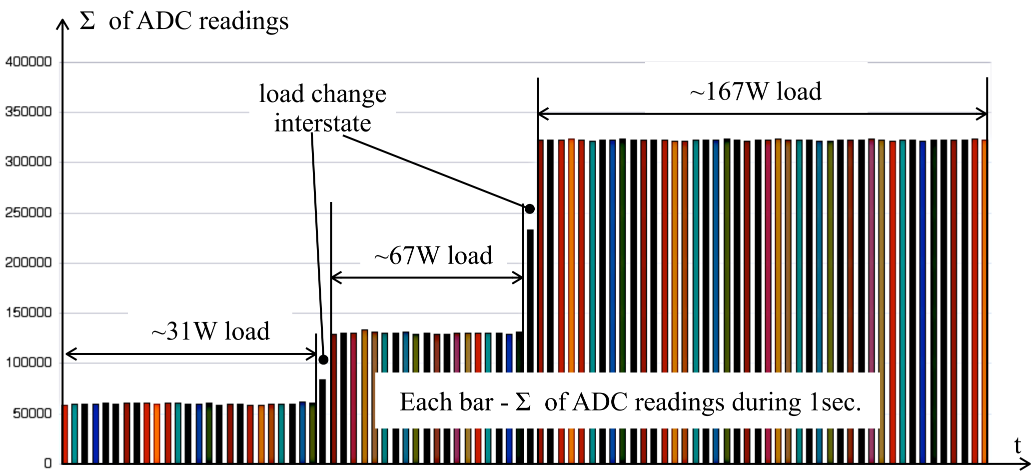


Fig.6. Metering module raw data (coefficient K aren't applied) output graph by 1sec.

Conclusion

Described method allow to create simple, effective and inexpensive electrical energy metering, monitoring and flow controlling / measuring devices for AC and DC consumers, energy sources and grids. Embedded in to micro-controller at least UART communication ports are ideal possibility for remote energy data readings. Communication with external data storage device (flash memory) or database software allow to create data logging system for one consumer / generator or synchronous data logging for several consumers / generators.

References

[1] Atmel AVR1631: Single Phase Energy Meter using XMEGA A, available: http://www.atmel.com/images/doc42039.pdf

[2] Apse-Apsitis P., Avotins A., Ribickis L., SYSTEM AND METHOD FOR MONITORING REAL POWER CONSUMPTION, International patent application WO 2013/093554 A1, published 27.06.2013

[3] available: http://www.analog.com/static/imported-files/application_notes/AN-679.pdf

[4] Apse-Apsitis P., Avotins A., Ribickis L., Zakis.J., Development of Energy Monitoring System for Smart Grid Application, 3rd IFIP WG 5.5/SOSOLNET Doctoral Conference on Computing, Electrical and Industrial Systems, DoCEIS 2012, Costa de Caparica, Portugal, 2012 Proceedings, Springer Heidelberg Dordrecht London New York, ISSN 1868-4238, ISBN 978-3-642-28254-6, p. 347.- 354.

[5] Apse-Apsitis P., Avotins A., Ribickis L., Concept of Low-Cost Energy Monitoring System for household Application, Proceedings ELMAR-2011, Zadar, Croatia, ISBN: 978-953-7044-12-1., p.149-152

[6] MYRRA transformer 6V,1A, available: http://www.farnell.com/datasheets/92144.pdf

[7] MURATA power solutions, datasheet, available: http://www.murata-ps.com/data/magnetics/kmp_5600.pdf

[8] EPCOS, SMT current sense transformers, datasheet, available: http://www.farnell.com/datasheets/817182.pdf

[9] Harmonic Current Emissions, Guidelines to the standard EN 61000-3-2, available: http://www.epsma.org/pdf/PFC%20Guide_November%202010.pdf

[10] available: http://www.atmel.com/devices/atmega328.aspx, http://www.atmel.com/devices/attiny85.aspx

[11] available: http://www.st.com/web/en/catalog/mmc/FM141/SC1169

[12] CT TA12-200 datasheet, available: http://www.seeedstudio.com/wiki/Electronic_brick_-_Electricity_meter_(Analog)

A Different Approach to Electrical Energy Consumption Monitoring / P.Apse-Apsitis, A.Avotins, L.Ribickis // 2014 16th European Conference on Power Electronics and Applications (EPE '14 - ECCE Europe) : Lappeenranta, Finland, 26-28 August 2014. Piscataway, NJ : IEEE, 2014. P.2573-2577. ISBN 978-1-4799-3016-6. http://dx.doi.org/10.1109/EPE.2014.6910970.