Experimental Digital Three-Phase Check Electrical Energy Meter Part 1

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Abstract – **A creating of digital electrical energy meter conduces to its correct measurement and to a price fixing of any electrical device. The article presents a digital three-phase test electrical energy meter realized on the base of especial integrated circuit manufactured by Analog Device®. The presented device has as a measuring as well an advanced application.**

Keywords – **Energy measuring, Digital measuring device, Energy measuring resources.**

I. INTRODUCTION

The electrical energy measurement is very important for a people being and an industry. On its correct measurement depends a price of any electrical product and its effective use. Therefore the precise electrical energy measurement is important and necessary.

The direct electrical energy measurement is fulfilled by an especial meter. The first types of these meters work on induction principle and are well known in practice and theory. Nevertheless their constructive feature and metrology do not enable to report on others energy system parameters except a consumed power. Now when alternative electrical energy sources are in use applied until recently bi-quadrant to the power induction meters are already not suitable because it is now necessary to measure the energy sent back to the energy network. So the induction electrical energy meters use is reduced but the interest in an elaboration of new electronic circuitry and technological decisions for electrical energy measurement is increased. The modern microelectronic technologies improvement enables combining on one chip a great number of functional unite which permits a construction of digital electrical energy meter only by one integrated circuit. It increases measuring apparatus reliability and a precision of data treatment and indication.

The purpose of the present working is to realize and investigate a three-phase check electrical energy meter created on the base of produced by Analog Device for such measurements especial integrated circuit [1-3].

II. PRESENTATION

The digital three-phase electrical energy meter block schematic diagram is shown in Fig. 1. The all phases (A, B, C) of the supply network are synchronously and absolutely independently watched by three identical current channels (CCA, CCB, CCC) and three also equal voltage channels (VCA, VSB, VCC). The current channels transform the consumed by phases electrical current to electrical voltages fed to respective inputs of special for electrical energy measurement integrated circuit. The voltage channels measure uninterruptedly voltages of all phases and after suitable amplitude reduction they are fed to measuring circuit EMC voltage inputs. The modes operation control is fulfilled by giving modes unit MU which defines a transformation coefficient of calculated energy to frequency signal. The device working state, phase existence or absence, output signal and running consumed electrical energy are watched by indication I. EMC disposed of precise analog-to-digital converter (ADC) and computing block. Their correct processing is guaranteed by an added block generating pulses PG. EMC enables to deliver measured data suitable to a treatment by diverse schemes. To this aim the output signals are applied through output circuit OC. It must not ignore the power supply stability. This primary task is entrusted on the power supply unit PU. The produced by Analog Device especial integrated circuit ADE7756 is precise three-phase electrical energy meter provided with serial delivering data interface SPI with leads for control of electromechanical or electronic counter. There are embedded two precise Σ-Δ analog-to-digital converters, digital integrator, regulated power supply, thermal sensor and all necessary for a treatment of active, reactive effective electrical energy and a calculator for effective value. This circuit is suitable for a measurement and of active, reactive and effective electrical energy generated by different three-phase connection (delta or wye) with three or four wires network. The integrated circuit ensures anyone adjustment – power factor correction, phase and power adjustment. An embedded phase register notes down an information of input signal form.

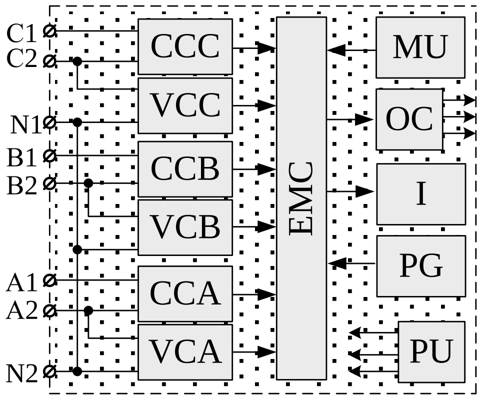

Fig. 1. Digital three-phase electrical energy meter functional block diagram

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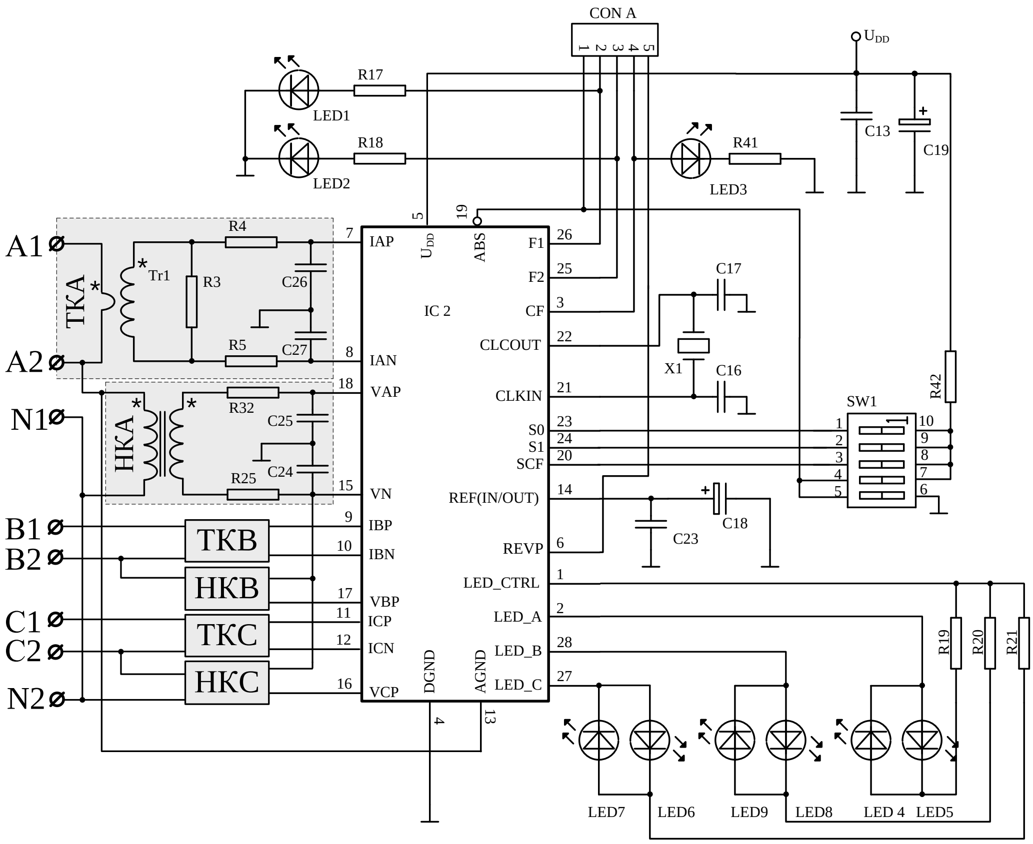

Fig. 2. Simplified schematic circuit diagram

It has taken out output leads of integrated circuit. A scheme for short connections and voltage small changes detection is embedded too. A zero watching circuit is synchronized against all phases voltages. A measurement is fulfilled on the base of input voltages periods of any phase [3]. Simplified schematic circuit diagram of a device for three-phase electrical energy measurement is depicted in Fig. 2.

A phase A current and voltage channels are shown. The other phases B and C channels are identical. The phase A current channel is built by elements R3, R4, R5, C26, C27 and current transformer Tr1. The task of Tr1 is to transform a flowing through primary coil current of phase A in voltage with a transmission factor 1:1000. This voltage is fed with suitable amplitude to current inputs IAP and IAN of integrated circuit IC2. The resistors R3, R4 and R5 define the parameters of delivered to integrated circuit inputs signals. According to the producer specification the amplitude of a delivered to pin IAP and IAN (and also to IBP, IBN, ICP, ICN) input signals must not be over ±500 mV.

The phase A voltage channel VCA is built by elements R32, R25, C25, C24 and transformer Tr2. This transformer ensures a signal giving an information for phase and amplitude of a voltage delivered to a consumer. It is a step down transformer and reduces 230V primary voltage to 5Vsecondary one. The amplitude of a signal delivered to inputs for measurement of the all phases voltage (VAP, VBP, VCP) must be not over ±500mV.

The peculiarity during the voltage switching on to the active inputs (VAP, VBP, VCP) for integrated circuit IC2 voltage measurement and common input to voltage channels VN is to observe the transformers coil terminals (Fig. 2). The primary winding beginning (marked with a dot *) is turned on to respective phase but the end is to zero conductor N. The secondary winding end is turned on to respective active input of IC2 (for example VAP) but the end to the passive one (VN).

An indication about correct switched current and voltage transformers gives the embedded in integrated circuit IC2 phasic monitor which by means of pins 1, 2, 27 and 28 can control six light emitting diodes (LED4 – LED9) switched as antiparallel pairs as is depicted in Fig. 2. The indicators LED4, LED9 and LED7 are in operating when anyone phase is fallen away. LED5, LED8 and LED6 are in operating when the phases with necessary voltage and current channels are correct switched to measuring leads. Then and with application of a third (neutral) conductor towards that the signals are measured the voltage lines will be dephased at 120° each to other,

$$
\begin{aligned}
U_{A(t)} &= \sqrt{2}.U_A.\cos(\omega_t.t) \\
U_{B(t)} &= \sqrt{2}.U_B.\cos(\omega_t.t + \frac{2\pi}{3}) \\
U_{C(t)} &= \sqrt{2}.U_C.\cos(\omega_t.t + \frac{4\pi}{3})
\end{aligned}
\qquad (1)
$$

where: U_A, U_B, U_C are RMS voltage values.

The signals received at the current inputs are computed by the equations,

$$I_A(t) = \sqrt{2}.I_A.\cos(\omega_t.t + \varphi_A)$$
$$I_B(t) = \sqrt{2}.I_B.\cos(\omega_t.t + \frac{2\pi}{3} + \varphi_B) \qquad (2)$$
$$I_C(t) = \sqrt{2}.I_C.\cos(\omega_t.t + \frac{4\pi}{3} + \varphi_C)$$

where: I_A, I_B, I_C are RMS values of the current in the phases, φ_A, φ_B, φ_C – phasic difference between current and voltage on each phase.

For the power momentary values can be written:

$$P_A(t) = U_A(t).I_A(t)$$
$$P_B(t) = U_B(t).I_B(t) \qquad (3)$$
$$P_C(t) = U_C(t).I_C(t)$$

After substitution of (1) and (2) in (3) the active power in each phase will be:

$$P_A(t) = U_A(t).I_A(t).\cos(\varphi_A) - U_A(t).I_A(t).\cos(2\omega_t.t + \varphi_A) \qquad (4)$$
$$P_B(t) = U_B(t).I_B(t).\cos(\varphi_B) - U_B(t).I_B(t).\cos(2\omega_t.t + \frac{4\pi}{3} + \varphi_B)$$
$$P_C(t) = U_C(t).I_C(t).\cos(\varphi_C) - U_C(t).I_C(t).\cos(2\omega_t.t + \frac{8\pi}{3} + \varphi_C)$$

The total power is defined as a sum:

$$P_{(t)} = P_{A(t)} + P_{B(t)} + P_{C(t)} \qquad (5)$$

The connector CON A leads are directly connected to the integrated circuit IC2 leads F1, F2, CF. By means of CON A the measurement information is applied to the treatment block. The process status is watched by indicators connected to some leads (F1, F2, CF).

A block MU is built by five microswitches SW1 and a resistor R24. Microswitch SW1 rules the integrated circuit IC2 leads S0, S1 SCF. By means of SW1 the frequency of received from leads F1, F2 and CF output signals is tuned according to a measured electrical energy. By means of them the analog-to-digital converter working frequency and adjusting frequency are tuned. Their status and their influence on output signals are shown in Table I. The output frequency values (leads F1 and F2) at different currents by 100 pulses per 1kW are shown in Table II.

By measurement of three-phase electrical energy the developed test device makes errors defined by next formula,

$$\varepsilon = \left(\frac{E_M - E_T}{E_T}\right).100 \qquad (6)$$

where: E_M – measured by developed device electrical energy, E_T – measured by certificated device electrical energy.

TABLE I

SCF (J6)	S1 (J7)	S0 (J8)	F1 и F2 *f*, Hz
0	0	0	0,92
1	0	0	1,84
0	0	1	0,46
1	0	1	1,84
0	1	0	2,09
1	1	0	0,46
0	1	1	0,23
1	1	1	0,23

TABLE II

I, A	F1 и F2 *f*, Hz
10	0,18
25	1,46
40	0,73
60	1,1
80	1,47
100	1,83

This error appears as a result of others errors depended on an elements selection and on printed circuit board construction. Some of they are:

- Difference between channels. It appears if there are faulty or unequal elements in filter group of current and voltage channels. As a result phasic difference appears between channels and phase correcting circuit (elements R4, R5, C26, C27 of current channel and R25, R32, C24, C25 of voltage channel). A phase correcting circuit compensates phases between current and voltage channels with ±0,1° at network frequency change from 45Hz to 65Hz and with ±0,2° at 40Hz to 1kHz;
- Unregulated power supply;
- Level replacement of analog ground against continuous current one, leads AGND and DGND.

In Fig.4 is shown the experimental characteristic of input voltage versus current channel $U_{IN} = f\,(I_{TEST})$. This is applied to pins 7 and 8 of IC2 (for phase A). Another characteristic describes an output signal frequency versus a test load current $F_{F1} = f\,(I_{TEST})$.

The analysis shows that the function $U_{IN} = f\,(I_{TEST})$ by a change in current from 0 to 50A input voltage is changed from 0 to 250mV almost linear and the output signal frequency is increased F_{F1}=0÷1,25Hz.

According to catalog data of the measurement circuit the experimental results obtained for the function of the frequency F_{F1} are overlapped with a minimum difference. In Fig. 3 with dotted line function is depicted according to catalog data whereas by means of points it is depicted with experimental values.

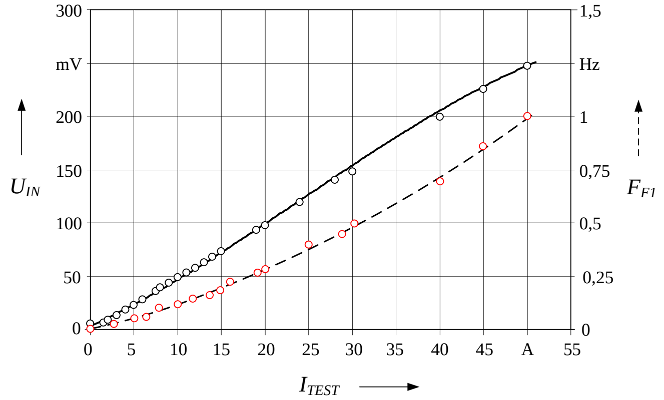

Fig. 3. Experimental characteristics $U_{IN}=f\,(I_{TEST})$ and $F_{F1}=f(I_{TEST})$

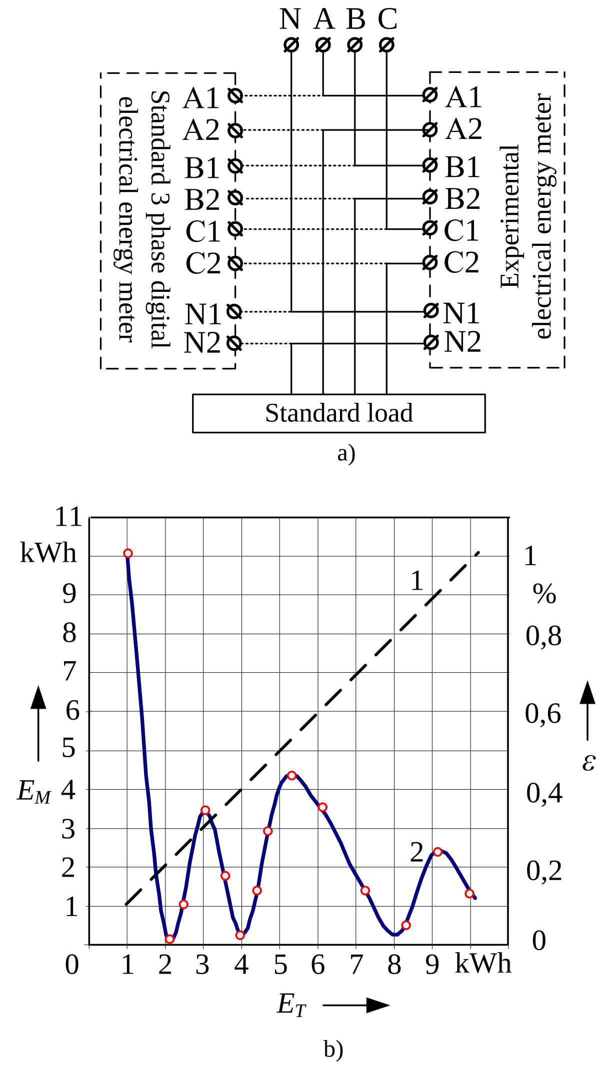

Fig. 4. (a) Experimental setup, (b) experimental characteristics $E_M=f\,(E_T)$ and $\varepsilon=f(E_T)$

The developed device has been tested with standard three-phase load. Fig.4(a) shows a scheme of the experimental setup. It consists of standard meter and experimental developed one. The results for the electricity measured by an developed electrometer are compared with those obtained with standard one. Measurements were performed sequentially, first with standard device then with developed (experimental) energy meter. The obtained results are presented in Fig.4(b). They give the dependence of the measured with experimental device energy between measured by standard energy meter $E_M=f(E_T)$ – graph 1. Another graph 2 $\varepsilon=f(E_T)$ shows the error obtained from the experimental device in accordance with Eq. (6).

The analysis of the obtained characteristics shows that the developed experimental electrical energy meter measures consumed energy with accuracy similar to that of a standard meter. The greatest error ε=0,45% occurs when there is a load about 5,2 kWh.

III. Conclusion

A block schematic diagram of developed and investigated three-phase digital test electrical energy meter has been submitted. It enables to control the transmission characteristic, the phase status monitoring and a treatment of received from electromechanical or microcontroller signals.

The experimental device is tested with a standard load. The characteristics of input voltage and frequency of the output signal versus the current through the load $U_{IN}=f(I_{Test})$, $F_{F1}=f(I_{Test})$ have been obtained. Approximately an error of the device is established by means of the constructed characteristics $\varepsilon=f(E_T)$.

Based on produced by Analog Device especial integrated circuit ADE7762 a schematic circuit diagram is developed. The described experimental device is characterized with simple realization and a possibility of easy adjustment and measurement data processing. The added LED indicators give a real notion of the measured signals momentary status.

This device for digital measurement of three-phase electrical energy can be used as in instrumentation as well in engineering investigations. An input channels schematic configuration and a transmission characteristic flexible control by means of MU enable this development to have measuring and advanced application.

A developed device is put to a more detailed studies in different COSφ, different phase voltages and others. This will be describe in the others article.

References

[1] T. Angelova, "Experimental Device for Automation Reeding of Galvanomagnetic Elements Transduser Characteristics", Journal of the Technical University of Gabrovo, Vol. 44, 2014.

[2] N. Draganov, "Contactless protection of induction motor", Scientific Works Volume LX, Food Science, Engineering and Technologies – 2013, 18-19 October 2013, Plovdiv.

[3] Analog Device, Application notes and part information, www.analog.com, Jan. 2014.