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The new power processor and its application for AC power and energy measurement

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Abstract: **The paper presents the new power processor and the first results of its application. Power processor is an electronic circuit which allows to separate the measured power signal (obtained from the multiplier circuit) to the components: P + and P- labeled in the literature as the input power Pv and the return power Pr, which is itself harmful, is heating back wires and supply transformers. It is produced by shifting the phase between the current and voltage and it is negative. Such natural division based on physical fenomena of energy direction and will be usefull in correct billing and dynamic power compensation. Theory is not based on standard power triangle and its difficult correction for dissortions.**

Keywords: power measurement, power processor, return power, input power, active power, delivery power.

I. INTRODUCTION

Separated measurement of Pv power and input energy Ev, as the measurement of power Pr and back return energy Er allows to correct the energy balance in the measurement node. The power delivered Pd is equal to the sum of the powers Pv and Pr. Both powers have should be added without a sign, In the equations P is the average value of the power and powers are unsigned, because they do not use the concept of negative power and the sign of Px is the power propagation direction, thus:

$$Pd=Pv+Pr \quad \text{rather than} \quad P_{+}+P_{-} \tag{1}$$

as in *[4], [15],* where:

$$P_v=\frac{1}{T}\int_0^T u(t)\cdot i(t)\,dt \quad \text{for} \quad u(t)\cdot i(t)>0 \,, \tag{2}$$

instantaneous values are marked with green line in Fig. 2 and:

$$P_r=\frac{1}{T}\int_0^T |u(t)i(t)|\,dt \quad \text{for} \quad u(t)\cdot i(t)<0 \,, \tag{3}$$

instantaneous values are marked with yellow line in Fig. 2.in opposite to the active power (or average power), which determines the difference as the power absorbed by the device and it is not always all the supplied power:

$$P=P_v-P_r \tag{4}$$

(return power *Pr* is unsigned as in [4]), sign (-) at *Pr* marks the direction and the average value or difference as in (2) gives the active power consumed by the receiver. It should be marked that consumers are paying for power or energy consumed and not supplied,, which may be higher as in equation (4).

The above equation shows that even a small value of the back power Pr reduces the active power which slows down the electricity meter. Triangle of power with reactive power,, which does not have any physicality, is used to close the balance of power to the effective value of the voltage and current product. Attempts to compensate by [9] on the basis there will always be an approximation of the wrong model to fulfill actual conditions. In [10] there is the concept of power components with a negative sign, which reduces the value of the first component of positive power unfolded in a series. Formula (4) is equivalent to formula (8) from [10] with the proviso that in [10] maintained at a negative power concept difficult to analyze, and consequently leads to errors. Substituting (2) into (1) we get:

$$Pd=P+2\,Pr \tag{5}$$

$$P=Pd-2\text{Pr} \tag{6}$$

Where 2Pr is called the power of mutual exchange. Power P equals Pd only when Pr equals zero.

Equation (3) shows why energy meters to measure active power P (in accordance with EN 50470-1:2006) release and count lower number of pulses or blade rotation when a harmful return power (of mutual exchange) of 2Pr. Power supplied Pd can also save a simple formula:

$$P_d=\frac{1}{T}\int_0^T |u(t)\cdot i(t)|dt \tag{7}$$

for the product of $u(t)\cdot i(t)$ of any character [1].

The instantaneous values of input and return powers are respectively positive *pv (t)> 0* and negative *pr (t) <0*, and thus the calculation and billing are based on theirrespective summation in formula (4) are correct for naturally various shapes of voltage and current (deformed and non). These are currently difficult conditions applicable standards and regulations not

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considered the natural distribution of instantaneous power values for positive and negative standard [12].

The behavior of the power components are presented in

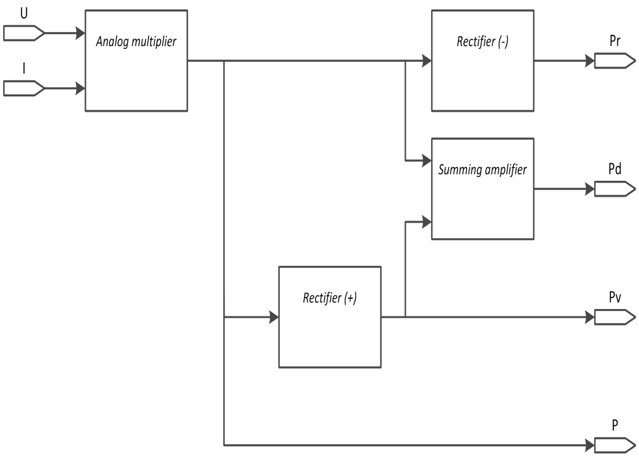

Figure 1: Block diagram of the power processor

waveforms of current and voltage. Analysis was used to prepare the equations (1), (2), (3) resulting from the work and research on processor power. The equations are the authors' original concept, are the basis for the patent application [15]. Power Pr and energy Er, allow to precisely determine energy loss in the load and have not been considered so far in the literature, excluding the references in [4] and the German first measurements using the analog circuit power processor, as shown in Figure 1. Block diagram of the power processor has been prepared in the form of training module for students in 2008.

II. SIMULATION

Power P is as defined by equation (2) and the definition of the integral value of the average power or as the active power, that occurs as a signal on one of the outputs of the power processor**:**

$$P=\frac{1}{T}\int_0^T u(t)\cdot i(t)\,dt=U\cdot I\cdot\cos\varphi=P_v-P_r \tag{8}$$

Figure 2 shows the separation of the instantaneous power measurement signal on the Pv output and return power Pr what has so far not been studied and measured. The power processor analog version as in figure 1 allowed to conduct research using high-quality measuring equipment at the Institute of Computer Systems for Automation and Measurements in Wroclaw. The measuring system consisted of a calibrator SQ-33 LUMEL and the power processor that works in the range of used input voltages.The system contains a shunt for current source calibrator 40 Ohm, thrird-degree RC filter and high-quality voltmeter Schlumberger to measure the average values of signals Pv, Pr, P, Pd. The dependence of changes in medium-power signals on the phase angle in accordance with the expected dependence of the work [11] is presented on fig.5.

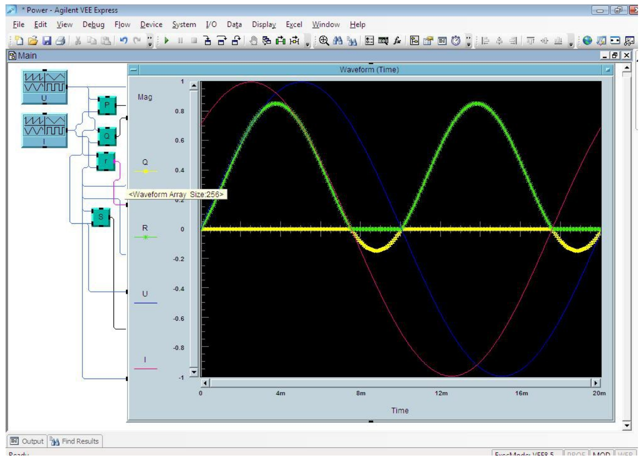

Figure 2: Computer simulation of the signal power and its division: Pv - green, Pr - the yellow curve

Power components described as the function of on the phase angle, determined by the equations from [11] are shown in Figure 3 and 5 (experimentally). Power supplied by [11]:

$$Pd(\varphi)=2\cdot U\cdot I\cdot\frac{1}{\pi}\sin|\varphi|+\frac{UI\cdot\pi-2|\varphi|}{\pi}\cdot\cos(\varphi) \tag{9}$$

$$P(\varphi)=UI\cos\varphi\,, \tag{10}$$

$$P_R(\varphi)=UI\frac{1}{\pi}\sin|\varphi|-UI\frac{|\varphi|}{\pi}\cos\varphi \tag{11}$$

$$P_V(\varphi)=UI\frac{\pi-|\varphi|}{\pi}\cos\varphi+UI\frac{1}{\pi}\sin|\varphi|\,. \tag{12}$$

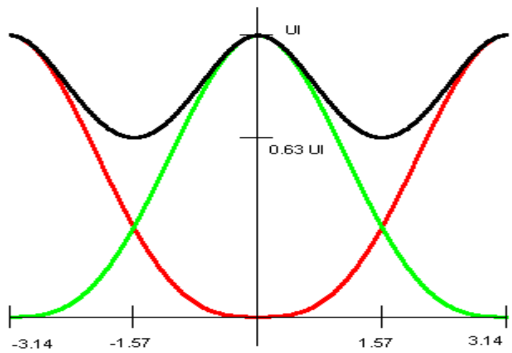

Figure 3: Theoretical curves of Pd (black), Pr (red), Pv (green) to phase angle. The phase angle is given in radians. Curves are given for sinusoidal waveforms.

III. RESEARCH

The first study relayed on checking the proper operation of the power processor by equations [11]. Results of the study are presented below. The tests were performed in the range of φ = (-100 °, 100 °). The figure 4 shows the behavior of the reactive power Q and back power Pr and 2Pr which is the value of the correction for the power P. Processor power is made according to the recommendations of DIN 40100 (revised in 1975) [15], the paper [4] and patent [6]. Visible changes in Pr and 2Pr depending on the phase angle between current and voltage are milder than the reactive power Q of setting the calibrator. Comparison of the results is subject to a 4% error arising out of the calibrator in the range of very low power to 3.5 W, although the same signal measurements with the power processor were made with

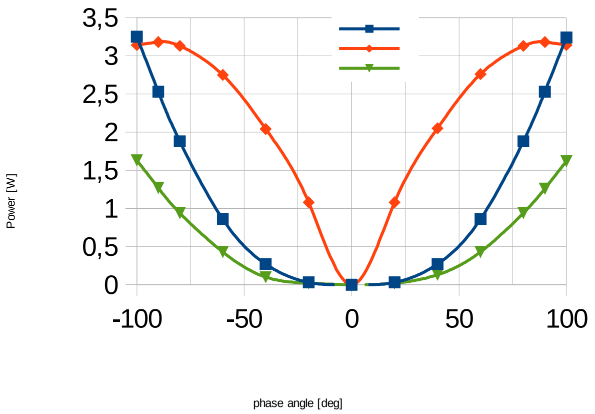

Figure 4: Part of analysis of calibrator setting Q, Pr measurement and 2Pr for the formula (3)

voltmeter Schlumberger (accuracy <0.01%) and the output signal of power processor shown in Figure 5, confirms the correctness of the design and suitability for applications in the form of an analog system (the power processor). Figure 5 confirms experimentally the power waveforms provided in [11] and shown in Figure 3. Power Pd is a sum of power values in accordance with formula (1), whose waveform is compared with the power Pd. The blue lines indicate the power signal P, the values of which are smaller in relation to Pv, and the more the Pd which in practice means, that use of counters including static measure P and energy E is only valid under resistive load and it is the power and the energy used to run the device. It is smaller than the power and energy supplied because some devices give amount power to the grid (Pr). The concept of the power delivered Pd is important for the power plant as the active power P and described correctly total energy consumption by device (not only power converted to the work).

IV. EXPERIMENT BY THE HEAT

The experiment by the heat of resistor R_L (fig.7) showed, that there is present a delivered power Pd, which is higher than active power P and thus, there is also return power Pr. The experiment rely on the current heating the load Ro and the measurement of the temperature by an electronic thermometer. The temperature is proportional to the measured power due to linearized construction of temperature converter:

$$T = k\, I_{rms} = k\, ki\, P \qquad (13)$$

Measurement circuit consist of electrodynamic watt meter, shunt R_p, divider, R_1 R_2 power processor, phase shift metter, current amplifier and measuring resistor R_L coupled with a digital thermometer as on fig.6,7. The amplifier amplifies power signal Up(t) = Uu(t)Ui(t) marked on fig. 6 as Uy and Ux. The temperature depends

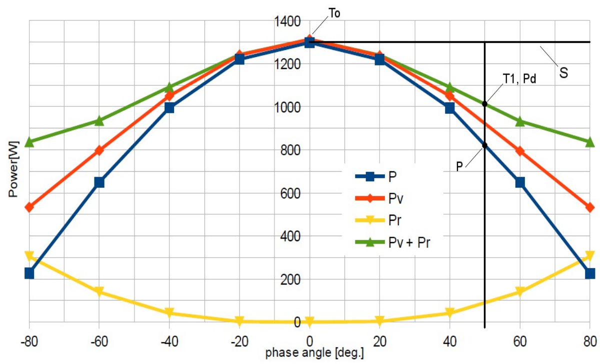

Figure 5: Results of power processor measurement (labels as in text)

on the phase shift created in the circuit (fig.5)-point T_0 T_1 The system has two types of load L_1 R_3 and R_4, which allow to measure the delivered power Pd and active one P for angle equal 0 and 50 degrees (measured voltage in the circuit is about 44Vrms, the current reaches 0.8 A rms).An equalizing resistor was added in the load RL, so that in both settings R and RL have the same voltage supply. Electrodynamic ammeter (class 0,5), Voltmeter V-542 (class 0,05), watt meter (class0,5) , Rd – resistor reducing input voltages up to 44 Vrms, phase shift metter (one of functions of accurate energy metter class 0,2).

Circuit produces signals Ui and Uv (X, Y) for the second part of a system (fig.(7)) in which an electronic watt meter is implemented, comprising a power processor with. This system also features an amplifier to separate the power of u (t) and I(t) across the resistor Ro as in Figure 7. A comparison of the power values was done through heat generated in the resistor Ro in terms of zero phase shift, and shift 50 degrees. The study shows that the power measured with the digital watt meter

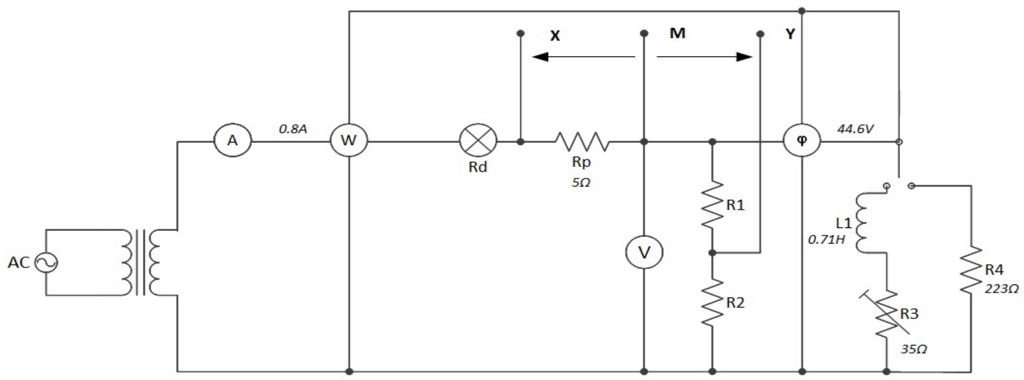

Figure 6: Laboratory system to supply the load R or RL

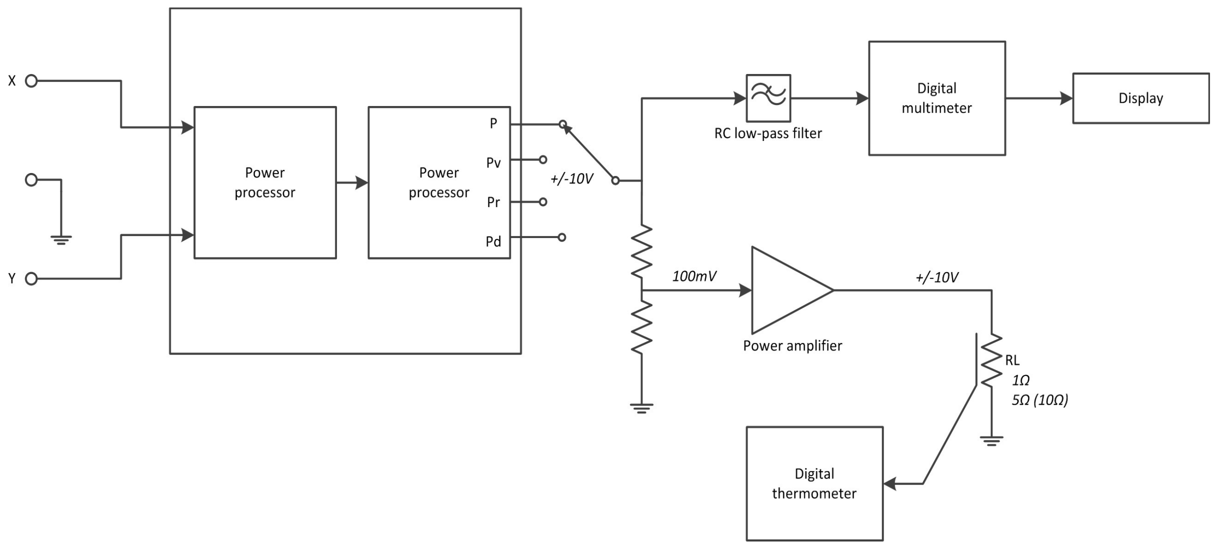

Figure 7: Watt meter system with a power processor, amplifier, resistor R_L and digital thermometer

and the temperature in point T_1 (fig.5) is greater than indicated P by the electrodynamic watt meter. The system is calibrated to an angle equal to zero, when the active power is equal to the delivered one, indicated by the same temperatures of resistor R_0 (T_0=66 ° C). Power value decreases with increasing phase angle for all the tested kinds of power. Active power drops to 66% of the initial value by the electrodynamic watt meter indications but the temperature of the resistor falls only to the 77% (power switch in position P). RL load which indicates the presence of a power greater than the active power. Delivered power Pd measured by electronic watt meter drops to 77%, which demonstrates the correct measurement in relation to the measurement of active power. The difference of 11% is a return power 2Pr according to equation (6).Calculating the percentage change in the value of the delivered power by the formula (6) or Pd/S value gives the same amount of 77% in relation to power resistive load.

V. STATIC AND DYNAMIC ERRORS ANALYSIS

The error dependence with phase shift between Uu(t) and Ui(t) for Up(t) and Upv(t) in fig.8 is presented. It shows that next step of digital calibration is necessary.

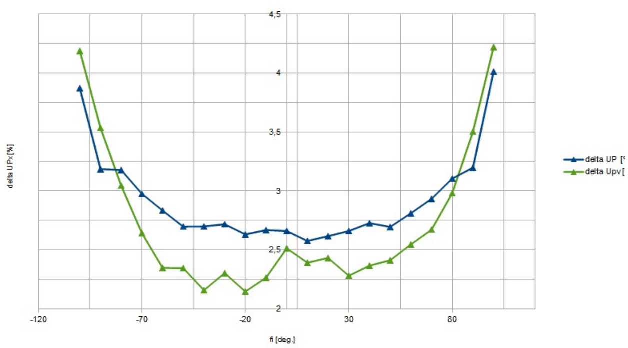

fig.8 Part of power processor errors analysis for 50 Hz

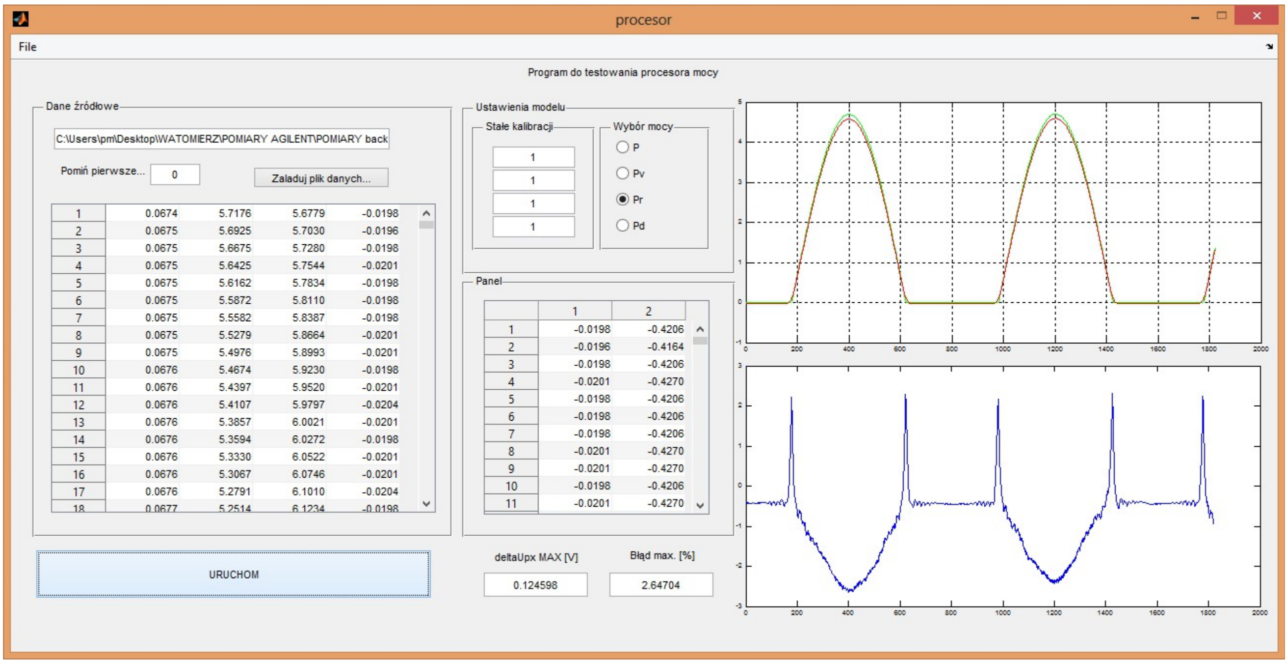

fig.9 Dynamic errors analysis with Matlab processing

In fig.9 the dynamic errors are shown, the operating frequency was 10 kHz. There are visible peaks from power output processor labeled Pr caused by shift phase between components (used amplifiers). There are not so important as additive error. That one should be reduced by calibration process.

VI. CONCLUSIONS

Power processor was established at Wroclaw University of Technology (WRUT)and its structure and electronic circuitry are developed at the Institute of Computer Systems for Automation and Measurements in order to improve the lowered indications of energy counters (especially inductive as well as electronic, in which a change in the software can be done in order to obtain the values of P_+ and P_+). Digital correction of 2Pr is simple and feasible. The return power Pr and a value of the compensation 2Pr (mutual exchange power) are suitable for modern types of receivers. These are for example computers (and other devices equipped with switched-mode power supplies), TVs, washing machines, refrigerators, thyristor circuits. Power processor allows to separate the instantaneous, positive and negative values of power signal, enabling separate measurement of the essence of its action [11], [15]. Signal distortion (especially for current) does not have a significant impact on the operation of the system due to the wide bandwidth (up to 1 MHz) operation of this the circuitry. Currently, further studies of power processor with the change of the shape and frequency of the signal, are carried out. These should confirm that the simple, integral formulas with separation of power signal are sufficient to describe all anomalies in common power networks.

Reactive power for large customers is measured as in fig.4 but its values are too large in relation to the real return power, which has its physical form and can be observed in the measurement system by multiplying current and voltage signals, amplified and dissipated on resistor as heat.

This paper presents a comparison of the values of power due to separation realized by the power processor. A comparison of standard active power P, reactive power Q and apparent power S of the triangle (fig.4) , was also made according to the possibilities of the calibrator SQ33 for sinusoidal signals. Research for the current signal containing distortions of different nature are actually conducted hovewer the laboratory system shown in fig.6 is real. It was found that the presence of harmonics does not significantly affect the operation of the power processor due to its wide signal bandwidth.

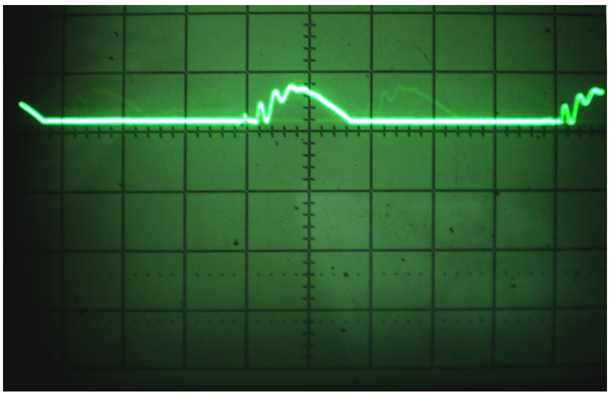

Figure 10: Waveform of return power caused by inductance in circuit from fig.6,7

The performance of constructed power processor and discussed measurement parameters have been confirmed as appropriate and feasible when used in measurement systems, primarily for financial settlements. Power processor can be used together with a simple digital meter or a chip containing a digital voltmeter as an extension module to control the return power, and supplied as an input or correction system for displaying static meters (2Pr).

In this situation should verify the concept of apparent power S = UI as a basis for settlement between the plant and the recipients. We do suggest to replace apparent power S by delivered power Pd accodring fig.5 and experiment by heat.

In 2013 in the IKSAIP two prototypes of the power meter with selectable type of power P, Pr, Pv, Pd, S and range of 3A/230V and 5A/230V were built. In 2014 we started with project of synchronous power metter as in [5] but the concept of construction is different and the technology is contemporary.

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