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Comparison of electricity meters accuracy in the case of degraded power factor and non-sinusoidal current load

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***Abstract* — This paper deals with comparison of the measurement using analog and digital meter when appliances with various negative impacts are connected as well as with layout for counting pulses of the digital meter in software LabVIEW. It also includes verification of the electricity meters at appropriate certified device.**

Keywords: electricity meters; analog; digital; Smart meters; network

I. INTRODUCTION

Nowadays, when the trends in the development and application of new kinds of electrical appliances are progressing very fast it is necessary to analyze what impact have these appliances on metering. Many of these appliances bring undesirable effects into network operation, which may adversely affect the consumption metering or more precisely the consumption can be measured with certain deviation. This deviation can occur either on the consumer side or on power system side. First of all, it is necessary to determine what side effects occur, then these effects should be assigned to individual groups of appliances that are currently most commonly used by consumers. However, the consumer may have an unspecified appliance with a significant influence on the network, which was made in third countries and is not certified for the European market. However such devices are not used often and specification of all undesirable effects of individual devices is not possible [1] [2].

Analog (disc-type) electricity meters are currently used, but they measure only active load power. However there are many appliances that work with low power factor and therefore the losses arise in the network. Because of these losses it is necessary to deploy such meters that would be also able to measure degraded power factor of the load. Consequently there will be charges for such kind of consumption. The way to solve this problem is to use two analog electricity meters, from which one would measure the reactive load power and the other the active load power [3]. Such arrangement has been used for major consumers. Its application on residential consumers' side might have a few problems, either due to not enough space for two meters in switchgears as well as due to the price and outdated technology. Digital electricity meters (Smart meters) could solve these problems. They are capable to measure instantaneous power consumption in different tariffs and quality of electricity according to EN 50160 in one device [4]. Some of these devices can also control switching of appliances. It is necessary to verify to what extent these modern devices can measure consumption of appliances, which bring adversely effects into the network [5]. For the verification it is necessary to use equipment, which is capable of measuring the power quality. The result should be a comparison and reviewing whether the digital meter is sufficiently capable of measuring or if it is necessary to fix the losses that still remain either with the use of such equipment and invest into a more expensive technology for measuring.

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II. ELECTRICITY METERS

A. *Analog (disc-type) electricity meters*

These meters are the induction ones and their principle consists in that an alternating magnetic flux of several electromagnets induces the currents in the rotating part, which is usually aluminum disk. The moment of movement is then created by the interaction of these currents and the magnetic field. Rotating device (disk) has no current supply and currents are just induced into it by alternating magnetic flux of fixed coils. The condition of the operation is thus AC power supply, so the system cannot be used to measure the DC current circuit. Aluminum disk passes through air gaps of two electromagnets E_1 and E_2. For a better understanding of the moment of movement formation it is sufficient if one considers what is the equation for calculation of the force acting on the conductor in the magnetic field, in which current flows

$$F = BI. \tag{1}$$

Alternating magnetic flux $\boldsymbol{\Phi_1}$ of electromagnet $\boldsymbol{E_1}$ induces a voltage in the disc, which forced whirling currents i_{v1} to flow there and they flow across the tracks spread in an area of the disk. Part of the current fibers of current i_{v1} flow under the pole of the second electromagnet in the place, where the magnetic flux $\boldsymbol{\Phi_2}$ of this electromagnet passes through. Interaction of current i_{v1} and magnetic flux $\boldsymbol{\Phi_2}$ creates a force $\boldsymbol{F_1}$ and a moment $\mathbf{m_{p1}}$. Similarly, magnetic flux $\boldsymbol{\Phi_2}$ induces current i_{v2} in the disk, which together with magnetic flux $\boldsymbol{\Phi_1}$ creates a force $\boldsymbol{F_2}$ and a moment $\boldsymbol{m_{p2}}$. The values of the moment of movements are proportional to the values of magnetic flux of both electromagnets. Both moments of movements counteract each other and the resulting moment has the value of:

$$M_p = m_{p1} + m_{p2}. \tag{2}$$

By complicated mathematical computation can be found out that assuming symmetry and identical design of both electromagnets the resulting moment has the value of:

$$M_p = k^{\prime}.\omega.\Phi_1.\Phi_2.sin\Psi, \tag{3}$$

where:

- ***k´***- is constant factor including influence of structural design of the device and resistance of the disk, the value of this constant as well as moment of the movement is proportional to the conductivity of the disk,
- ω – angular frequency of both magnetic fluxes
- Φ_1 , Φ_2 – amplitudes of both electricity meters magnetic fluxes,
- Ψ- phase shift between the magnetic fluxes.

$$M_p = \frac{k\omega}{\omega L}\frac{UI}{\sqrt{2}\sqrt{2}}sin\left(\frac{\pi}{2} - \Psi\right) = k_p UIcos\varphi = k_p.P \qquad (4)$$

We can see, that the moment of the movement is proportional to the active power of the AC current.

Induction devices can measure the active and reactive power, however nowadays induction devices are used solely as electric work meters – they measure the time integral of the AC power.

$$E = \int_0^t u_z(t).i_z(t).dt. \qquad (5)$$

The induction system is suitable for measuring electric work because its moment is independent of the position of the disc and so the disc could rotate permanently without limitation, what is not possible in other measuring devices because the movement of the pointer is limited by the maximum deviation [6] [7].

Rotation speed of the aluminum disc is transferred to the mechanical counter in the meter.

Analog electricity meter consists of the following systems:

- measuring system,
- driving system,
- braking system,
- rotating system,
- stop yoke,
- full load control,
- phase control,
- upper bearing,
- double-row ball race ring,
- magnetic lower bearing,
- counting machine single rate/two rate.

Measuring system consists of:

1. rotating system,
2. voltage system,
3. current system,
4. braking system with full load coarse control,
5. braking system with full load fine control,
6. magnetic stop yoke,
7. course control of the low load,
8. fine control of the low load,
9. phase control,
10. frame [8].

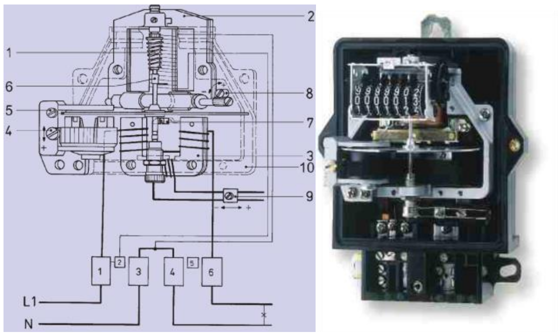

Figure 1. Analog meter.

B. *Digital electricity meters*

Digital (static) electricity meters have several advantages compared to the analog ones:

- Lower self-consumption - this parameter brings savings in term of reducing losses to the DSO,
- Measurement of lower minimum currents - this parameter in turn resulted in increased income. The meters are capable of measuring the current of less than 15 mA. The meters are therefore able to measure several devices, which are in the Standby mode.
- Utilization of processed results of the measurement - electronic processing of the measurement enables to monitor other parameters associated with consumption. These data can be stored in memory but also send by communication lines. It is possible to have several tariff of consumption measurement.
- Higher reliability.

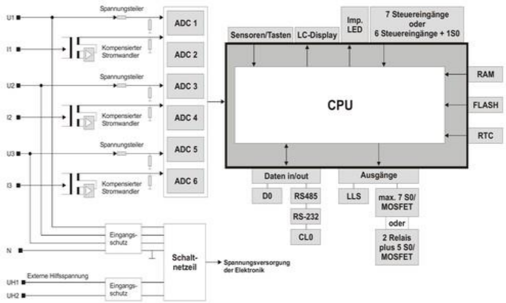

Figure 2. Principle diagram of the digital meter.

The basic principle results from the block diagram. The input signal is adjusted by the voltage divider and compensated current converters. Six synchronous A/D converters convert input signals to the digital signals. Next part is a processor, which consists of the control unit, the memories used to store data, a display used to display values, controls and communication circuits [6]. The basic interface that contains most of the electricity meters is a serial line. Some electricity meters can be extended to other communication interfaces such as PLC, GPRS, M-BUS, and LAN. The meter can be provided by many other functions and circuits and it is all depending on customer requirements. Recording and evaluation of the quality of the network are the additional functions of the meter.

The meters record following parameters:

- minimum, mean and maximum value of the voltage,
- mean and maximum value of the current,

- total harmonic current and voltage distortion,
- flicker,
- system frequency.

The period of the record is according to EN 50160 10 minutes, but it is adjustable to 1, 2, 5, 10, 15, 30 or 60 minutes. The disposal is for standard setting about 32 days [9].

III. MEASUREMENT

Before the measurement, it was necessary to test the functionality of meters and determine if their parameters meet the requirements. This verification was made with a certified device, which consists of power reference standard. Testing may also be made at the same time for the both meters but as they do not have the same maximum current, we have to verify them separately. It can be seen in Table II that the values labeled with asterisk present tests in which the meter have failed. The serial number of the meter is read during the test labeled as Serial number. In the test labeled in the table as 10 % Ib, UPF the meter is tested at 100 % voltage value, 10 % of the rated current Inom and the fundamental harmonic power factor cos φ=1. In the next test labeled as 50 % Ib, UPF the values are set to the same value as in the previous test, except the current that is set to the 50% of the rated current Inom. In the following two tests 50 % Ib, 0.5 PF and 50 % Ib 0.5 LEAD the values are the same as in the previous test, except the fundamental harmonic power factor. Indication 0.5 PF represents that the value of fundamental harmonic lagging power factor is set to cos φ = 0.5 and 0.5 LEAD responds to the value of fundamental harmonic leading power factor of the value cos φ = 0.5. The test 100 % Ib, UPF, 100 % Ib 0.5 PF and 100 % Ib 0.5 LEAD were done at the 100 % of the rated current Inom value. The last test Imax, UPF was carried out at maximum current.

The first verified meter was the digital one. It has passed all of the required tests. The accuracy class of the device was much higher than specified by the manufacturer.

TABLE I. TEST RESULTS OF THE DIGITAL METER

Test	1 NOT	2 #	3 NOT
Serial Number	---	**40247***	---
10% Ib, UPF	---	0.01	---
50% Ib, UPF	---	0.00	---
50% Ib, 0.5 PF	---	0.25	---
50% Ib, 0.5 LEAD	---	-0.26	---
100% Ib, UPF	---	0.01	---
100% Ib 0.5 PF	---	0.25	---
100% Ib, 0.5 LEAD	---	-0.26	---
Imax, UPF	---	0.05	---

Next step was the verification of the analog meter. In this case, the meter has passed only in one test and has failed in others. Deviations from the values provided by the manufacturers had great extent as can be seen from the table.

TABLE II. TEST RESULTS OF THE ANALOG METER 1 & 2

Test	1 NOT	2 #	3 #
Serial Number	---	**8165573***	**6756385***
10% Ib, UPF	---	**99.99***	1.86
50% Ib, UPF	---	**-8.76***	1.81
50% Ib, 0.5 PF	---	**-8.45***	-1.95
50% Ib, 0.5 LEAD	---	**-4.06***	1.92
100% Ib, UPF	---	**-2.22***	1.80
100% Ib 0.5 PF	---	**-7.75***	1.85
100% Ib, 0.5 LEAD	---	**-8.45***	-1.81
Imax, UPF	---	-1.30	-1.75

We have replaced the analog meter that failed the test by another and have tested it again. This one has passes the test, so we could started the measurement.

Figure 3. Testing stand

The measurement was made in the way that it was possible to verify both meters at the same time. The meters and the power network analyzer ENA were connected in series. The values measured by the meters were compared to the values measured by the analyzer ENA 330. Thank to this connection it is possible to say that the measurement was carried out under the same conditions. Load was represented by light bulbs, fluorescent lamps, LED and frequency converter which had supplied the motor. The choice of appliances was not random, because we wanted to maximize the negative impacts and thus verify how they will affect the consumption metering.

A. *Analysis of appliances negative impacts*

The light bulb is a resistive load and therefore it is not considered as source of negative impacts. This type of appliance, does not produce undesirable harmonic distortion. The fundamental harmonic power factor of this appliance is cos φ=1.

The compact fluorescent lamp contains electronic circuit composed of semiconductors creating the inverter and thanks to that it becomes a producer of non-harmonic current. The most significant high-order harmonics, which can be seen are 3^{th}, 5^{th} and 7^{th} harmonic component of the current. The cos φ has values around 0.908, the power factor pf=0.6 and the total harmonic distortion of current THD_I = 112 %.

Luminescence diode (LED) also contains electronic circuit composed of semiconductor. The 3^{th}, 5^{th} and 7^{th} harmonic component of the current can also be observed as the most in the case with this kind of load. The fundamental harmonic power factor of such appliance is cos φ=0.936, power factor pf = 0.55 and total harmonic distortion of current THD_I=128 %.

The frequency converter, which supplies a motor, causes the fundamental harmonic power factor of 0.95 on the grid side, but also high asymmetry and harmonic distortion of the load current.

Whereas all appliances were connected simultaneously during the measurement, the following values have been measured: fundamental harmonic power factor cos φ=0.92, power factor pf=0.69 and total harmonic distortion THD_I = 92%.

B. *Measurement using analog meter*

ZPA analog meter measures only active power, which is directly displayed on the dial plate. The initial state of the meter had to be recorded before measurement. Initial value was 04906.91 kWhr (Fig. 3). Consequently, we could continue with measurement. We were checking the state of the meter during the measurement, especially for motor speed changes caused by frequency converter. The state of the meter dial plate was also recorded at the end of the measurement. The final state of the meter at the end of the measurement was 04907.37 kWhr

(Fig. 3). Both states are shown in Fig. 3. We calculated the final consumption, which was 460 Whr, from these states.

Figure 4. The initial and final state of the meter.

C. *Measurement using digital meter*

Digital meter Schrack LZQJ-XC displayed on the display the measured value only in integer values, what in this case would results in large measurement error. Error could be eliminated partially in the case that we would measure high power consumption and the meter has to be reset before measurement. The exact value can be obtained from the register of the meter, but as the manufacturer does not indicate, in which registry such a value is recorded, it was necessary to use another method. One way was to use a pulsed output of the meter and thereby achieved sufficient accuracy for comparison. With this type of meter is 250 pulses per kilowatt hour at active power measurement and 250 pulses per kilovar hour for reactive power one. Measuring card was used to detect pulses. Measuring card was connected to a computer via USB. The measurement in software LabView was created to interpret the measurement values from the card. The output of this program was the number of pulses and consumption in Whr. The value of the active power consumption determined by this meter using the pulse output was 476,52Whr.

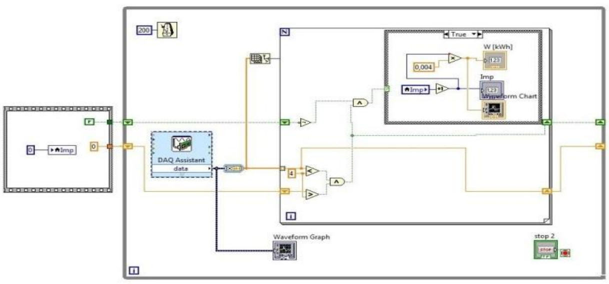

Figure 5. Measurement in software LabView.

D. *Measurement using power network analyzer ENA330*

Measurement using power network analyzer ENA330 was done only to verify the measured values. Instead of this device another device or meter could be used, with which the measured values were compared, but as we wanted to know exactly which undesirable high-order harmonics and other negative impacts of chosen load, we had used power network analyzer. We measured the following values using power network analyzer: active power consumption 474.85 Whr.

TABLE III. THE MEASURED CONSUMPTION

Measuring device	Active power consumption (Wh)
ENA 330	474,85
Analog meter ZPA	460
Digital meter LZQJ-XC	746,52

IV. CONCLUSION

We have tried to verify the effects of various appliances at the consumption measurement using analogue and digital meter in this paper. The values were compared with those measured by Quality Analyzer ENA 330, whose the accuracy class declared by the manufacturer is much higher than that of the meters. Measured values of consumption for each meter are presented in the paper. It implies from these values that an analog meter measured lower value of the consumption, despite the fact that both meters have declared the same accuracy class by the manufacturer. By verification of the meter at testing device was found out that the accuracy class declared by the manufacturer is much higher than that measured by us, the accuracy class of the analog meter had measured value and declared value by the manufacturer almost the same. The fact that the analog meter measured lower consumption, constitutes losses for the electricity supplier, which will result in reduced profits. The reason, why the analog meter measured lower value of consumption, could be the influence of the chosen appliances and their negative impacts. It would be better to do the measurement either by major consumer or distribution substation with using the same measuring devices, and to compare these consumptions, since a larger number of various appliances would be connected in this case and the negative impacts would have been larger. However we can say in general that the use of a digital meter to measure consumption will significantly reduce the losses for suppliers. Another advantage is the use of one device for measuring the consumption of active and reactive power. By using that a supplier will reduce the total number of meters, thereby reduce the number of meters that will required calibration after a certain period of the operation. Another advantage is that the majority of these meters can monitor also the voltage quality according to EN50160.

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