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Power network parameters standards with implements IEEE-1459 Power Definitions

***Abstract**. The development of Polish portable standards of power network parameters and their concepts are presented, taking into account the requirements of the IEEE-1459 standard in the scope of the separation of the fundamental frequency power components P1 and Q1 from apparent power S for the purpose of calibrating electricity meters. The issues of calibration uncertainty of working active power P1 meters were discussed and two concepts of their calibration were presented: with the use of active power P standards and wit the use of working active power P1 standards.*

***Streszczenie.** Przedstawiono rozwój krajowych przenośnych wzorców parametrów sieci energetycznej i ich koncepcje z uwzględnieniem wymagań standardu IEEE-1459 w zakresie wydzielenia komponentów mocy P1 i Q1 o częstotliwości podstawowej z mocy pozornej S dla potrzeb wzorcowania liczników energii. Omówiono zagadnienia niepewności wzorcowania liczników roboczej mocy czynnej P1 oraz przedstawiono dwie koncepcje ich wzorcowania: z zastosowaniem wzorców mocy czynnej P i z zastosowaniem wzorców roboczej mocy czynnej P1. (**Wzorce parametrów sieci energetycznej z implementacją definicji mocy wg IEEE-1459**).*

Keywords: electricity meter, reference meter, power calibrator, automatic test system.
Słowa kluczowe: licznik energii elektrycznej, licznik wzorcowy, kalibrator mocy, automatyczny system testujący.

Introduction

The state of the three-phase power network is presented by means of a vector graph and a set of values of such network parameters as: voltages and currents, phase shift angles (or power factors), angles between voltages, frequency and also active, reactive and apparent powers and energies. To calculate the values of these parameters, parameter definitions and their analytical models in the form of equations are needed, which are implemented in the algorithms of measurement (for meters) and reproduction (for sources) of the power network parameter standards.

In 2010, after 30 years of discussing new power definitions, when the mechanism of electricity flow under non-sinusoidal conditions was well known, IEEE 1459 [1] was developed, which provides consistent and unambiguous power definitions better suited for electricity billing purposes under sinusoidal and non-sinusoidal conditions. The primary innovation of the IEEE 1459 standard is the separation of the fundamental frequency power components P_1 and Q_1 from the apparent power S. The active, reactive and apparent powers with basic frequency are the quintessence of the power flow in electric networks. They define what is generated, transmitted, distributed and sold by the electric utilities and bought by the end users. This standard is based on the belief that a fair distribution of financial burdens between the electricity supplier and recipient is a prerequisite for maintaining a high quality of electricity supply. In addition, it is stated that the current level of microprocessor technology allows manufacturers of electrical instruments to construct new, accurate and versatile metering equipment that are able to measure electricity defined by means of advanced mathematical models.

Technical specifications and subject standards for active energy meters currently used in North America (ANSI C12 series) and Europe (IEC 62052 series) and international recommendations OIML R46 [2] are not yet adapted to the rational settlement of energy in non-sinusoidal conditions. Currently, the need to measure the first harmonics of power for energy billing purposes only applies to reactive energy measurement [3].

Works [4, 5] describe the design of electricity meter construction with implemented the new power definitions of the IEEE 1459 standard for the needs of comparative measurements of power P and P_1, Q and Q_1 as well as S and S_1 of energy flow in connections of real users. A Radian 4150 Meter Test Set [6] was used to calibrate and test these electricity meters. The 4150 includes a Radian RD-30 Reference Standard for determining the accuracy of the meter under test. Unfortunately the Radian RD-30 measures only P and Q powers and it is not possible to measure the fundamental frequency power components P_1 and Q_1 in non-sinusoidal conditions.

The errors evaluation of a wattmeter for the measurement of IEEE 1459 standard power quantities in non-sinusoidal conditions was described in [7]. A Multifunction Calibrator Fluke 5720A [8] and a precision current shunt were used as a power network parameters standard.

Induction meters are replaced for electronic meters in the last 20 years on a massive scale. During this time, many papers [9-12] were published on the errors of active energy electronic meters in relation to the requirements of current standards for meters. Unfortunately, these standards are based on the definition of power developed in the 1940s, this definition does not take into account the changes that have occurred in the last 50 years, in particular the flow of energy caused by harmonic voltages and currents [1, 13].

The development of polish standards for sinusoidal and non-sinusoidal, stable and variable power networks parameters, by 2009, is described in [14]. At that time, papers were published on the subject of energy flow directions as well as working and reflected active power [15] as well as the correctness of electricity meter readings. An important area of using network parameter standards is checking revenue electricity meters in two situations: meters connected to the network and meters disconnected from the network. The next part of the work describes the development of polish standards of network parameters in the last decade, with particular emphasis on the possibility of checking electricity meters P, P_1, Q and Q_1 under non-sinusoidal voltages and currents.

Standards for testing of electricity meters connected to the network

The indications of revenue electricity meters are the basis for financial settlements between the energy supplier and its recipient, and therefore checking the accuracy of meter indications is given big attention. This is manifested, inter alia, in checking the accuracy of the meters connected to the network on site of their installation. The recommended form of verifying the correctness of connecting the meter to the network and checking the error of the meter is the non-invasive connection of the meter tester (reference meter) into the circuit of the measuring and billing system, without the need to disconnect the current and voltage circuits of the meter, as shown in Figure 1.

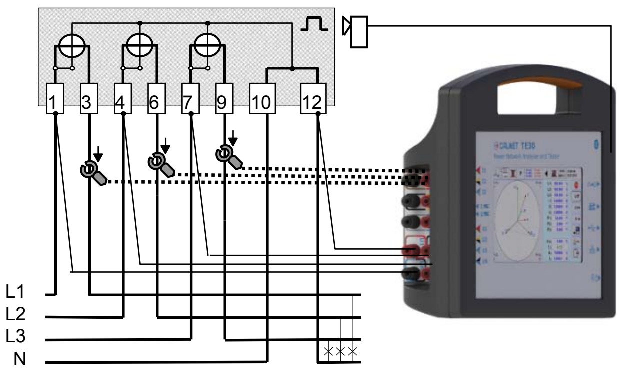

Fig.1. The scheme of connecting the meter tester in the measuring and billing circuit

Meter testers, in accordance with the draft standard IEC 62057-2 [16], are named as the Portable Working Standard [17] or the Portable Reference Meter [18] and according to the definition [16] are working standards used for measurement of current, voltage, power, energy and error of electricity meters and also, if needed, for measurement of the burden for voltage and current transformers, determination of the ratio error and phase displacement for current transformers. The most advanced testers have implemented the power quality analyzer functionality, such as MTE PWS 3.3 [17] or the polish Calmet TE30 [19], which according to the terminology used in the standard [16] is named as a Portable Three Phase Standard Meter and Energy Quality Analyzer.

The TE30 tester introduced in 2014 meets the requirements of the IEC 62057 standard and has the functionality of an power quality analyzer and also is distinguished by the innovation possibility of measuring power and energy according to various versions of the power cuboid [20], in particular according to the IEEE 1459 [1] with separate components power P_1 and Q_1. The implemented functions of measuring the power spectrum, reflected active power, harmonic power and distortion power allow evaluation of energy flows. The reference meter function of the fundamental active power enables the measurement of percentage error in the calculation of electricity due to uncontrolled energy flows through the installed measuring and billing system. The energy cuboid measurement function with separated components of the first harmonics enables the measurement of all energy components for the calculation of non-technical losses of electricity caused to the harmonic energy flow [21].

Standards for testing of electricity meters disconnected from the network

The advantage of using standards to reproduce network parameters is that they allow checking electricity meters at all required load points of the meter, but this requires disconnecting the voltage and current circuits of the meter from the power grid, as shown in Figure 2. Two concepts are used to construction of standards to reproduce power network parameters:

- as a set of measuring power supply and reference meter necessary to ensure the required accuracy of voltage, current and power reproducing,
- as a three-phase power and energy calibrator (Fig. 2).

In Poland, in Zielona Góra, from many years [14], the building concept of standards for testing of electricity meters disconnected from the network is been developing, based on the power and energy calibrators. In 2014, the three-phase power and energy calibrator Calmet C300B [22] was introduced with the function of an automatic electricity meter tester, which allows checking the meter error in two measurement configurations:

- with reference to the accuracy of the internal calibrator standard (Fig. 2). This makes it possible to check the electricity meter error of powers P and P_1, Q and Q_1 with uncertainty up to 0.02%,
- with reference to the accuracy of the external reference meter (Fig. 3). The measurement system is then implemented according to the first concept of standard construction, in which the calibrator performs the function of a precise three-phase measuring power supply and the function of standard is taken over by an external reference meter.

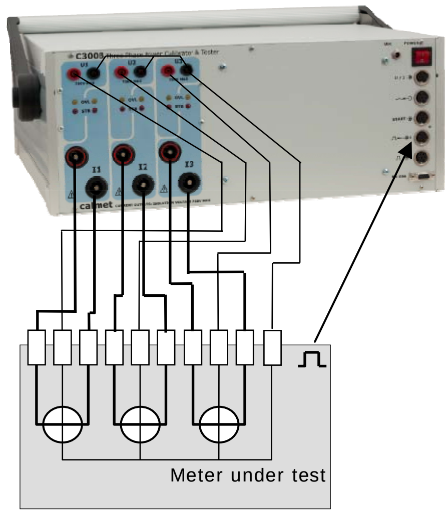

Fig.2. The scheme of the measuring system for checking the electricity meter error with the accuracy related to the calibrator

In the system with an external reference meter, shown in Figure 3, the calibrator has two impulse inputs for counting impulses from the meter under test and the reference meter. In this system it is possible to check electricity meters of such powers, which are measured by reference meters and with such uncertainties as guaranteed by reference meters. Well-known reference meters measure electricity of P and Q powers, e.g. the Radian RD33 meter [23], while the authors are not known of other, than TE30 [19], reference meters of P_1 and Q_1 powers.

Comparing the systems presented in Figures 2 and 3, it can be seen that the use of an external reference meter (Fig. 3) results in an almost double increase in the number of connections required. The revenue meter is a highly non-linear load and connected as a meter under test to the calibrator output can cause additional distortion of the calibrator output signals. In a situation where additional and uncontrolled distortion of the calibrator output voltages and currents affects the accuracy of the meter error determination, it is recommended to use a system with an external reference meter.

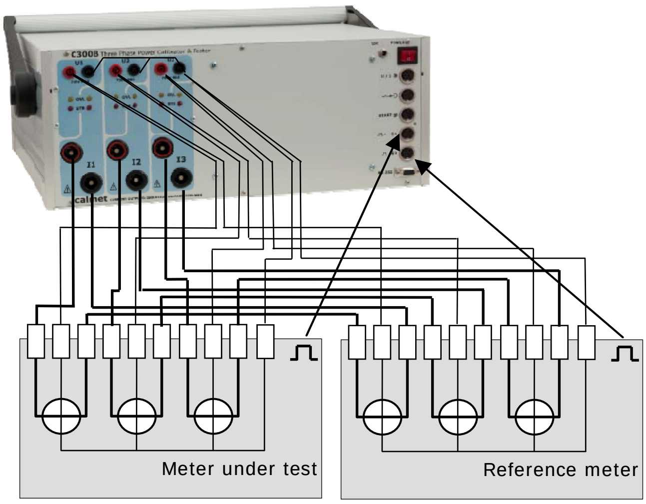

Fig.3. The scheme of the measuring system for checking the electricity meter error with the accuracy related to the external reference meter

Automatic Test Systems

In recent years, a new kind of standards for checking electricity meters has appeared, which are named as the Three-phase Fully Automatic Test System with Reference Standard and Integrated Current and Voltage Source. Examples of such systems are Zera MT781 / MT786 [24], MTE PTS 3.3C [25] and the first Polish Calmet TS33 system [26]. These systems allow the checking of meters completely connected to the network (Fig. 1) or completely disconnected from the network (Fig. 2) and additionally checking the meters in the "mixed" connection system shown in Figure 4.

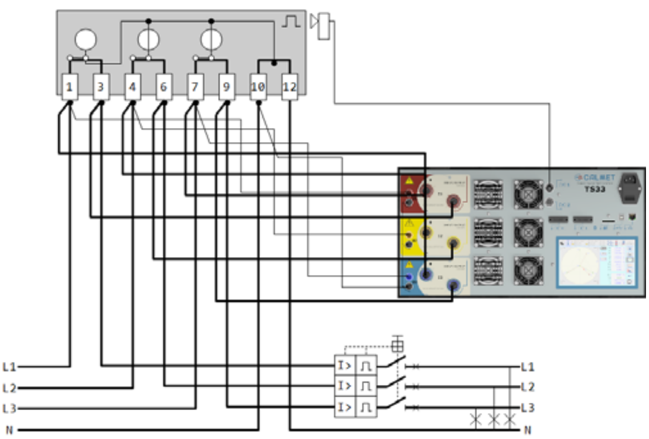

Fig.4. The scheme of the measuring system for checking the electricity meters in current injection mode

Checking the electricity meter error in a mixed system has two advantages simultaneously:

- non-invasive test - no need to disconnect the meter voltage and current circuits,
- the possibility to perform an automatic test at predefined load points.

In the discussed connection system, the TS33 test system is used as a system with a reference meter and an integrated current source - the power calibrator of this system works in the mode of a three-phase synchronized current source (frequency and phase shift angles) with input voltage.

The TS33 system introduced in 2019 meets the requirements of the IEC 62057-2 standard [16] for the function of a reference meter, has the functionality of the power quality analyzer and is distinguished by the innovation possibility to measure and reproduce power and energy according to the IEEE 1459 [1] with separate components P_1 and Q_1 power for checking the error of electricity meters P, P_1, Q and Q_1 powers with uncertainty up to 0.05%.

Calibration uncertainty of electricity meters at fundamental frequency

Active power in non-sinusoidal conditions is given by the formula:

$$P = \sum_{1}^{\infty} P_n = P_1 + \sum_{2}^{\infty} P_n = P_1 + P_H = \sum_{1}^{\infty} V_n \cdot I_n \cdot \cos\varphi_n \tag{1}$$

where: P_1 – fundamental active power, P_n – harmonic active power of order *n*, P_H – harmonic active power, V_n – RMS value of harmonic voltage of order *n*, I_n – RMS value of harmonic current of order *n*, φ_n – phase angle between the V_n and I_n .

Equation (1) shows, that two concepts of P_1 electricity meter calibration are possible. The first, using the standard of fundamental harmonic active power, according to the following calibration equation:

$$P_{1MUT} = P_{1S} + u(P_{1S}) \tag{2}$$

where: P_{1MUT} – reading from meter under test, P_{1S} – fundamental active power measured or reproduced with used power network parameters standard, $u(P_{1S})$ – uncertainty of fundamental active power of standard.

In the second concept, the active power standard can be used according to the following calibration equation:

$$P_{1MUT} = P_S + u(P_S) - (P_H + u(P_H)) \tag{3}$$

where: P_S – active power measured or reproduced with used power network parameters standard, $u(P_S)$ – uncertainty of active power of standard, P_H – harmonic active power, $u(P_H)$ – uncertainty of harmonic active power of standard.

Equation (3) shows that calibration of the P_1 electricity meter using the P power standard under non-sinusoidal conditions is possible - the P_1 working power value is obtained by subtracting the calculated value of the harmonic power P_H from the active power value P_S . However, the uncertainty balance should take into account the uncertainty of harmonic active power expressed by the formula:

$$u(P_H) = \sum_{n=2}^{\infty} P_n \cdot \sqrt{\left[\frac{u(V_n)}{V_n}\right]^2 + \left[\frac{u(I_n)}{I_n}\right]^2 + [u(\cos\varphi_n)]^2} \tag{4}$$

where: $u(V_n)/V_n$ and $u(I_n)/I_n$ are the uncertainties of voltage and current harmonics and $u(\cos\varphi_n)$ is the uncertainty of the harmonic power factor given by the formula:

$$u(\cos\varphi_n) = \frac{\cos(\varphi_n + u(\varphi_n)) - \cos\varphi_n}{\cos\varphi_n} \quad (5)$$

where: $u(\varphi_n)$ is the uncertainty of the harmonic phase shift angle.

Analysis of equations (4) and (5) shows that when calibrating the P_1 active power meter using the P active power reference meter in the measuring systems shown in Figures 1 and 3, or using a calibrator (Fig. 2), knowledge is required on the values of amplitudes and harmonic phases of test voltages and currents of distorted signals and on the uncertainty of their reproduction.

The TE30 [19] reference meter, the C300B [22] calibrator and the TS33 [26] test system with the error check function of the P and P_1, Q and Q_1 power meters in non-sinusoidal conditions allow to check electricity meters according to the IEEE 1459 without the need for laborious procedures associated with taking into account the uncertainty of harmonics reproduction according to the formula (4).

Conclusions

The discussion about the need to measure the electricity of the fundamental active power for accounting purposes has been going on for many years and was crowned with the development of the IEEE 1459 standard. Over the past ten years, a new generation of portable power network parameters standards has been developed and introduced for production: TE30 reference meter with power quality analyzer function, C300B three-phase power / energy calibrator with automatic meter tester function and the first Polish Automatic Test System with a reference meter and integrated current and voltage source model TS33. All of the above standards have the functions of automated checking of active and reactive power electricity meters as well as the first harmonics of these powers implemented, which is an innovation in the area of power network parameters standards for the purposes of checking electricity meters. Calibration of P_1 electricity meters using the P_1 reference meter improves the calibration process because there is no need to include harmonics uncertainty (uncertainty of amplitudes and phases) in the uncertainty balance, what is required when using the P reference meter.

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