Paweł WĘGIEREK, Michał KONARSKI

Lublin University of Technology, Faculty of Electrical Engineering and Computer Science, Lublin, Poland

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Electricity measurement accuracy in the smart metering system

***Abstract**. The smart metering to the power system implementation significantly changes the way of measurements and settlements in the electricity sector. This paper presents an analysis of realized measurement accuracy and the key information about the smart metering and the components of the advanced metering infrastructure. It also shows the scope of authors' ongoing research on the temperature effect of electricity measurement accuracy in the smart metering system.*

***Streszczenie.** Wprowadzenie do systemu elektroenergetycznego inteligentnych systemów pomiarowych znacząco zmienia sposób przeprowadzanych pomiarów i rozliczeń. W artykule przedstawiono analizę dokładności realizowanych pomiarów oraz zaprezentowano kluczowe informacje dotyczące inteligentnego systemu pomiarowego i zaawansowanej infrastruktury pomiarowej. Przedstawiono również zakres aktualnie prowadzonych przez autorów niniejszego artykułu prac badawczych, dotyczących wpływu temperatury na dokładność pomiarów energii elektrycznej w inteligentnych systemach pomiarowych. (**Dokładność pomiarów energii elektrycznej w inteligentnych systemach pomiarowych**).*

Keywords: electricity measurement, measurement accuracy, smart metering, smart grid.
Słowa kluczowe: pomiary energii elektrycznej, dokładność pomiarów, inteligentne systemy pomiarowe, sieć inteligentna.

Introduction

The smart grid implementation in Poland recently definitely accelerated. Successful pilot programs resulted in the beginning of new, large-scale investments. The smart metering system is an essential part of the smart grid. The smart grid can be described as a modernized electricity grid supplemented by a digital two-way communication system between a supplier and a consumer and smart measurement and monitoring systems [1]. The main smart grid concept is an integration of activities of all participants in the process of generation, transmission, distribution and consumption of electricity, in order to deliver it in an economical, safe and secure manner. The realization of this objective is only possible by taking multi-faceted activities. The most important actions related to the smart grid introduction are substitution of a conventional, centralized model of the electricity generation by a dispersed model and complement an energy transmission layer by an information technology layer, permitting advanced measurement and control functions [2].

Smart Metering System

The implementation of the smart grid and the achievement of its objectives are not possible without the introduction to the power system advanced metering, control and safety infrastructure [2]. A fundamental part of the intelligent infrastructure, particularly from the customer perspective, is the smart metering system, which is a common system for automatic measurements, two-way exchange of information and transmission of signals and commands to final customers [3]. The smart metering system consists of two equivalent parts – the advanced metering infrastructure and the meter data management system. The advanced metering infrastructure (AMI) is an integrated set of measurement elements, consisting of smart meters, communication modules and systems, data concentrators and recorders, which enable two-way communication between meters and the meter data management. Meter data management system (MDM) is a computer system used in measurement data processing for billing purposes and to cooperate with other information systems [4].

The most important difference between the smart and the conventional metering system is the implementation of a two-way communication between a meter and a power system operator, enabling a complete automation of the electricity settlement process [4]. Achieving the two-way communication is not possible with commonly used analog electricity meters. This effect can be accomplished only by the use an electronic, equipped with communication module meter – called a smart meter. A meter-MDM communication can be done in two ways – directly using the GSM network or indirectly through a collecting device called a data concentrator. Most of the present methods based on the solution using the concentrator. The concentrator is generally placed in a MV/LV transformer station and it is responsible for a multiple meters communication with the MDM. A meter to concentrator communication is realized by using the power line communication (PLC). Measurement data from the concentrator is then routed to the connected communication module, linking with the MDM via GSM [5]. All of these devices and communication methods are parts of the AMI, which simplified structure is shown in figure 1.

The main objective of the smart metering implementation is to rationalize electricity consumption, which shall reduce overall cost of the power system operation. Smart metering is expected to create many benefits to all participants in the process of production, distribution and consumption of the electricity. The introduction of new technology will mean [6]:

- for distribution system operators – reduction of cost by obtaining more accurate market data and revenue increase by reducing losses and inefficiencies,
- for the transmission system operator – improvement of system security and reduction of the balancing mechanism cost,
- for electricity sellers – ability to customize offers to the individual needs of final customers,
- for electricity producers from renewable sources – facilitation in processes of settlement and grid connection,
- for final customer – liquidation of based on forecasts settlement, energy saving possibility by the use of advanced monitoring tools and improvement of the electricity quality.

The smart metering is now a primary area of the Polish smart grid implementation. In addition to the benefits, significant impact on the smart metering development have applicable legal regulations, such as Directive 2009/72/EC of the European Parliament and of the Council, which requires member states the obligation to equip in smart metering systems by 2020 at least 80% of customers [7]. In the Polish case, this means the need to install by 2020 approx. 15 million smart metering systems, with the current implementation level of only 2.7% [6].

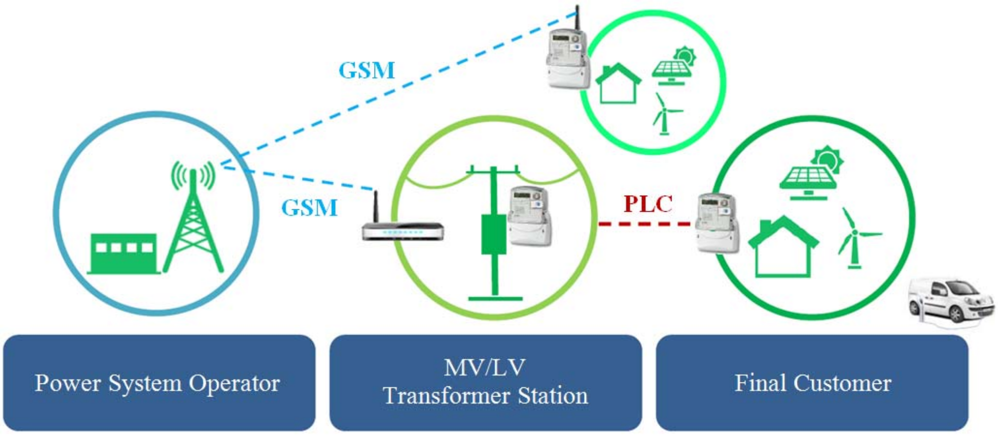

Fig.1. Advanced metering infrastructure [8]

Smart Electricity Meter

A smart electricity meter (Fig. 2.) is a basic element of the AMI and of its functionality affects the functionality of the entire metering system. The most important feature of this meter is the possibility of a two-way communication with the power system operator. The communication is implemented in the PLC technology via a built-in communication module, enabling the connection to a data concentrator. In justified cases, complement of the PLC transmission can be direct communication with the MDM via the GSM transmission.

Fig.2. Smart electricity meter [9]

In the order to ensure the quality of measurement and communications, a smart meter must meets the requirements set out in the applicable, published by the Polish Energy Regulatory Office *The Exemplary Technical Specification for the standard tender procedures for the supply of metering infrastructure for AMI systems*. According to the Specification, smart meter must enable [5]:

- two-way active energy measurement and registration in the accuracy class at least B,
- four-quadrant reactive energy measurement and registration in the accuracy class at least 3,
- load profile registration in 15, 30 and 60-minute intervals,
- operating temperature range at least -30°C / +70°C,
- two-way PLC communication with a data concentrator,
- electricity supply monitoring,
  - remote reading of measurement data on a concentrator demand,
- immediately transmission of information about power failure, cover opening or activation of an external magnetic field,
- remote change of the applicable tariff,
- remote customer connection and disconnection.

Measurement Data Concentrator

A measurement data concentrator (Fig. 3.) connects customers' meters with the MDM. The main task of the concentrator is to download via PLC measurement data from meters, and then transfer them via Ethernet, modem and GSM to the power system operator. Most of the commercially available concentrators allow the use of an external or built-in modem.

Fig.3. Measurement data concentrator [10]

Similarly to a meter, a data concentrator also must meet a number of requirements specified in *The Exemplary Technical Specification*. According to the Specification, data concentrator must enable [5]:

- operating temperature range at least -25°C / +60°C,
- two-way PLC communication with at least 800 meters,
- acquisition of measurement data from the meters at least four times a day (in the six-hour cycles),
- two-way communication with the MDM via Ethernet, modem and GSM,
- transmission of measurement data to the MDM at least once a day, with the exception of data requiring immediate transmission.

Power Line Communication

The primary method of communication between the meters and the concentrators in the AMI is the power line communication. This communication used as a transmission medium a low-voltage power grid and is made possible by the use of communication modules in the grid devices. The basic PLC operating principles are modulation and demodulation. The modulated high frequency signal is added to the voltage waveform in the supply line. The receiving module separates the transmitting baseband signal from the supply voltage and restores the original data by demodulation [4]. The bandwidth currently used in the Polish grid is the CENELEC A band of frequencies 3 - 95 kHz using the Orthogonal Frequency-Division Multiplexing modulation (OFDM), which consists in dividing the frequency band into many independent carriers and transmit several data streams in parallel [5,11]. The OFDM modulation operating principles is shown in figure 4. The most important requirement for the PLC communication is assuring appropriate quality, which is affected by the grid infrastructure condition as well as interference and noise made by other devices and external factors [4, 5].

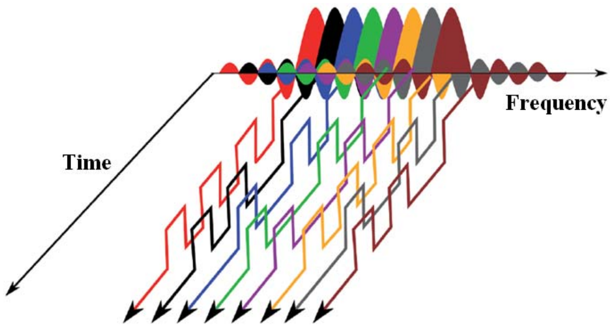

Fig.4. OFDM modulation [11]

Electricity Measurement Accuracy

The use of advanced metering infrastructure has a significant impact on the electricity measurement accuracy. In the traditional approach, the only device affecting the accuracy is a meter. The smart metering system measurement quality depends on more elements, which is associated with extended measurement data flow path from a meter to the MDM. Measurement precision in the smart metering typically depends on the quality of:

- meter measuring and registering,
- PLC modulation in a meter communication module,
- supply line PLC communication,
- concentrator PLC/Ethernet processing,
- Ethernet communication,
- modem Ethernet/GSM processing,
- GSM communication,
- GSM/Ethernet processing of a MDM communication module.

The basic AMI element, which has the greatest impact on the measurement accuracy, is an electricity meter. Also used as a component in the traditional measurement systems, it has well defined metrological requirements. The main parameter determining the quality of the meter measurements is its accuracy class, specifying the maximum permissible error at reference conditions. These values are determined separately for active and reactive energy measuring. In smart meters the minimum class for an active energy measurement is B – corresponding to the 1% maximum permissible error. A reactive energy measurement must be realized in the accuracy class at least 3, with the 3% maximum permissible error. These requirements, as mentioned previously, apply only to the reference conditions. This means, that at changing external conditions or worse quality of the supplied power, the measuring quality may be decreased [5,12,13]. Influence quantities of the meter maximum permissible error are an ambient temperature, voltage and frequency changes, voltage unbalance, harmonics presence as well as magnetic induction and electromagnetic field effect [14].

The error introduced by the influence quantities is called the additional error and it affects the value of the maximum permissible error in other than the reference conditions. For example, the maximum permissible error of the class B meter, which is 1% in the reference conditions, in adverse conditions may rise to 4.5% and this will be a correct and class-consistent value [14]. Requirements for meters are distinctly defined in the law as well as in the Polish and the European standards. The question is whether the currently installed, yet unproven on a large scale smart meters, meet all the requirements and whether their measurement accuracy is sufficient.

In the case of other AMI components metrological requirements are not clearly defined. This applies to both physical devices and communication methods. The lack of regulations is probably associated with the relatively recent introduction of these components for measuring systems. No metrological requirements for these parts and small scale of existing implementations resulting in an unspecified accuracy of the overall measuring system. It is especially important from the perspective of the electricity settlement, where errors in the measurement data transmission and processing have a direct impact on the customers' bills, which in the smart metering are issued automatically. These facts prove the need for urgent legal control of the smart metering measurements quality. Fortunately, this problem was already discussed in the ongoing legislative works. The draft law proposed by the Ministry of Economy assumes, that minister responsible for the economy will specify, by ministerial decree, the detailed operating conditions of the measuring system. The decree shall contain [6]:

- measuring system requirements,
- requirements of:
  - o communication standards between a smart meter and the MDM,
  - o measurement data,
  - o commands received by the smart meter and the conditions of their transfer,
- measurement data correcting methods,
- communication reliability parameters.

The decree should introduce solutions to ensure the metrological control of the all smart metering components. However, the legislature provided that the proposed law will not come into force until 1st January 2016 [6].

Ongoing Work

The presented situation requires a comprehensive verification of the measurement accuracy in the smart metering system. It is especially important to check the measurement accuracy at varying operating conditions, where, in the most unfavorable cases, may occur an extreme errors. One of the most significant influence quantities seems to be the ambient temperature. This assumption is associated with the use in the smart metering system of temperature-responsive semiconductor devices and the location of most of the system components in places directly exposed to the outdoor temperature. The temperature effect of electricity measurement accuracy in the smart metering system is the subject of authors' ongoing research.

The research scope includes an analysis of temperature effect on quality of:

- measurement and registration of the smart meter,
- data processing of the smart meter communication module,
- PLC transmission,
- data processing of the data concentrator.

The research is carried out by using a specialized climatic chamber, which allows conducting tests in constant, user-specified temperature. The university-owned chamber is Discovery DY600C, produced by Angelantoni Industrie, with a useful capacity of 559 liters. The chamber enables conducting experiments at the temperature range from -75°C to +180°C. The use of advanced adjusting methods provides exceptional stability of internal climate conditions, with the possible temperature fluctuation of only ±0,1°C to ±0,3°C. Due to equip the chamber with the hermetic portholes it is possible to input and output electrical wiring without affecting the internal temperature stability.

Conducted experiments consist of placing inside the climatic chamber tested AMI component, verifying the obtained at a set temperature amount of electric energy consumed by a connected receiver and comparing it with the amount obtained in the reference conditions (temperature of 23°C). For each temperature, on the basis of received values, is calculated a temperature additional error. In the first stage, the research is conducted in device operating temperature range (-40°C to +70°C for the meter, its communication module and PLC communication, and -25°C to +60°C for the data concentrator). In the next research stage it is planned to expand the experiments outside the operating range. To thoroughly check the measurement system operation, the tests are conducted for different devices producers and for different types of loads – both for their power (load current from 0.25 A to 16 A) and character (power factor from 0.5_{ind} to 0.8_{cap}). The first device under test is the three-phase smart electricity meter with built-in GSM/GPRS modem. The meter enables measuring and registration of active (two-way, accuracy class B) and reactive (four-quadrant, accuracy class 2) energy and it allows all other activities required for the smart meter, such as load profile registration, electricity supply monitoring and remote two-way communication. It is also equipped with optical port for local meter programming and data downloading. The tested meter's operating temperature range is -40°C to +70°C.

The main objective of the research is to determine the real effect of temperature on indicated by metering system amount of consumed electric energy. An additional objective for the meter is to check whether its accuracy is class-consistent. The expected result of the research is a significant deterioration in the accuracy with moving away from the reference temperature. In the meter case it is also expected the possibility of exceeding, in the most unfavorable temperatures, a maximum permissible error.

Conclusions

Implementation of the smart grid and the smart metering system seems to be unavoidable because of the possible benefits and applicable legal regulations. This situation significantly changes the way of measurements and settlements in the electricity sector. Universality and scale of the introduction of the advanced metering infrastructure requires the special care about its measurement quality. The appropriate measurement accuracy is particularly important from the electricity settlement perspective. Not all of the AMI system components are now covered by the legal metrological control, which can lead to abnormalities of realized measurements. Particularly important for the measuring system operation is its appropriate work also at varying operating conditions. The research conducted by the article authors aims to determine the relationship between the measurement accuracy and the ambient temperature. The results and the conclusions of this research will be presented in the future publications.

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***Authors**:*
dr hab. inż. Paweł Węgierek, prof. PL, mgr inż. Michał Konarski, Lublin University of Technology, Department of Electrical Devices and High Voltages Technologies, Nadbystrzycka 38A, 20-618 Lublin, Poland, E-mail: p.wegierek@pollub.pl, konarski.michal@pollub.edu.pl.