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Model of Smart Electricity Meter

***Abstract**. This paper presents the concepts of smart electricity grids with particular emphasis on aspects of the metering of customers through the implementation of smart meters. On the basis of the literature study, an analysis of the scope of the functionality of smart meters was performed. The paper presents a model of the smart electricity meter developed by the authors, which has the possibility of working with the energy management system.*

***Streszczenie.** W artykule przedstawiono koncepcje inteligentnych sieci elektroenergetycznych ze szczególnym uwzględnieniem aspektu opomiarowania odbiorców poprzez wdrożenie inteligentnych liczników. Na bazie studium literatury przeprowadzono analizę obszaru funkcjonalności inteligentnych liczników. W artykule zaprezentowano opracowany przez autorów model inteligentnego licznika energii elektrycznej posiadającego możliwość współpracy z systemem zarządzania energią. (**Model inteligentnego licznika energii elektrycznej**).*

Keywords: smart meter, energy management systems, advanced metering infrastructure.
Słowa kluczowe: inteligentny licznik, system zarządzania energią, zaawansowana infrastruktura pomiarowa.

Introduction

Technological development and, consequently, the economic development of states determine an increase in demand for energy. The key is not only the amount of energy delivered, but the time of its delivery and its quality. These factors make adaptation and, consequently, development of infrastructure of energy production and transmission necessary. These works are focused on research on the implementation of smart power grids. One of the basic assumptions of these grids is the "activation" of the final user who should be actively involved in the energy market. An intermediate element in this action will be a smart meter, which allows basic communication between the energy supplier and the user. The effectiveness and form of this communication will be an indirect evidence of the validity of the implementation of the solution. In the outlined vision of the development of electricity grids, research on the detailed rules for the operation of smart meters becomes legitimate.

Smart grid

The objective of smart electricity grids is to achieve the most efficient power management. This grid must adapt to changing conditions in real time. The idea of smart grids assumes the implementation of two-way communication between the consumer and the supplier of energy, and the integration of distributed energy sources [2,3].

Achieving these objectives will be possible thanks to a series of sensors, communication systems and control devices. In addition, the intelligent grid management requires ordering local control and large area procedures.

Smart grid should therefore be [2,4]:

- Self-repairing – it should be able to detect the energy disturbances and automatically repair their source. A continuous analysis and monitoring of the status of the grid, affecting their online self-evaluation, will be responsible for the opportunity for self-repairing. This will allow for a quick response, which will significantly mitigate the effects of the interference, or very rapid restoration of power.
- Interactive – it should enable active participation of consumers in meeting their demand. By installing appropriate applications, multidirectional communication between the energy distributor and individual consumers or businesses will be possible. The system designed in such a way will provide the user with a wider range of information that will enable them to manage the energy in a balanced way, both in respect to their needs and current capabilities of the power system.
- Optimized – the intelligent grid is designed to optimize the power system works according to certain criteria and make effective use of the resources. This is aimed to reduce energy losses and improve power grid load level as well as efficiency of management of supply disruptions. When failure occurs, such grid generates additional information for engineers and planners. This will allow for checking exactly what and where is needed, what is the lifespan of the device or which device is damaged. The software also allows for managing the workforce. All this ultimately aims to reduce operating costs, and that will directly contribute to reducing the cost of electricity.
- Protected – in case of natural disasters or attacks, smart grid will ensure a smooth operation. The solutions used reduce physical and information vulnerabilities throughout the system security. They also allow for quick repair of interference. It is important that such a grid should be considered as a whole rather than single units, as, at the time of the attack on the unsecured part of the whole system, the energy from large power plants may be undelivered to the secured part. This grid can be compared to a chain that is only as strong as its weakest link.
- Compatible – the intelligent grid must be compatible, ensuring consistency and compliance of both centralized and distributed generation of energy with the energy storage devices. It must receive all the generated energy and have a tool to store it. It should therefore be adapted to all eventualities of production and reception.
- Integrated – optimized processes, information, management and standardization should be subjected to integration. The grid should contribute to the development of local energy markets and the use of new products. It will link sellers with buyers; among others, it will enable integration with infrastructure of home area network as well as charging control or passing energy from the batteries of electric cars to the network.

An integral part of the smart grid is smart metering creating an integrated computer system comprising of:

- Electronic energy meter dedicated to work in smart metering systems,
- Telecommunications infrastructure,
- The central database,
- Management System.

Smart metering enables real-time two-way communication between the supplier and the consumer of energy. Computer systems in combination with energy meters make it possible to automate both the client side and the supply side of energy. Due to the information given by a smart meter, the electricity grid user may have the ability to manage power consumption with maximum efficiency and cost effectiveness. What is more, the supplier can completely automate the process of settlement with recipients, starting with reading measurement data followed by their processing and analysis, and, finally, issuing the invoice and sending it to the user.

Such a system consists of two parts:

- AMI – Advanced Metering Infrastructure, including: meters, concentrators, modules and communication systems as well as software.
- MDM – Meter Data Management, used for data processing and in the process of settlement.

IBM classifies Smart Metering systems according to the most important features [5]. The last one called fourth generation and implemented since 2010, in addition to bidirectional transmission, also works with Home Area Network (HAN).

Advanced Metering Infrastructure

Elements of Advanced Metering Infrastructure (AMI) are designed to enable two-way communication using a variety of media and technology between the central database and individual meters (consumers). This allows remote configuration, receiving data from the user or sending control messages [6].

AMI systems allow for meter reading data from different utility services: water, gas or heat. In addition, they are also able to collect data on all kinds of events that occurred in the network. Specific data should be read at the right intervals, or through direct forcing of both the consumer and the supplier [7].

The use of smart meters has consequences in the form of a dispersion of data sources across the network. Therefore, safe, fast and efficient communication infrastructure is necessary [8].

Because of the extent of the area of communication, AMI can be divided into [4]:

- Home Area Network (HAN) – the network used for control at home,
- Local Area Network – the network for automatic meter reading through concentrators,
- Extensive Network – the network for the exchange of data between concentrators and specific data acquisition servers.

According to the principles outlined by the President of the ERO [9-12], the smart meter should communicate with the HAN, that is communications infrastructure and equipment (receivers and sources of energy), which react on the information from the meter according to the assumptions and conditions of the end user.

The basic solution which fits into the requirements of the HAN is a display on which the user can only preview the current and archival energy consumption and can receive information from the energy supplier. Nevertheless, this solution has two major drawbacks. First, the cost of installing additional screens is largely unfounded. Taking into account the development of mobile technologies and the fact that practically in most households there is a tablet or smartphone, according to the authors, the solutions, in which the equipment will be able to act as an interface enabling communication with the user should be looked for. The second issue is the type of information and the form of its transmission. It should be noted that the awareness of users in the use of electricity is relatively low [13].

The smart meter

The smart meter is part of the AMI; it contains mainly metering system for measuring energy consumption. However, it is distinguished by the fact that it captures not only the total energy consumption, but the value of the consumed energy and power at specific intervals (usually 15 min.). This allows for getting detailed consumers' profiles of demand for power. The meter allows real-time transmission of information from the energy supplier to the individual consumer or group of consumers. This information can be the current price for electricity. Currently, in most countries, the electricity market is a regulated market and, for individual consumers, tariffs having one or possibly two rates for electricity, including the fixed peak and off-peak periods, are available. However, this situation needs to be changed because the prices for electricity in the wholesale markets are subject to dynamic change, especially as a result of increase in the share of renewables in the power system. The smart meters will allow for dynamic and diversified over time changes in the prices of electricity for the end users dependent on the current wholesale prices of electricity in the energy markets [14].

In the literature [15-18], it was shown that the most effective and the most desirable information for users is information on the cost of energy consumption, the costs with respect to one day, month and year. Shekara S. et al. [17] point out the elements that the smart meter should include:

- current energy consumption (kWh)
- current energy costs expressed in (EUR/kWh or EUR/day),
- cumulative daily costs,
- energy consumption in the last day, week, month or quarter.

An interesting suggestion is an individual user adjustment of the meter maximum daily energy consumption (the costs), above which an alarm would be signalized [19].

The model of the smart meter working with the energy management system at a communal consumer

As part of the work, the authors developed and made an actual model of the smart meter, which, firstly, has the full functionality of smart meters, as outlined in the position of the President of the ERO and, secondly, has the ability to communicate with the energy management system at a communal consumer [20]. In addition, the smart meter has the ability to change the operation of the software. The model was made for single-phase networks. The model consists of three main systems: acquisition, transmission, and data analysis. Fig. 1 shows a block diagram of the model of the smart meter which was designed and made. The metering system is responsible for the acquisition of metering signals and their transmission to the data transmission system. The data transmission is carried out via Wi-Fi, after which the data is transmitted to the data analysis system.

The metering system is responsible for the metering of voltage and current in the circuit under test. The diagram of the metering system is shown in Fig. 2.

An element responsible for the remote transmission of measured values is the cDAQ9191 Wi-Fi module of National Instruments company with NI9215 measurement chart. This module has an Ethernet connection, the Wi-Fi connectivity with antenna, power connector and a slot for popular measurement C Series modules. This solution provides many opportunities through the simple installation and easy replacement of the module with another one of the same series.

The application developed in the LabVIEW software is responsible for data collection and analysis (Fig. 3).

It is an application of National Instruments company fully compatible with all products offered by it. The application includes eight basic groups of blocks:

1. Reading data from cDAQ-9191 measuring unit,
2. The basic waveform analysis,

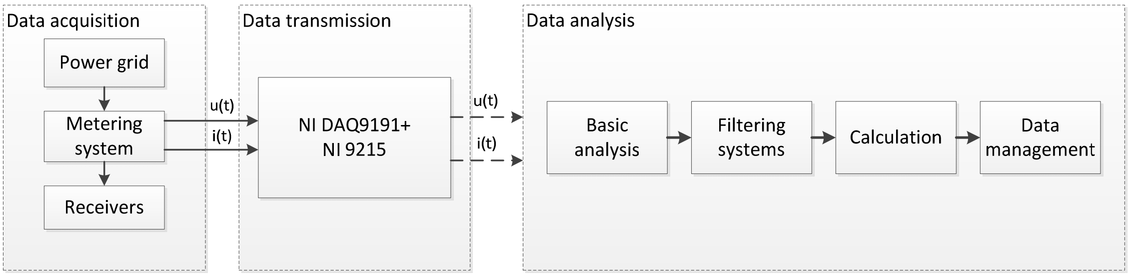

Fig.1. A block diagram of the model of the smart meter

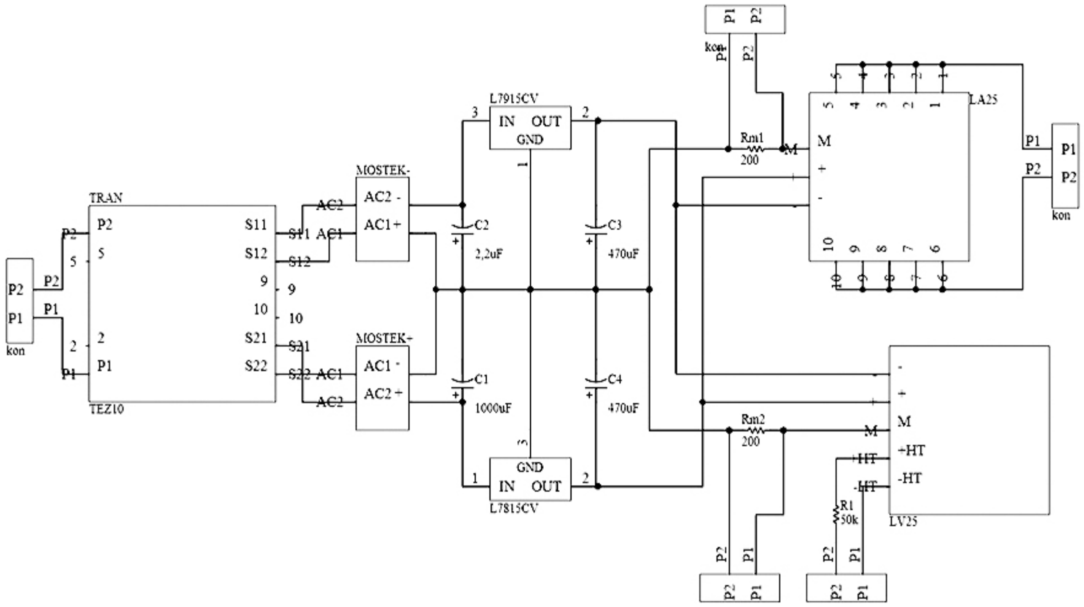

Fig.2. A block diagram of the model of the smart meter
TRAN – 230V / 2x15V voltage transformer, BRIDGE – bridge rectifier in the DIP housing, L7915CV – 15V voltage stabilizer, L7815CV – 15V voltage stabilizer, C1 – C4 – capacitors, Rm - measuring resistors, R1 – resistor for the input signal, LA25 – current transformer, LV25 – voltage transformer, kon – assembly connector.

3. Filtering the results obtained,
4. Reading the phase shift and frequency,
5. The power calculation and creating a graph of its value in the time-domain,
6. Aggregation of energy consumption and its costs,
7. Support for the application,
8. Data Management (writing to a file and/or communication with the energy management system in the building).

Each group is responsible for a specific task. The end result of groups action is the creation of the model of the smart meter, which allows the management of acquired data.

The basic analysis is designed to visualize the input signals from a transmission system. This allows for verifying the correctness of operation of the system prior to the transfer of signals to filtration systems. The model of the smart meter allows for calculating and recording the vast majority of electrical quantities, including: the instantaneous values, RMS voltage, current, frequency, phase angle, power factor, the value of the instantaneous power, active power, reactive power and apparent power. In addition, the simplified calculations of the cost of energy intake are made. Each of these parameters may be averaged and stored in any time interval.

In addition to the basic elements, the meter was extended by the possibility of communication with power management system at the communal consumer. Such systems are of particular importance in facilities equipped with renewable energy sources [21, 22]. This system was developed based on the CompactRIO controller from National Instruments company [23]. Additionally, a basic user control panel, on which most of the parameters are displayed, was developed. Because the LabVIEW allows for preparing applications for mobile devices, in the future, this application will also be developed for this type of device.

User control panel is divided into three tabs: Parameters, Power and Energy. In the "Parameters" tab, parameters on the voltage and the current flowing in the network at a sampling frequency of 10 kHz and update of the information on the display every second are presented. These are: a graph of voltage, current, RMS supply voltage value, RMS current value, phase shift (φ), sin (φ), cos (φ), frequency and THD voltage coefficient.

In the "Power" tab, the visualization of information on active, reactive and apparent power takes place. The elements of this tab are graphs showing the power values in the time domain. These graphs are drawn in real time for each of the power, which allows for viewing the history within the app by scrolling graphs. In addition, four-column table saving value of each of the power of one second interval is created. After the work of the meter is finished, the values in the table are saved to a text file, which can then be exported to a spreadsheet for analysis or data processing.

The last tab "Energy" displays information about energy consumption and costs. Elements located in this tab are: price per 1 kWh, cost in PLN, the value of the consumed active, reactive and apparent power.

The values of the costs can be used to stimulate the activities of recipients, on the one hand, by an increase in the awareness of users, on the other hand, through the launch of demand-side management programs.

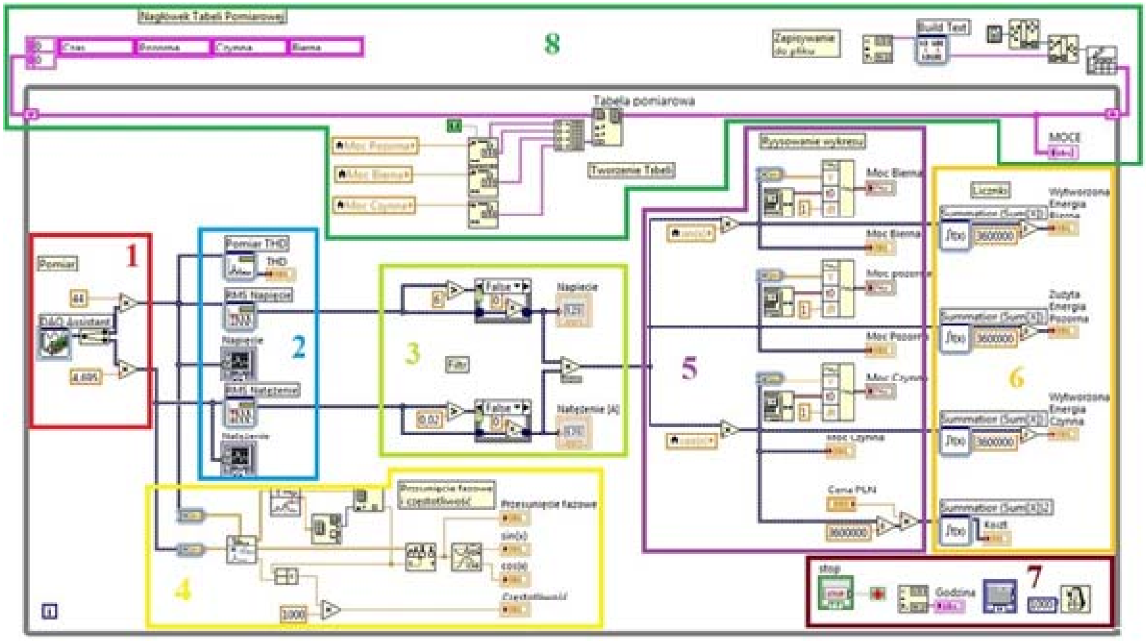

Fig.3. Diagram of data analysis application together with the division into groups

Summary

The developed model of the smart meter includes the fundamental assumptions about smart meters described in the analyzed literature and the position of the President of the ERO. It has the ability to communicate with the power management system and was extended by a range of functionality. It provides information on the current values of many parameters concerning electricity. The application that could be used for the primary display of information on mobile devices was also developed. This solution also provides the ability to easily expand it by functions controlling receivers in the HAN network in the future by using a smartphone or tablet. With the ability to generate a text file with the data, analytical and statistical possibilities also increase. In addition to the summarizing function, the developed model of the smart meter has also some features of the analyzer. It can provide parameters that indicate the quality of electricity.

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