The significance of wireless communication
for the metering data transmission via Smart Grids

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The article presents technological solutions of the communication and data transmission area that are indispensable for the organization of smart metering. As the term "smart metering" is very broad, particular attention has been focused on solutions based on the GSM-based wireless transmission that makes possible to flexibly model the process of remote meter reading with the use of the existing technological infrastructure. The article determines factors that can decide over the application of a such communication type as well as technical specifications to be met in order to develop a system that could successfully operate over an extensive network. Characteristics of the communication equipment used in real-time metering and billing systems have also been presented.

1. Introduction

Among the most important smart grid components there is a technologically advanced (smart) metering system that provides information about energy consumption and consumer profiles. The realization of such a system requires many technical and organizational actions to be performed in order to ensure correct operation of the system and to secure the expected profits. The term *smart metering* contains many issues [1] and among them the most important is an *advanced metering infrastructure* (AMI) and its integral components such as *automated meter reading* (AMR) and *advanced meter management* (AMM).

Smart metering makes possible to supplement the basic metering function by such ones as the configuration of metering and communication circuits, energy supply management and a real-time data analysis at the levels of a consumer or the distribution system operator (OSD). Smart metering can be understood as an automated process of data acquisition, management of the data and their transmission realized by the remote meter control, bilateral communication as well as taking actions that increase the system management efficiency.

The application of AMI is advantageous as it makes possible to obtain additional information concerning the grid operation and the consumer characteristics. The basic information includes readings of power and electrical energy consumption as well as the load profile recording. Among supplementary information data there are readings of voltage and its parameters, load control and

detection of power outages (failures) and of energy theft. The data will make enable faster response to changes and events occurring at the consumer side as well as better adjustment of tariffs to the needs of individual consumer groups. The end results should be beneficial for both the energy supplier and the consumers.
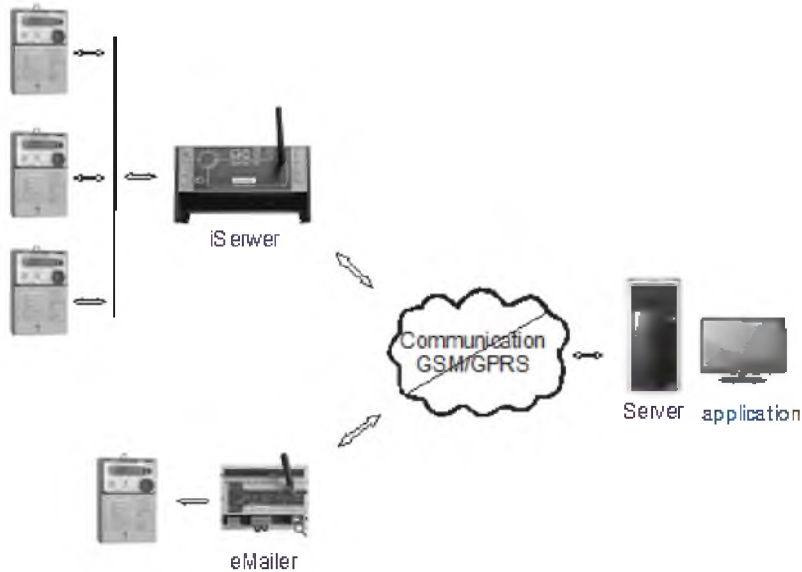

Fig. 1. Communication model of the system installed in the buildings
of the Lublin University of Technology

Technical specifications presented in the article are based on the metering system shown in Fig. 1 The system has been developed within the framework of a research project carried out in the Department of Power Systems of the Lublin University of Technology. Component elements of the system have been located in the switchgear units of the University buildings and are sources of real-time data concerning the buildings.

2. Advanced metering infrastructure

The development of advanced systems for automatic meter reading is possible owing to fast developing information technologies and electronic applications. The systems include equipment and consumers distributed over vast areas. They record consumption of not only electrical energy but also of other media.

The AMR offers basic functions for the data access. The abbreviation, according to its definition, describes distributed metering systems that enable remote meter reading for residential and industrial consumers. Usually, such

systems are composed of meters that are equipped with incorporated or external communication modules. Interrogation of the metering instruments is realized by the data-acquisition server that makes a data source for later downloads to billing applications of the energy supplier.

Within the AMR system structure the three below-given layers can be distinguished:

1. **Reading layer** that is responsible for data acquisition. It is composed of the consumer measuring circuits (meters) that collect metering data. Pulse meters, electronic meters as well as the latest microprocessor meters can operate within that layer. They cooperate with communication modules.

2. **Communication layer**, whose task is to secure data exchange between meters and communication modules and subsequently – between the modules and the data-acquisition server. The cooperating devices communicate based on the master-slave rule and the data transmission is unidirectional. .

3. **Information layer** that is responsible for data processing Its task is to archive, process and present the obtained data for the system operator.

As compared to the AMR systems the AMI ones realize much more developed functions. They operate based on the assumption that the metering is realized by smart meters and the obtained data are accessible for both the network operator (who also is the energy supplier) and the energy consumers. Within such an arrangement two below-given communication areas can be distinguished:

– between a meter (or a concentrator) and devices connected to the consumer installation;

– between a concentrator and the operator billing system that processes the data.

It can be easily noticed that at upgrading the AMR system to the AMI, unidirectional communication over one area has to be replaced by bidirectional communication over at least two areas. It is more difficult technically-wise, but seems to be advantageous as it brings benefits both for the system operator and for the consumers.

The benefits at the operator side are the following:

1. Automatic reading of the basic data concerning electricity consumption metering.
2. Reading of supplementary measuring data concerning:
   – power consumption and the load profile record,
   – feeding voltage and its parameters,
   – load control,
   – detection of power outages (failures),
   – detection of energy theft.
3. Fast response to changes and events occurring at the consumer side.
4. Tariff adjustment to the needs of individual consumer groups.
5. Modeling of energy demand.

6. Easier forecasting of energy consumption in the operator system and balancing of the system.
7. Load control for individual elements of the system.
   Among benefits at the consumer side the following ones can be indicated:
1. Load operation time adjusted to the tariff (actual energy price).
2. Control of the supplied energy parameters.
3. Permanent control of energy costs.
4. Reduced cost of the energy purchase.

In order to obtain the above listed benefits it is necessary to secure communication between the AMI component elements. The kind of communication technology to be applied depends on the number of cooperating devices, distances between them, accessibility of individual technologies and of the considered AMI area. At the consumer area, data transmission between a smart meter and the loads can be realized by:
− wireless transmission with the application of power line communication (PLC),
− Ethernet,
− local wireless networks (WLAN, Bluetooth),
− wireless network technologies used for the control of intelligent building installation elements (ZigBee, EnOcean).

In the case of the concentrator application, data transmission between a meter and the concentrator can be realized by pulse signals or with the use of RS232, RS485, CLO connections. Data transmission over the area between the concentrator and the acquisition system can be realized via:
− radio frequency networks,
− GSM/GPRS networks,
− public switched telephone network (PSTN),
− Ethernet,
− wireless transmission with the application of power line communication (PLC).

Additional legal and technical requirements arise when a consumer wants to function at the Energy Market and choose his energy supplier. In such a case, a consumer will have to adjust his metering-billing system to the required standards. The requirements are specified in the Regulation of the Minister of Economy of 4 May, 2007 on the detailed conditions for the functioning of the electricity system as well as in the IRiESD (Distribution Network Operating Manual) - Balancing.

The AMI is based on standards that meet the above assumptions. Particular attention is paid to the correct exchange of data, which is ensured by data transmission protocols. The Distribution Network Operating Manual assumes that metering-billing data transmission protocols generated by electronic meters and electrical energy recording meters should be publically accessible and their data format should be concordant with the *distribution system operator* requirements. The data should meet the DLMS requirements or their equivalents specified by the

IEC 61334 and IEC 62056 standards. The protocols are meant for AMI systems both at the wired and wireless communication mode.

3. Electrical energy meters

Although electricity meters are measuring instruments that have been used since electrical energy became a commodity, their design has essentially changed over the last few years. Popular induction meters get gradually replaced by digital or microprocessor meters.

Energy metering can be described by the following dependence:

$$A = \int_{t_1}^{t_2} P dt \tag{1}$$

where: *P*- power, whose value can be time-variable: t_1 - t_2 –energy metering time.

In the case of digital meters, current and voltage readings are the basic data. Digital metering of current and voltage makes an essential issue of modern measuring techniques. There are two fundamental solutions for that type of instruments and they differ by the input data processing mode. Processing of the signals at first is realized in analog functional units, then the output analog signals get processed to the digital form by analog-to-digital converters or undergo preliminary sampling and the ADC processing followed by processing with numerical methods [7].

In a digital circuit, electrical energy of a single network voltage period can be determined as follows:

$$A = \int_{t_e}^{t_e+T} u(t)i(t)dt \tag{2}$$

where: $u(t)$- instantaneous value of alternating voltage, $i(t)$- instantaneous value of alternating current, T - network voltage period, t_0- time.

analog signal   digital signal   basic data   output data

A/D   signal procesor   micro-procesor

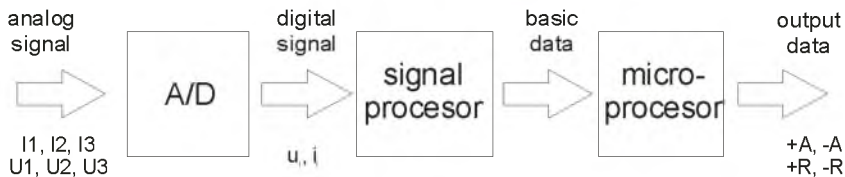I1, I2, I3   U1, U2, U3   u, i   +A, -A   +R, -R

Fig. 2. Block diagram of the metering unit

Modern electric energy meters are manufactured as ever more complex devices. Initially, mechanical electricity meters were equipped with attached communication units to process their readings into signals. Modern meters realize

energy measurements by solely electronic methods. Example diagram of signal processing is presented in Fig. 2. Analog signals of current intensity I1, I2 i I3 and of voltage U1, U2 i U3 are supplied to the meter directly or via transformers. Out of the analog input signals, the measuring circuit calibrates instantaneous digital values of voltage and current for each phase. Based on the signals, a signal converter determines the following measurands:

- active power P1, P2 i P3 together with the direction indicator,
- reactive power Q1, Q2 i Q3,
- phase voltages (U1, U2, U3), phase currents (I1, I2, I3), and neutral current I0,
- phase angles between voltages U1 and U2 as well as U1 and U3,
- phase angles between voltages U1 and currents I1, I2 and I3,
- network frequency f_n .

Aside with the mentioned signals, a meter can provide supplementary data calculated on the basis of the above given values and among them:

- total active, reactive and apparent power,
- the content of selected higher harmonics in current and voltage for each phase,
- THD coefficient for current and voltage.

Modern meters are also equipped with a real-time clock function, which makes possible to realize complex tariff plans.

Such meters offer various communication arrangements. Usually, it is realized via RS232, RS485 ports. Presently, it has become a norm to install optical port according to the IEC62056 (previously IEC61107) standard. IEC62056, Modbus, DLMS are applied as protocols. Apart from the above pulse outputs are also used.

4. Remote data reading and configuration of meters

Present-day meters are modern digital instruments characterized by a number of metering and control functions. The functions determine quantity of data that can be processed and stored in a meter, such as:

1. Measuring data that include information described in the previous chapter.
2. Control data that include information of external events (opening of the casing, magnetic field action), voltage decay, changes in the meter parameters, tariffs or the date and time as well as of critical errors.

Aside with the above mentioned control data, information that enables remote reconfiguration of selected meter settings, tariff change or disconnection of a consumer (by the cooperation with the switch module) can also be supplied to the meter.

The concept of remote meter reading and reconfiguration is not novel, but development of the applied solutions is in constant progress. Initially, the reading process has been realized by the system shown in Fig. 3.

The above shown system enables remote data transmission from a meter to an application and the reverse way for the meter reconfiguration. The application can store data of various meters, but the communication model remains unchanged. Modems that are used for the communication purposes are applied to organize the communication channel, but at no modification of the transmitted data. Classical data transmission methods based on remote access to single meters with the use of modems present a solution that has evolved by the application of both telecommunication networks and wireless ones. Standard equipment of the present-day meters includes communication interfaces that meet the readout system requirements. In the situation of reading many thousands of metering points, such a communication model needs a developed communication unit at the system data processing side (a readout server or a configuration server), in order to make it possible to set a connection and interrogate the instruments. Although the solution dominates in the presently used equipment, it is not efficient and cannot be calibrated [8].

Fig. 3. One-to-one communication system

In the case of a large number of measuring circuits to be included into a smart grid the above mentioned communication model would be impractical. Alternative solutions that are proposed by some metering circuits make possible to differently organize the data acquisition system. Such circuits include intermediate devices such as data concentrators that supply data collected from many meters to the readout server or an application A model of such a communication system is presented in Fig. 4.
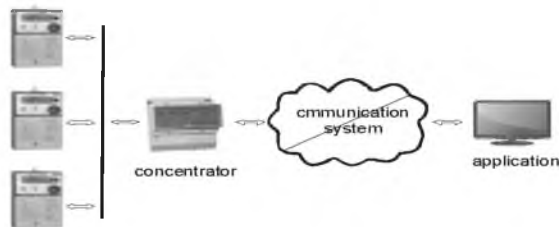

Fig. 4. Communication system with an incorporated concentrator

Concentrators can be classified into two groups:
– **Passive** ones that usually realize one-way communication and enable reading of a group of meters.
– **Active** ones that realize two-way communication and enable local data acquisition, their storage and recording of events that occur in the feeding and communication systems. They also make remote change of the meter configuration and settings possible. Apart from the realization of communication functions, a concentrator also stores data and manages their transmission and access for various users [7].

5. Application of the GSM connection

The development of a communication system that could meet requirements of the *smart metering* concept involves a solution of many technical problems with the organization of communication infrastructure in that number. The applicable technologies have been discussed in the Chapter 2. Technical characteristics and implementation costs are decisive factors at the selection of a technological solution.

Wireless networks seem to make a good solution for a few important reasons, such as:
– small data size, quantity of the data that are sent from a single meter depends on a kind of the transmitted information and usually ranges from 50 to 300 kB,
– in most cases the data are sent periodically, which can be precisely determined in the schedule,
– in the case of data loss, there is a possibility of their retransmission,
– as compared to cable networks, their infrastructure does not have to be as much developed and the number of formal documents and procedures that are necessary for the legal validity of their operation is much smaller.

Wireless networks offer a selection of a few applicable technologies with the following options among them:
– networks operating at the 2.4 GHz frequency range, such as local networks WLAN or Bluetooth as well as standards of intelligent installations as ZigBee or EnOcean,
– dispatching or trunking networks presently applied to billing systems for commercial consumers,
– networks operating within the ISM band (433 and 868 MHz); investigations into the application of that band are currently carried out by the APATOR S.A. [3].
– GSM networks operating within the frequency band of 900 and 1800 MHz.

In the presented article, the GMS (GPRS) wireless transmission method has been selected for further discussion. It is applicable, where investments into permanent connections are not cost-effective. Owing to the GSM telephone

network system development the service is available all over the country and the signal can reach objects distributed over large distances. The GSM technology development has contributed to the increase of data transmission rate.

Along with the GSM network development, a dynamic development of devices used for data transmission over the network can be observed over the recent years. It is driven by a few below listed factors:
− the GSM signal covers an area of almost the whole country,
− package communication GPRS or even newer solutions can be applied together with the IP protocol,
− APN can be provided for a user,
− data can be buffered and stored in communication modules,
− various communication modes can be applied.

GPRS-based wireless communication makes an interesting application for measuring systems that realize remote meter reading. It is a case when communication equipment is used both as the basic channel and as a diagnostic one. In the basic channel, meter-collected measuring data are cyclically transmitted. The same interface can form a diagnostic channel that enables configuration of the meter. It is the character of the measuring instrument operation that makes it possible to couple the basic and diagnostic channels into one. It is feasible because of the cyclic transmission of metering data and only sporadic use of the diagnostic channel. In that situation metering and configuration data do not have to compete for the shared communication channel.

Electricity metering performed by electronic meters is of periodic character. The metering is realized by measuring cycles and a billing period is also defined. Such cyclic character makes local data collection feasible and it is one of the factors that has made the GSM communication applicable to transmit data of measuring instruments such as meters and the cooperating equipment.

Data of electricity meters can be transmitted by three modes: cyclically, on demand, and on-line. The cyclically transmitted data contain information about metering results concerning billing periods such as 24 hours or other time-bound events. The on-demand transmission is meant for the download of data that are currently saved to the meter memory. The on-line metering first of all concerns actual values of current and voltage as well as of active and reactive power.

In order to download the meter data it is necessary to determine its connection to a concentrator or a readout server. Three methods can be distinguished there. The first one applies meters with an incorporated communication module and then the GSM-based communication is realized directly between the meter and a readout server [4]. The second method uses a concentrator connected to the meter via pulse outputs. A pulse number corresponding to the energy value is counted at the concentrator and then is transmitted to a server by radio waves. The third method uses the meter-concentrator connection via RS 232, RS 485 or CLO. A

concentrator can include many configurable readout interfaces, which enables its flexible cooperation with many meters of different configurations[1], [7].

Fig. 5. iSerwer GP of the NUMERON company manufacture

An additional advantage of concentrators that use the GPRS transmission is that they apply the IP protocol to the communication process. Owing to that, data are accessible not only for the network operator but also for a consumer, which is the basic requirement at the AMI development within smart grids. Another benefit of the concentrator application is that it makes possible to avoid the GSM operation disadvantages, such as the system overloads, as till the moment of setting another network connection, all the data are stored in the concentrator memory.

Useful functions of concentrators operating within GSM networks can be exemplified by a device called **iServer,** made by the NUMERON Ltd in Częstochowa [8]. The device enables:

− data download via various interfaces like CLO, RS485 or RS232 and pulse outputs,
− automatic send of its data to various users via the FTP server or e-mail,
− an access to the data of internal memory (buffer mode) or directly to the meter (transparent mode),
− data transmission in their original format or PTPiREE,
− monitoring of the network parameters including those related to the energy quality,
− monitoring of events (collapse/recovery of voltage or transmission),
− determination of 10 reading schedules and of the readout data type and range,
− configuration via the embedded www page, from the command line or with the use of specialized software tools,
− update of the device software.

Fig. 6. GP Server of the NUMERON company manufacture

Data of the device can be transmitted via the GSM network or LAN, which makes possible to reserve data transmission channels and to adjust transmission methods to the operator and consumer needs.

Additionally, the device is equipped with a GPS module that can be used for time synchronization. It is particularly important for industrial consumers and institutions, whose settlements are based on balancing readings of a few metering circuits. In such a case clocks of all instruments have to be synchronized.

As all devices that use the GPRS wireless transmission have to be identified by the APN, all of them have IP addresses and can take advantage of services based on that protocol. Their operation can be currently controlled. Fig. 6 presents an example window that shows current operation state of a concentrator. With its use it s possible to determine status parameters of the device as well as the information of the GSM and LAN operation.

6. Conclusions

The GSM network used for metering data transmission makes possible to flexibly develop an arrangement for the AMI. Regarding the broad GSM coverage, the equipment can be installed at any site and owing to the cyclical transmission character, little interruptions of the network operation or its overload do not affect the process of data acquisition. The application of the IP protocol and data-buffering concentrators make possible to freely define the time and methods for the transmission of current data. The data can be accessed both by the distribution system operator and by the energy consumers, Monitoring of the equipment operation with the use of the GPRS communication and the IP protocol introduces a number of supplementary functions that make possible to manage the entire metering system.

There are also some disadvantages of the presented solution. The most important of them are high costs of the GMS services and of the APN setting. However, even with those costs taken into account, for now the available GSM infrastructure makes the presented solution a preferable one for the wireless communication.

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