Measurement systems in Smart Grid

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The paper presents to-day's state of development of intelligent measurement systems used for monitoring and analysis of operation of renewable energy sources. Advantages and faults of various systems of remote electric power read-out.

KEYWORDS: Smart Grid, automatic electricity meter reading, transmission media, renewable energy sources

1. Introduction

The intelligent electric power network, commonly called Smart Grid, is understood as an electro power system operating with assumption of full integration of the actions undertaken by all its participants. This is possible thanks to the use of advanced computer and telecommunication technologies.

Growth in advancement level of AMI (Advanced Metering Infrastructure) leads to monitoring, control, and management of the electric power network at the SMART GRID level. Figure 1 shows a diagram of SMART GRID network. In the SMART GRID networks, in case of micro-generation of on-grid type, the development of AMI technology is aimed rather at bilateral communication with HAN or HEMS systems, than at direct communication with the electric power network. On the other hand, in case of micro-generation of an off-grid type, the development of communication technology tends towards monitoring and/or control, and management of the system. The development of the last technology is directly related to the level of technical infrastructure [1, 2].

The advantages resulting for the Operators of the Distribution Network (ODN) from implementation of the intelligent measurement systems referred to as AMI, may be categorized as direct and indirect ones [4, 5]. The most important advantage among the direct ones consists in reduction of commercial and technological losses. Among the commercial losses are reckoned, among others, the losses caused by illegal electric power consumption. AMI shall enable data collection in real time, that should improve detection of the sources of illegal electric power consumption. In Poland the loss of this kind is at present estimated to about 9 percent.

Table 1 presents forecasted rate of AMI infrastructure development, measured in proportion to the number of installed intelligent electric power meters.

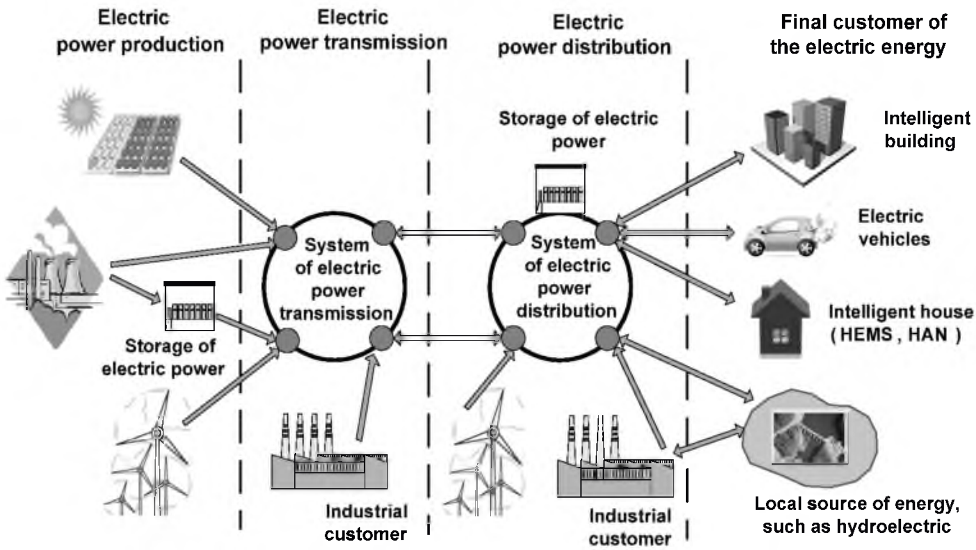

Fig. 1. Smart Grid conception

Table 1. Development of AMI infrastructure [own elaboration]

Country	The number of intelligent meters installed	
	in 2011	forecast for 2020
USA	$8 \cdot 10^6$	$60 \cdot 10^6$
China	$500 \cdot 10^3$ (2010)	$350 \cdot 10^6$ (2030)
India	-	$130 \cdot 10^6$
Brazil	-	$63 \cdot 10^6$
South Korea	$750 \cdot 10^3$	$24 \cdot 10^6$
EU	$45 \cdot 10^6$	$240 \cdot 10^6$
Poland	$60 \cdot 10^3$	$3.29 \cdot 10^6$ (2018)

Analysis of the results shown in Table 1 gives evidence of extensive growth of the number of installed meters. In EU countries the growth of intelligent meters to be installed in the nearest years indicates that ODN's should carefully analyze the plans for possible purchase of proper number of the meters. It is possible that the demand will exceed the supply, which could result in the need of making use of the meters of worse parameters.

Introduction of a system of intelligent networks is imposed by implementation of a Directive of the European Parliament and the Council 2009/72/WE, related to common principles of internal market of electric energy, 2009/28/WE on promoting and use of the energy from renewable sources, and 2012/27/WE on electric power effectiveness.

2. The AMI infrastructure

Irrespective of the chosen technology, the architecture of communication system in Smart Grid is usually divided into three levels or layers, e.g. the bottom, middle, and upper layer. The layer includes a set of teleinformatic devices enabling data collection, transmission, compilation, and elaboration with a view to ensure bilateral communication [2-5]. The communication channels ensure bi-directional communication between the layers. Figure 2 presents architecture of the AMI system.

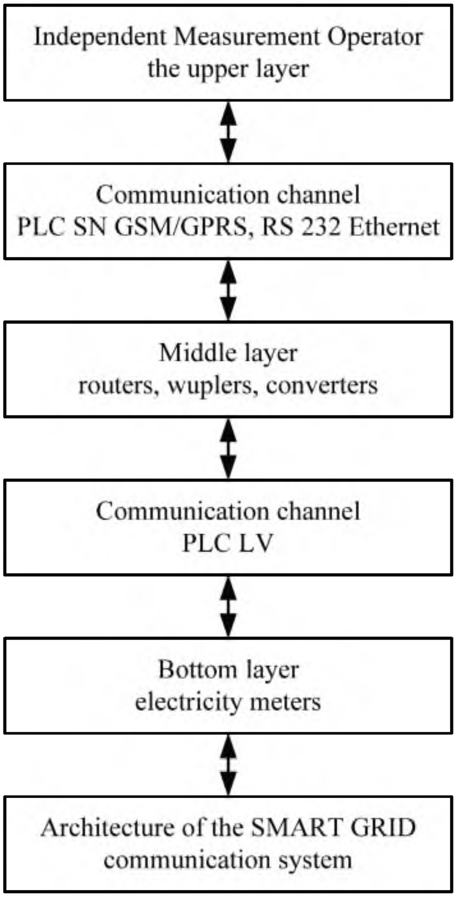

Fig. 2. Architecture of the AMI system (own elaboration)

The low- and medium voltage networks have a large significance as communication media reckoned as PLC (Power Line Carrier or Power Line Communication).

3. Adaptation of AMI infrastructure to automatic electricity meter reading

In EU, and consequently in Poland, the AMI technology leading to achieving the Smart Grid level is implemented with a step-by-step method [7,8]. In Poland the ENERGA Group is a leader in implementation of the most modern AMI technologies and solutions. In the first quarter of 2013 the action of installing of 310 thousand intelligent meters in PRIME technology will be launched. During the first stage more than 100 thousand meters have been fitted. The ENERGA Group intends to expend by 2020 about PLN 1.4 MIL for purposes of Smart Grid development.

Automatic meter reading enables automatic data collection from the meters or on grid operating energy sources, and their transmission to the database in order to process and settle the accounts. Such a communication is assumed to be bi-directional.

In the PRIME technology (Power line Intelligent Metering Evolution) the narrow-band transmission is used. The communication proceeds in master/slave mode. At present in physical layer the OFDM modulations are used. Data transmission rate depends on the modulation and encoding type. The object is identified with the help of OBIS code, in case of the COSEM informatic model. Advantage of the COSEM data model consists in its full independence on the application layer protocol.

In the PRIME technology the communication module is intended also to integrate the HAN networks (Home Area Network). Communication between the communication module and the concentrator should operate with the use of the meter and the PLC technology (PLC V). Frequency band used in PRIME complies with EV 500651/2001+A1/2010. Security level of the data transmission is AES-128 (AESGCM 128). Operation mode is of coding-certifying type. The data are transmitted in DSCML protocol as enlarged SML standard, defining the COSEM informatic model. It operates in the client-server mode, to which it is oriented.

Theft of electric energy or its illegal consumption is effected, in principle, in two ways – by interference in the metering system or illegal connection before the meter. In the first case the electricity meter seal must be removed.

The most common connections used with intelligent meters are shown below. Figure 3 presents proper connection arrangement, used by more than 90 percent of the customers.

Figures 4-8 present the most common ways of illegal electric power consumption.

The meter measurement system (Fig. 4) detects variation of the current flow direction with regard to proper flow, and generates an alert signal.

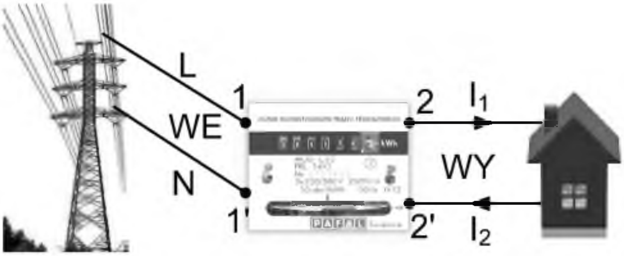

Fig. 3. Proper connection arrangement of the electricity meter:
1-1' INPUT terminals of the meter measurement system, 2-2' OUTPUT terminals of the meter measurement system

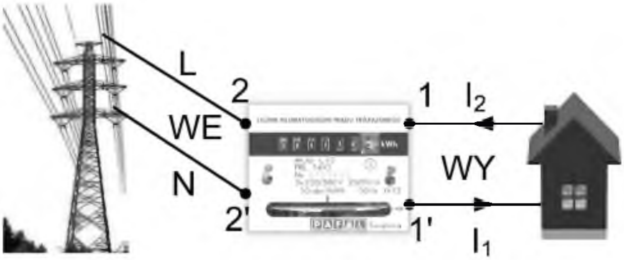

Fig. 4. Theft of electric power by means of changing the INPUT/OUTPUT connection (own elaboration): 1-1' INPUT terminals of the meter measurement system, 2-2' OUTPUT terminals of the meter measurement system

The meter measurement system (Fig. 5) enables detection of the difference between I_1 and I_2. Comparison of these values allows to generate the alert information. In case of "proper" wiring detection of this situation is difficult.

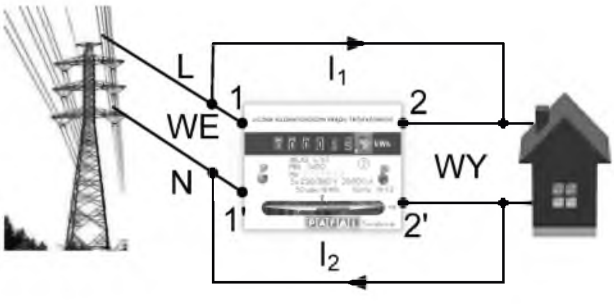

Fig. 5. Theft of electric power by meter shunting (own elaboration):
1-1' INPUT terminals of the meter measurement system, 2-2' OUTPUT terminals of the meter measurement system

The meter measurement system (Fig. 6) analyses the operation mode, i.e. the lack of I_1 current and improper direction of I_2 and generates an alert signal.

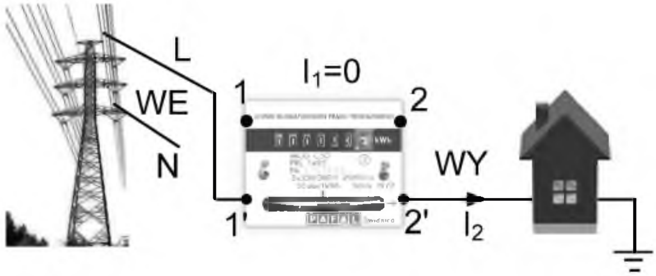

Fig. 6. Theft of electric power by changing over the L wire and disconnecting the N wire (own elaboration): 1-1' INPUT terminals of the meter measurement system, 2-2' OUTPUT terminals of the meter measurement system

In the case shown in Fig. 7 read-out of the balancing meter enable detection of such a way of electric power theft.

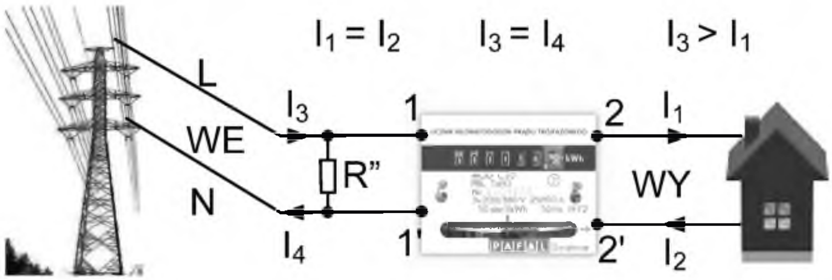

Fig. 7. Theft of electric power in result of connection of a part of the receivers before the meter (own elaboration): 1-1' INPUT terminals of the meter measurement system, 2-2' OUTPUT terminals of the meter measurement system

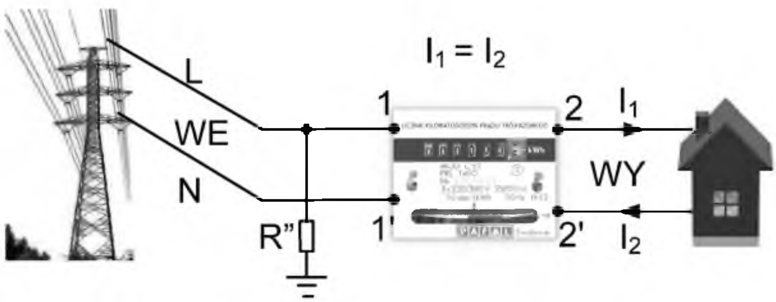

Fig. 8. Theft of electric power in result of connection of a part of the receivers before the meter and disconnection of the N wire (own elaboration): 1-1' INPUT terminals of the meter measurement system, 2-2' OUTPUT terminals of the meter measurement system

The method of illegal electric power consumption shown in Fig. 8 is detected by the balancing meter. This results in generation of proper alert signal to the

Central Data Management System. Other, less frequent theft methods may be mentioned too. For example – total supply of the receivers omitting the meter. The electricity meter indicates then $I_1 = I_2.=0$. The measurement system gives an alert signal. It may be also considered as meter damage The use of an electricity meter assumed to be intelligent does not eliminate illegal power consumption. Independent double measurement of each of the customers ensures 100 percent detection of the culprit of illegal power consumption. From technological point of view and taking into account the features of the AMI structure such detection is possible, although economically unjustified. It seems that location of all the meters in the buildings at the ground floor should restrain illegal electric power consumption by interference into the meter. On the other hand, it is not clear what will be the effect of such an action on illegal before-meter consumption of the electric energy, as the detection of illegal power consumption does not indicate the culprit of it.

5. Summary

The lines of development of the Polish power industry by 2030 are defined in the deed drawn by the Ministry of Economy, accepted by the Cabinet in November 2009. Contents of the document complies with the 3rd Liberalization Package of European Union. The Polish efforts tend to fulfill one of its main assumptions, i.e. achieving the level Smart Grid Ready.

Based on the PSE analyses the Ministry of Economy estimated that the amount of $6.0 \cdot 10^6$ PLN invested in construction of the AMI system should give the benefit of $12.4 \cdot 10^6$ PLN within 15 years. The amount of $4.5 \cdot 10^6$ PLN of it will fall to ODN. Total benefit of the energy customers should reach more than $2.7 \cdot 10^6$ PLN. Energy sellers should enjoy the same benefit. Remaining $2.4 \cdot 10^6$ PLN will be transmitted to PSE Operator. Effectiveness of the investment into AMI development will be significantly affected by the power consumed by the meters. In case of single-phase meter the energy consumption is from 0.5 to 1.5 W. The power consumed by the concentrators is much higher. Moreover, the values of the power consumed by the concentrators from various manufacturers are also varied.

The use of intelligent meters, inclusive of the balancing ones, will improve detection of the sources of illegal consumption of electric power. Ernst Young [4] indicates even the need of the use of an additional "business intelligence" application. It should enable to appoint the customers or customer groups that potentially might illegally consume the electric energy [4, 8]. The AMI communication methods will allow to determine the location of illegal energy consumption, nevertheless, the problem will not be avoided. The legal changes are necessary. At present the High Court stated that the definition of illegal consumption of electric energy is fulfilled only provided that the energy has been really consumed. This, in practice, imposes the need of detection of the illegal consumption during the control procedure. Taking into account expected increase in electric energy price, the risk of development of illegal consumption of the energy seems very likely.

The use of Renewable Energy Sources (RES) in individual households becomes more and more common. The investment in a wind-power station of the power equal to 300 W, provided with a controller, is related to net cost of about 4000 PLN. The cost of a gel battery of 100 A·h capacity is equal about to 3000 PLN. Assembly of the parts of such a system is simple and inexpensive. Possibility of monitoring the operating parameters is a first step to control and manage the system operation. Polkomtel intends to enlarge soon its services also towards bilateral communication with the other HAN system elements. Programming of the WSH0.3-0.15 controller allows for such a solution.

In case when the AC supply is required by the customers, the low-power inverters of hundreds watts, easily available on the market, may be readily used. The price of an off-grid 300 W inverter is about 1200 PLN.

It is expected that for purposes of bilateral communication the wire- and wireless transmission media should be used. Controller software already to-day makes such a choice possible. It seems that the future power industry should be founded on two pillars, i.e. the Smart Grids networks and the energy management systems, based on multi-layer data transmission systems.

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