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Metering systems in smart electric power grids

Grzegorz Twardosz
Poznań University of Technology
60-965 Poznań, ul. Piotrowo 3a, e-mail: Grzegorz.Twardosz@put.poznan.pl

The paper presents the most important aspects of AMI (Advanced Metering Infrastructure) implementation in Poland. The technological aspects of AMI implementation and the effect of formal-legal conditions on its course are shown. The choice of the communication system of the smart electricity meter (SM) with the Metering Information Operator is analyzed. Possible use of the low and medium voltage lines for the purposes of data transmission is depicted.

KEYWORDS: smart metering, smart electric power grid, transmission media, electricity meters

1. Introduction

Implementation of technologically advanced measurement systems, referred to as AMI (the Advanced Metering Infrastructure) is advantageous for the Distribution Network Operator (DNO) for several reasons. The benefits are divided into two groups, e.g. the direct and indirect ones. Among the direct benefits the reduction of commercial and technological losses may be mentioned. Among the commercial losses there are, among others, the losses caused by unauthorized electric power consumption. At present the estimated losses of that type are equal about to 9 percent.

Definition of uniform requirements imposed on the Distribution Network Operators (DNO) shall enable developing the standards related to technological requirements with regard to the AMI equipment. The smart metering systems belong to the elements of a so-called intelligent electric power network, often referred to as Smart Grid. Figure 1 presents a general scheme of a Smart Grid.

The smart electricity meter enables bi-directional communication between the final customer and the Metering Information Operator (MIO), irrespective of the data transmission methods and the communication media. The communication between SM and the home network infrastructure must operate bi-directionally. Instead of the concept of "home network infrastructure" the term "HEMS" (Home Energy Management System) is often used. It is a system operating within HAN (Home Area Network). The systems designed for managing the technical infrastructure of a building are referred to as BMS (Building Management Systems). Data transmission between the customer and SM, SM – MIO, and SM – BMS takes place via the transmission media. Figure 1 presents a scheme of a smart electric power grid.

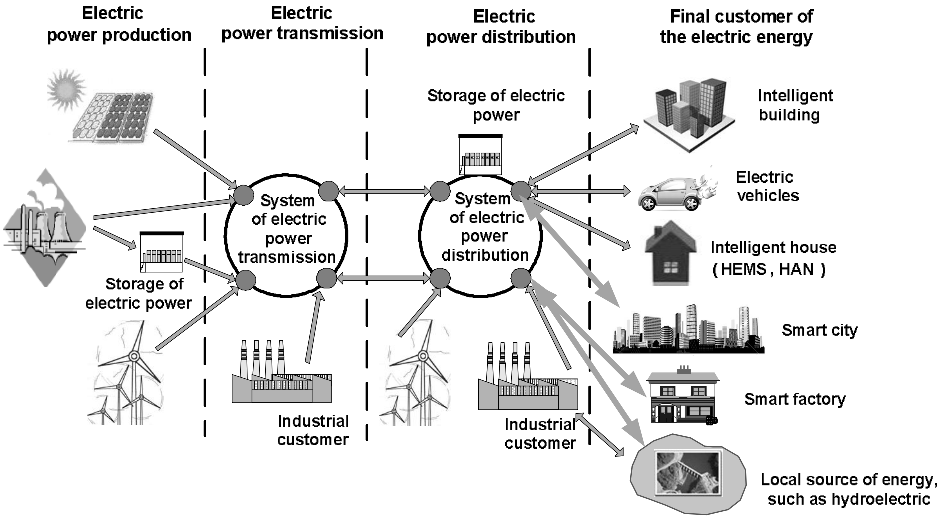

Fig. 1. Smart Grid conception [own elaboration]

The communication media are divided into wired and wireless ones [1]. Among the most important technological parameters of the transmission there are the quality, rate, and the method of protection against unauthorized data access. The concept of the Smart Grid tends to achieve a certain level of self-diagnosis and self-optimization of the processes of electric power transmission and distribution. Data transmission, regardless of the system hierarchy, occurs by means of the media. The transmission media are divided into wired and wireless ones. Organization of the system deviates from the ones discussed earlier [3] by implementation of two new elements, i.e. the intelligent factory SF (Smart Factory) and intelligent city SC (Smart City).

2. The AMI development in Poland

The state of AMI implementation in the European countries is assessed based on various criteria. One of frequently used criteria consists in division of the European Union states into UE15 and UE13 groups. The UE15 comprises the countries that became EU members before May 1, 2004. The territorial division, in which Poland is reckoned among the countries of Central and South-East Europe, is used, among others, in the Ernst&Young publications [2]. Possibility of AMI implementation was estimated in [2] in accordance with seven criteria, with a definite weight (Table 1). Each of the criteria is assigned the importance scale.

The ranking included the following countries: Greece, Romania, Cyprus, Slovenia, Hungary, Estonia, Turkey, Poland, Bulgaria, Malta, Latvia, Czech Republic, Slovakia, and Lithuania. In case of Poland total score was equal to 171 points, that gave about 55.5 percent. In this ranking Poland took the 12th place.

First place was granted to Greece, with total score amounting to 222 (72.2 percent). The last place had Lithuania with the score of 132 (43.1 percent). One of the main factors affecting the development of technologically advanced metering systems is the size and structure of the energy market. The market structure is determined by the number and type of the energy customers. Poland has the second biggest market. The number of the electric power customers is now estimated at 16.5 million. Individual customers account for around 86 percent of SME, with the industry taking 14 percent. SME means Small and Medium Enterprises. According to various assessments the individual customers consume 25-30 percent of the electric energy.

Table 1. Criteria of AMI implementation [own elaboration]

Criterion	Weight in points	Poland, weighted average	Ranking
1. Size of the market	2	26	2
2. Average energy consumption	2	12	8
3. Average consumption fee	5	25	10
4. Reduction of network loss	3	30	5
5. Quality of the supplied energy	4	48	2
6. Planned RES share in energy production in 2030	5	20	11
7. Complexity of the project, the number of DNOs	1	10	11

Table 2 presents the DNOs active in Poland, their shares in the electric energy market and commitment in AMI implementation.

Table 2. AMI implementation by DNOs [own elaboration]

Item	DNO	Number of customers [million]	AMI implementation
1	PGE	~5.1	15 thousand by the end of 2014
2	ENERGA	~3.5	800 thousand by the end of 2014
3	RWE Stoen	~0.8	100 thousand, under installation
4	ENEA	~2.0	Pilot projects
5	TAURON	~5.3	350 thousand by the end of 2014

Analysis of the results shown in Table 2 clearly indicates leading role of the ENERGA Company in AMI and SMART GRID implementation in Poland. The Holding Company ENERGA Joint Stock Company plans to install the smart meters at about 22.8 percent of the customer's sites by the end of 2014. The second place in this respect went to TAURON (5.7 percent).

With regard to the quality of electrical energy Poland holds the 7th position, behind the Czech Republic, Cyprus, Slovakia, Slovenia, Estonia, and Lithuania [2].

The number of interruptions in energy supply per one customer is referred to as SAIFI (System Average Interruption Frequency Index). Duration of lacking access to the electrical grid is determined by SAIDI (System Average Interruption Duration Index). Value of the SAIFI factor enables determining the reliability level of the elements of the electric power grid. On the other hand, the SAIDI factor reflects efficiency of the relevant service in eliminating the interruptions and AMI system breakdowns. In case of Poland the SAIFI factor reaches ~3.7, while SAIDI ~315 minutes.

The towns occupy only 2 percent of the surface of the earth, but nearly 50 percent of the people inhabit there. The towns are sources of 80 percent of total CO_2 emission and 75 percent of total electric energy consumption. The SC development concept consists not only in improving the energetic effectiveness but is closely related to general direction of balanced development.

The first stage of AMI system implementation includes installation of the SMs and, in consequence, the choice of the technology of communication between the final customer and the Metering Information Operator (MIO). The report [4] presents the current state of AMI development in the European Union countries and in Norway. The countries are divided into five groups, according to the state of progress of AMI implementation. Qualification to a definite group directly results from the formal-legal basis of smart metering implementation in the electric power sector, valid in the given country. Figure 2 shows the Gartner square depicting AMI development in EU27 and Norway.

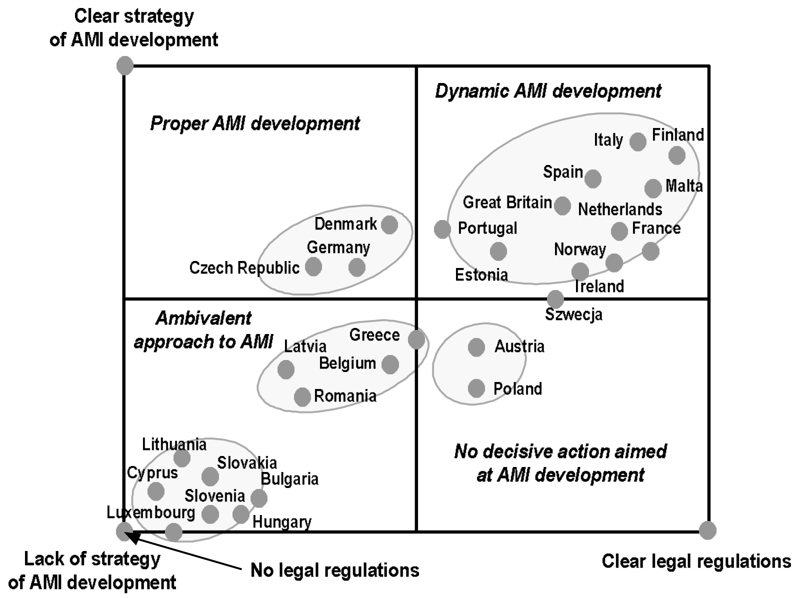

Fig. 2. AMI development in EU27 and Norway [4]

The formal-legal state allowing for AMI implementation in Poland is similar to that in Austria, Portugal, and Estonia. With respect to this we are ahead, among others, of Czech Republic, Germany, and Denmark. What concerns the number of smart meters, Poland is in the stage similar to Belgium, Greece, Romania, and Lithuania. Poland in the report [4] is classified under the group 3, i.e. among the countries characterized by the lack of clear strategy of AMI development, with above medium level of the formal-legal state.

The report [4] indicates also the leading role of the ENERGA Holding Company in AMI implementation in Poland. Among the most important legal acts and other documents contributing to formal-legal basis of smart metering implementation there are:

- Directive 2006/32/EC of the European Parliament and of the Council of 5 April 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC;
- Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC;
- Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC;
- Communication of the Commission to the European Parliament, Council, European Economic and Social Committee, and Committee of the Regions, of 12 April 2011, entitled “Smart Grids: from innovation to deployment”;
- The complaint of the European Commission of 20 December, 2012, brought to the Court of Justice in Luxembourg against the Republic of Poland, alleging failure to implement a number of provisions of the Directive 2009/72/EC;
- The document entitled “Polish Energy Policy by 2030”;
- A deputies’ bill of law of amendment of the law – Energy Law (publication No 946 of March 5, 2013.

Discussion of the above mentioned legal acts and documents is included, among others, in [4-6].

3. Data transmission in smart electric power grids

Communication in Smart Grids is effected by various methods. The DNOs choose the technologies based on the European or world-wide standards [7]. As an indicator in the choice certainly the UE standardization mandates are used. In 2005 the European Union Countries published the standardization mandate related to the Smart Grids. It is the mandate M/374 of 20 October 2005. At present the mandate M/441 of 12 March 2009 is considered as the most important. It defines the requirements imposed on the AMI standards with regard to the communication protocols. Among another mandates there are M/490 of 1 March 2011, that complements M/441, and M/468 of 29 June 2010, related to standardization of charging the electric cars.

The technology applied must ensure bi-lateral communication with other systems [1,7]. It is referred to as system interoperability. According to M/441 the system devices must be interchangeable. It means that e.g. a damaged or non-legalized device may be replaced with a device of equal parameters of another manufacturer.

Smart Grid standardization enables to construct an open system. In such an open system the recommendation of, among others, the mandate EU M/441 are fulfilled. The standardization may be of global range, e.g. ISO, IEC, ITU, European range, e.g. CEN, CENELEC, ETSI, or national range, e.g. PN. The Smart Grid standards are discussed, among others, in [3]. In Smart Grid the final customer communicates with MIO by means of the electricity meter. Integration of BMS and Smart Grid is achieved by bi-lateral data transmission between SM and HEMS. Figure 3 shows HEMS cooperation with the electricity meter. Figure 4 presents the paths of the electric power flux in case of V2G vehicles.

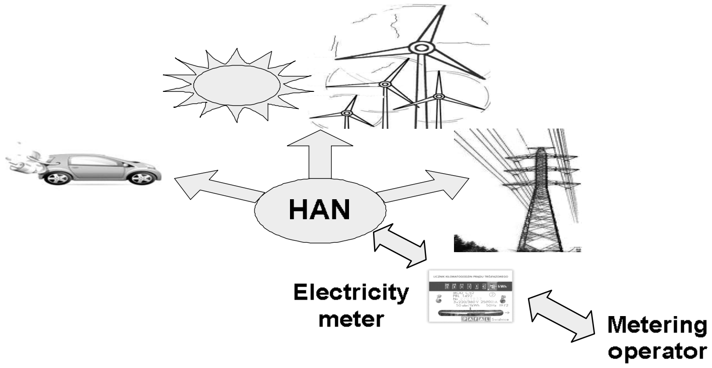

Fig. 3. HEMS – SM cooperation [own elaboration]

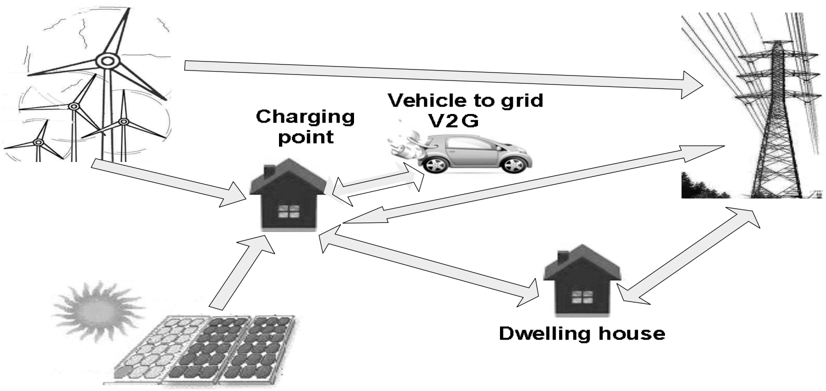

Fig. 4. Electric power flux in case of V2G [own elaboration]

The data transmission is carried out by the media, regardless of the system hierarchy. In Poland the bi-lateral data transmission between the supplier and customer is foreseen to be carried out by wire means. This should be achieved with the use of the low- and medium voltage lines. This transmission method is referred to as PLC (Power Line Communication). Figure 5 presents various communication paths used with the Smart Grids, and the most commonly used communication standards.

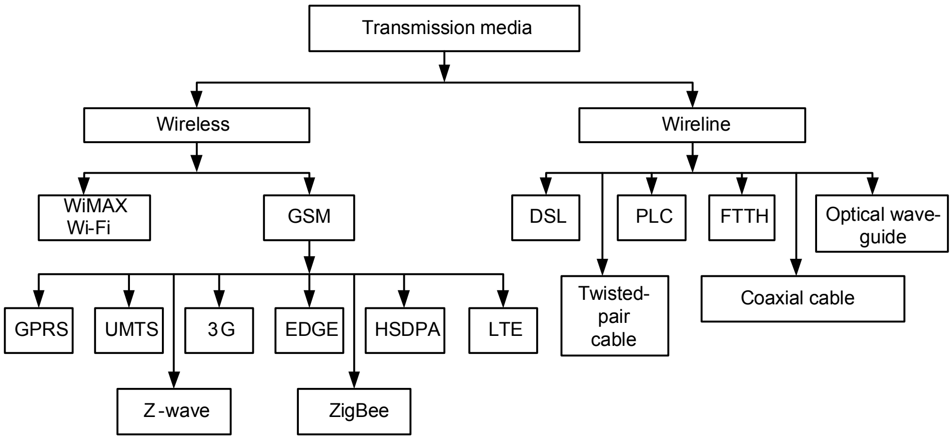

Fig. 5. Transmission media and communication standards in Smart Grid

In Finland and Great Britain the wireless technology is mainly used. On the other hand, in France, Germany, Sweden, The Netherlands, and Spain both transmission methods are applied to AMI. The final customer is a user of a home network technical infrastructure HAN (Home Area Network) [9,10]. In order to manage the Smart Grid equipment the interoperability is necessary, i.e. cooperation, among others, with the communication systems used in HAN. Among the technologies often used in HAN there are ZigBee, WiMax, M-Bus, Ethernet. PLC is also the technology that is often used for purposes of managing the home network technical infrastructure. Home Plug is a frequently used standard in HAN.

In the buildings, where a system of managing the technical infrastructure is used, various system and communication technologies are applied. In most cases they are open systems. Such an open system allows to use the equipment coming from various manufacturers, both at the design and operation stages. Among the most commonly used technologies there are KNX/EIB, LCN, BACnet, LON, X-Comfort, CEBUS, PROFIBUS. In open systems various communication standards may be used.

Among the wireless technologies the following ones deserve the attention: HSDPA (High Speed Downlink Packed Access) and LTE (Long Term

Evolution). HSDPA is an extension of the UMTS, i.e. 3.5G technology. Implementation of the HSDPA standard enabled in practice the throughput growth by an order of magnitude. Data transmission rate in HSDPA oscillates now from 1.8 Mbit/s to 3.6 Mbit/s. LTE achieves the data transmission rate in cities equal around to 175 Mbit/s [7].

Among the wired technologies the PLC is considered as the most important, while the most developmental one is FTTH (Fiber to the Home). In the FTTH technology the point – multipoint architecture is used. A single optical fiber may transfer the Triple-Play service, e.g. TV, Internet, and phone. In this case a supply device at the fiber – customer segment is not required. It is a service of the PON type (Passive Optical Network). In BMS the wired communication technology of the PLC Home Plus type is widely used. Moreover, the ZigBee technology should also be noticed, as the one ensuring maximum level of data security.

The choice of communication standard in HAN depends first of all on the customer. In the simplest cases the FSK, S-FSK, or BPSK transmission is used. The most modern devices use the PRiME or MAXIM standards. The existing low- and medium voltage lines are considered by the Distribution Network Operators as the main transmission medium.

4. Protection of the data transmitted in SMI

Quality of the services provided by MIO to the final customer is determined, among others, by the SLA coefficient (Service Level Agreement). From the legal point of view it is a contract concluded between the final customer and MIO, with respect to the level of quality of the services provided by MIO to the service recipient, i.e. the final customer. Determination of the SLA coefficient is difficult, since it depends on many factors. Taking into account that the relationship between the final customer and MIO is of serial type, the high complexity of data transmission reduces the final SLA value. During the operation the SLA level should theoretically increase. Access of unauthorized persons to the data bidirectionally transmitted in Smart Grid should be impossible. The access security level is defined and ensured by MIO. The data coming from the electricity meter are deemed as sensitive. The publications [11, 12] specify general principles at the Smart Grid level, related to data protection against unauthorized access. Taking into consideration very general data on AMI system protection in Poland, the American concept served as a basis. The protection level against unauthorized access is not published by MIO. It might be only supposed that the transferred data are encrypted at the AES128 level, while the registration with the use of the ECC-253 code.

Figure 6 presents the data transfer method in open Smart Grid systems.

Once the Smart Meter is installed, an identification-registering signal in the ECC 253 code is sent to MIO. When the information reaches the MIO operating system, it sends the data in ECC and AES codes to SM. Once the SM recognizes the MIO information, the installation process is finished. During the operation the Smart Meter transmits the data in the ASM 128 code. The data between MIO and final customer are transmitted in ECC 253 and AES 128 codes.

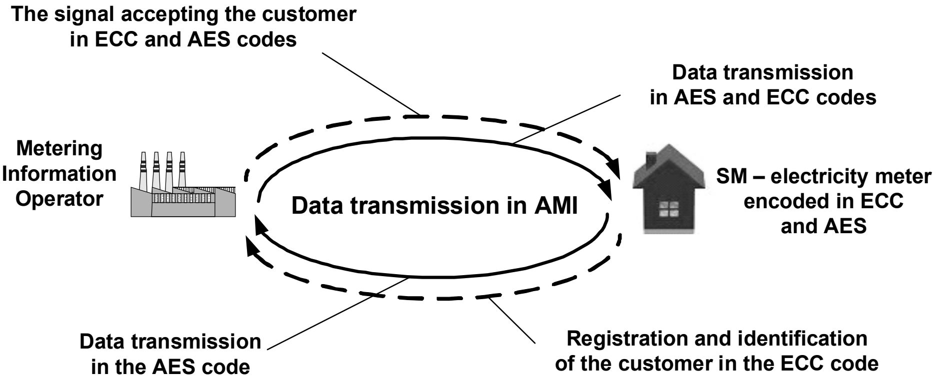

Fig. 6. Data transmission in AMI [own elaboration

5. Summary and conclusions

According to EU directives smart metering implementation, inclusive of installation of the meters, must be terminated by the end of 2020. In Poland about 13 million electricity meters are to be installed. It is assumed that implementation of computerized systems enabling to manage the data at the Metering Information Operator level will last 2 to 3 years. The measurement data will be collected in the Central File of Measurement Data. Moreover, it is assumed too that only a half of the meters assembled in given year will achieve their full functionality. It should be noticed that "full functionality" consists in achieving bidirectional data transmission in the standard defined by MIO. Figure 7 shows graphical analyses of implementation of a basic variant of smart metering [5, 6]. In 2020 80 percent of smart meters should be installed, with full functionality of the meters equal to 62.5 percent. It is expected that the balance in 2013-202 shall amount to PLN 43 million, while in 2013-2026 PLN 4.6 billion. The optimal variant of the forecast predicts PLN 790 million and PLN 5.6 billion, respectively.

In the low-voltage lines the PLC method is the most commonly used for data transmission. In case of a so-called narrowband PLC the frequencies from 1.6 kHz to 148.5 kHz are used for this purpose. In case of the BPL method of data transmission, a so-called broadband PLC uses the frequencies from 4 to 20 MHz. The BPL method (Broadband Powerline) has both proponents and opponents in Poland.

The use of the frequencies in narrowband PLC is not restricted by any licenses and, in consequence, is free of charge. It is a so-called free access band ISM (Industrial Scientific Medical). During data transmission the requirements determined by legal regulations should be fulfilled.

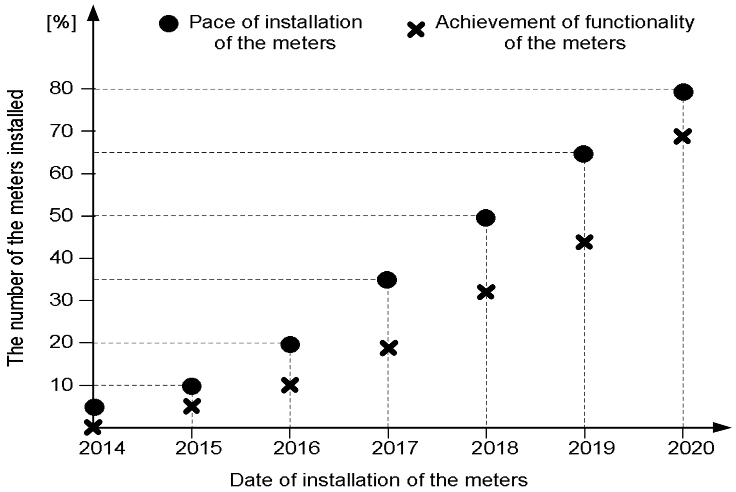

Fig. 7. SM installation in Poland, functionality level in 2014 – 2020 [own elaboration]

Interoperability and interchangeability of the AMI equipment is one of the requirements of open character of the Smart Grid communication system. It complies with the recommendation of, among others, the EU M/441 mandate, being fully observed in Poland. Electricity meters belonging to the class SM intercommunicate usually in the PRIME technology, making use of the protocols DLMS/COSEM and/or IDIS, G3,DSGP. Another problem affecting the deployment of smart electric power grids is related to data protection against unauthorized access and possible change of the data.

Taking into account high data protection level against the unauthorized access, the computer crimes of the DOS, DDOS or DRDOS become possible. DOS is Denial of Service, DDOS means an attack against the computer system simultaneously from many locations (Distributed Denial of Service). The DRDOS attack consists in transmission of large amount of wrong information to the customer, apparently sent from MIO.

Among the typical examples of infringement of security there are jamming, appliance impersonation, reply attack, and non-repudiation. While implementing AMI system in Poland it should be noticed that reduction of electric power consumption is possible only provided that the DSR (Demand Side Response) of the customers is changed accordingly. The DSR is significantly affected by the price of electricity and the tariffs.

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