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Development of intelligent metering systems in Smart Grid

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The paper presents selected technical and legal aspects of AMI (Advanced Metering Infrastructure) implementation in Poland. The need is indicated for the choice of an open system of bi-directional communication between the electricity meter of SM type (Smart Meter) and the Metering Information Operator (MIO). Current legal status pertaining to the intelligent electric-power network is assessed. The AMI development and its influence on greenhouse gases emission is presented.

KEYWORDS: intelligent software, hybrid and V2G cars, Smart Grid, CO_2 emission

1. Introduction

The energy security, being directly affected by disturbances in oil supply and by permanent supplies of the power from low-CO_2 emission sources, is an important problem related to the analysis of Smart Grid operation. These problems will be extensively discussed in December 2015 in Paris, during the conference organized by the International Energy Agency, i.e. so-called Conference of the Parties COP 21 [1].

The demand for the electric energy is expected to increase by 80 percent by 2040 as compared to 2012. The fossil fuels will still remain a basic source of the energy. In 2040 the fossil fuels shall cover 55 percent of the demand, while in 2012 this share amounted to 68 percent. According to the forecasts the renewable energy sources in 2040 should ensure 33 percent of the demand, Unfortunately, the total CO_2 emission shall grow from 13.2 Gt in 2012 up to 15.4 Gt in 2040.

The electric energy is the fastest growing form of the final energy. Nevertheless, it is estimated that about 620 million people in Sub-Saharan Africa have no access to the electric energy. About 730 million people in the region use a solid biomass for preparing meals. Taking into account low efficiency of the furnaces it is conducive to premature mortality of about 600000 persons. About 1.3 billion people all over the world do not use electricity and about 2.7 billion use the solid biomass for cooking. Commonly used oil lamps emit from 3 to nearly 40 times more CO_2 than compact fluorescent bulbs. Stopping the use of the oil lamps would reduce the CO_2 emission by 35 Mt annually. In 2014 the

CO_2 emission stabilized at the level of 32.2. Gt, despite the 3 percent increase in the Gross Domestic Product. This happened for the first time in 40 years.

2. Intelligent metering systems

The intelligent metering systems make one among many parts of a so-called Intelligent Electric Power Network, often called Smart Grid. Figure 1 presents a general Smart Grid arrangement.

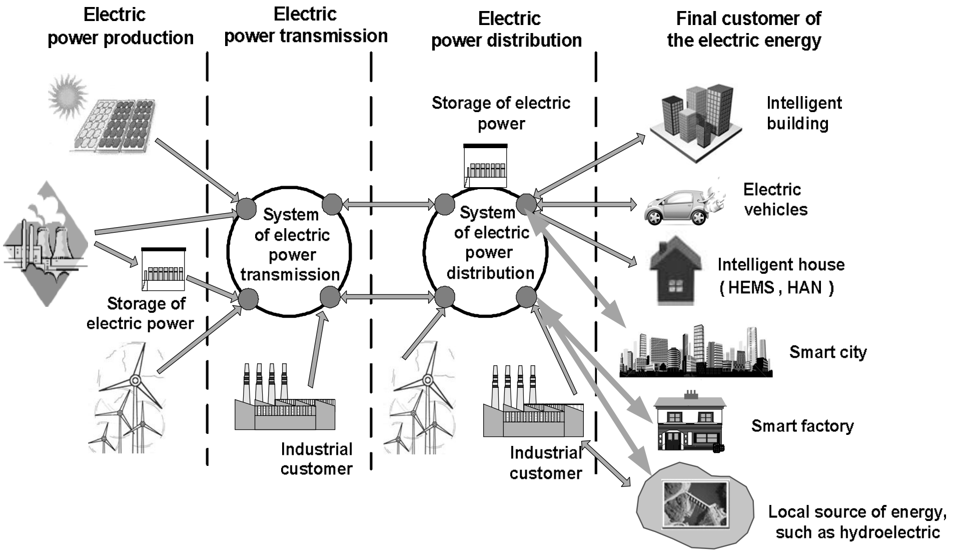

Fig. 1. Diagram of the Smart Grid [2]

One of the parts of the "Europe 2020" strategy approved by the European Council on March 26, 2010, includes creation of Trans-European Energy Networks, i.e. integration of the renewable energy sources [3]. The recommendations [4] provide, among others, the binding definitions of the intelligent network and intelligent metering system. The recommendations [5] of the European Commission define, among others, the scope of activities pertaining to dissemination of the intelligent metering system.

At present the "intelligent network" is considered as an enhanced energy network, supplemented with bi-directional digital communication between the supplier and customer, intelligent metering systems of monitoring and control [4]. The intelligent metering system is considered as an electronic system enabling measuring of the energy consumption and production and handling the data with the use of electronic transmission [4]. Such a meter provides more information than a traditional one. The European Commission published the data related to AMI implementation in the countries of European Union, that served as a basis for the forecast for 2020 [6]. By 2020 about 200 million meters of consumed electric energy and about 45 million meters of consumed gas will be installed in EU. It is estimated that in 2020 about 72 percent of EU population will be provided with intelligent electricity meters and about 40 percent of the population with intelligent gas meters. It is expected that the gas and electric energy savings may amount to 3 percent. The installation cost of an intelligent meter in EU countries amounts about to EUR 200-250. In [7] Poland is reckoned among 7 EU countries that in 2020 will achieve 80 percent of operating electricity meters. Figure 2 presents, based on the Domestic Operating Plans, the stage of progress in SM implementation in selected EU countries. It should be noticed that the forecast presented by another author participating in the same conference indicates that Poland is not included in the list. Figure 3 shows the relationship between the profit attained by the Distribution Network Operator and the expenditures.

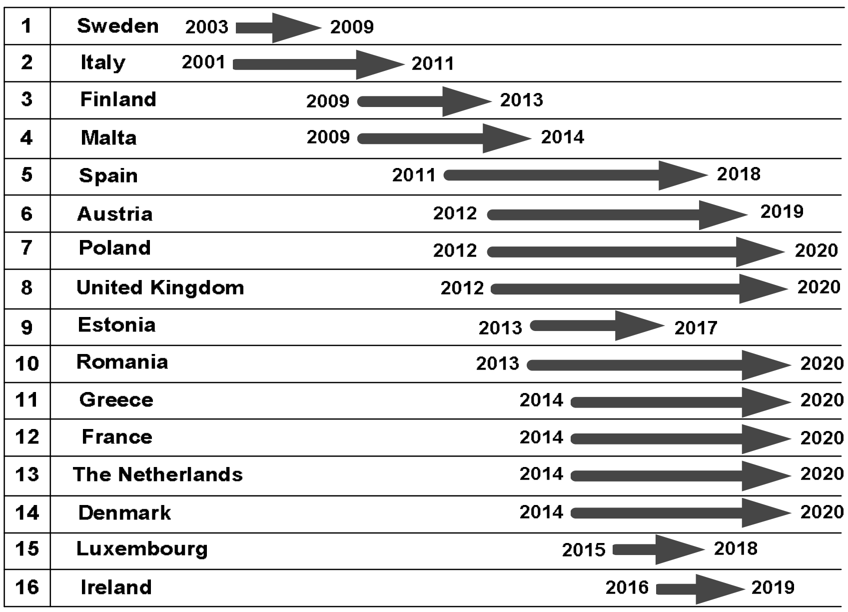

Fig. 2. The installation process of the intelligent meters in EU [7]: in 1, 2 countries – the SM are fully assembled; 3, 4, 5, 6, 8, 9, 11, 15, 16 – the SM are installed by 80 percent of customers; 7, 10 – the installation scale is under consideration; 12, 13, 14 – the SM installation is in the course by 80 percent of customers, a framework program is under development

The materials of the European Conference on Smart Metering of 2014 specify the data showing the value of domestic investment per one Smart

Metering and one Smart Customer. Unfortunately, taking the above into account, Poland took the lowest position among all the EU countries.

Renewable energy sources and energy storages are important elements of the Smart Grid. In this respect there are no revolutionary changes during recent years. The FACTS (Flexible AC Transmission Systems) is successfully used, in which the SVC solution (Static Var Compensator) is applied. The D-Var system provides a certain modification of it.

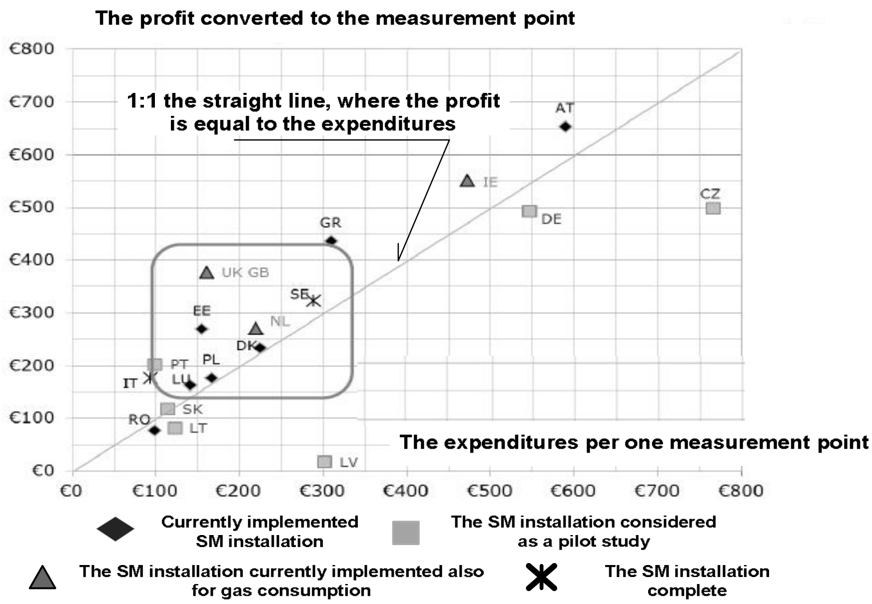

Fig. 3. Value of the investment expenditures vs. direct cost of AMI implementation per single customer [7]

In this case the storage is assembled directly next to the Renewable Energy Source (RES). In China the Wind RT Systems storage is used. It allows to switch on the energy storage just after 20 ms from the moment when the wind speed achieves the turbine cut off point. In some cases the Super Gear system works well. In this arrangement the electric energy of the wind power plant is delivered directly to the power grid. i.e. in the point of the wind power plant location. It is expected that effectiveness of the Smart Grid cells and of the trans-European power grid (TEN-E) will increase in result of development of new technologies in the sphere of production, transmission, and control of the power of the energy system.

Table 1 presents effectiveness of various RES technologies under Polish conditions. It is an average production of electric energy in MWh converted to 1 MW of the installed power.

Table 1. Productivity of the installation of various renewable energy sources [8]

Technology	MWh per 1 MW, annually
Land wind power plant	2 200
Offshore wind power plant	3 900
Solar energy	950
Biogas	7 000
Biomass (without co-incineration)	7 000
Small hydroelectric power plant	4 600
Large hydroelectric power plant	2 500

What concerns the investor, not only the investment expenditures are important but also the operating cost of RES installation, converted e.g. to the unit of the installed power.

The most capital-intensive investments are related to the use of water energy, followed by the biomass and biogas installations. The lowest RES investment expenditures amount about to PLN 6.0 million /MW. They occur in the cases of photovoltaic cell and wind plant installations. The lowest total operating costs arise in case of photovoltaic cells (~PLN 87 thousand/MW), while the highest occur in biogas and biomass installations. They are 27 times higher than for biogas and 23 times higher than for biomass. On the other hand, the operative cost of the wind power plant exceeds the cost of the photovoltaic installation only by about 25 percent. Under Polish conditions the use of capital consuming technologies is viable but only in case of significantly lower operative cost. This is the case of RES using the wind and solar radiation energy [8] – Table 2.

Table 2. Status of electricity CBAs and roll-out plants in the EU-27 [9]

Status of electricity CBAs and roll-out Plants	Parametr
Countries that have conducted a CBA	20
Positive result of CBA	13
Countries for which no CBA is available	5 (2 not applicable + 3 in progress)
Countries with large-scale (>80% of consumers) roll-out plans	16 (for 2 official decision pending)
Countries with positive result in national CBA for a selective roll-out 2020	3
Countries having decided not to proceed with a large-scale roll-out under present conditions	4
Countries where there is neither an official CBA nor a decision yet for a roll-out	4

In seven European countries, i.e. Belgium, Czech Republic, Lithuania, Latvia, Germany, Portugal, and Slovakia, the results of cost analyses were negative or inconclusive. In Germany Latvia and Slovakia the intelligent measurement was considered as economically reasonable only in case of some definite customer groups. In these countries the intelligent meters are to be assembled by the end of 2020 in 23 percent of all the measurement points. In Germany this results in installation of about 11 million devices, in Latvia about 2.5 million, and in Slovakia slightly above 6 million. In Poland 13.2 million meters will be installed by the end of 2020, which complies with the Union recommendations, i.e. these meters will be located in 80 percent of the measurement points. The action of installation of the intelligent meters will be completed by the end of 2022.

According to the technology applied to the meters the lifetime, i.e. the period after which the meter should be legalized or exchanged, is between 8 to 20 years. Only in Poland the period of 8 years is applied. In most of the countries it amounts to above ten years, while in case of France, Luxembourg and Romania it amounts to 20 years. An important operating parameter of the intelligent meters, or rather intelligent network, is the rate of data transfer. According to the transmission medium it amounts from 10÷15 s, through above ten minutes, up to an hour. Table 3 presents 27 transmission media implemented or expected to be implemented in EU.

Table 3. Summary of preferred communication infrastructure for smart metering roll-out in Member States [9]

Country	Option 1	Option 2	Option 3
Austria	- Smart meter (SM) - Data Concentrator (DC): 70% PLC and 30% GPRS, - DC-DMS: 100% Fibre Optics		
Belgium	see Country Fiches		
Bulgaria	PLC, GPRS		
Cyprus	First phase implementaton: PLC with GPRS		
Czech Republic	- SM - DC: PLC+GPRS (where not possible to se PLC) - DC - DMS: GPRS+Fibre Optics		
Denmark	PLC+GSM/GPRS and wireless radio frequency		
Estonia	90% PLC and 100% GPRS		
Finland	PLC (~30%)+GPRS (~60%)+RF (~10%)		
France	PLC		
Germany	Market-driven		
Greece	- SM-DC: PLC - DC-DMS:PLC	- SM-DC: GPRS - DC-DMS: GPRS	- SM-DC: Fibre Optics (90%) and RF/GPRS (10%) - DC-DMS: Fibre Optics (90%) and RF/GPRS (10%)

Table 3. cont. Summary of preferred communication infrastructure for smart metering roll-out in Member States [9]

Hungary	N/A		
Ireland	All options to be considered; decision during design phase		
Italy	SM-DC: PLC DC-DMS: GSM/GPRS		
Latvia	PLC - tbc at official procurement stage		
Lithuania	- SM-DC: PLC/GPRS - DC-DMS: GPRS	Fibre optics network (FTTx) available	
Luxembourg	To be decided Considered&tested: Consumption data: PLC, GPRS and fibre optics; M-Bus between electricity and gas meters		
Malta	PLC/GPRS		
Netherlands	Not prescribed; DSOs to decide, GPRS chosen for small scale rollout; Reference scenario - 20% GPRS and 80% PLC		
Poland	Most probably PLC - choice will be influenced by standardisation		
Portugal	85% PLC, 15% GPRS		
Romania	- SM-DC: PLC - DC-DMS: GSM/GPRS, WiFi/WiMAX, Fibre Optics		
Slovakia	More used: GPRS/ETHN PLC (testing PLC-FSK, OFDM, BPL, eventually radio)		
Slovenia	PLC+GSM		
Spain	PLC		
Sweden	- SM-DC: GPRS (1%), RF (17%); PLC (37%) and GPRS+PLC+RF (46%) - DC-DMS: GPRS (86%); IP (33%); RF (9%); PLC (8%) and other (17%)		
United Kingdom - GB	(subjest to final technical design) Smart meter to Data and Communications Company (DCC): - 65% cellular (GPRS and 3G) - 33% long range radio - remainder mesh radio		

In case of the use of LV network, i.e. PLC, the time may reach dozen minutes or more, while in extreme cases even still longer. Table 4 shows main advantages and basic costs related to installation of intelligent network in Poland.

Table 4. Most significant cost/benefits share from electricity smart etering roll-out considered in Poland analyses [9]

Country	Main benefits	Main costs
Poland	- Energy savings (27%) - Reduction of balance sheet differences in respect of both technical and commercial losses (25%) - Reduced meter reading costs (24%) - Postponement of generation lant and of extra grid capacity due to peak shaving (15%)	- Meter reading costs (24%) - Customer service costs (3%) - Cost for extra infrastructure to increase the grid capacity (7%)

Table 5 specifies the costs and benefits of intelligent meter installation converted to one measuring point.

Table 5. Costs and benefits normalise by number of metering points [9]

Country	Cost per metering point [€]	Benefit per metering point[€]
Member states already completed roll-out		
Finland	10	NA
Italy	94	176
Sweden	288	323
Member states rolling out smart metering in ELE and GAS jointly		
Ireland	473	551
Netherlands	220	270
United Kingdom - GB	161	377
Member states rolling out smart metering		
Austria	590	654
Denmark	225	233
Estonia	155	269
France	135	NA
Greece	309	436
Luxembourg	142	162
Malta	77	NA
Poland	167	177
Romania	99	77
Spain	NA	NA

Table 5. cont. Costs and benefits normalise by number of metering points [9]

Member states NOT rolling out smart metering yet		
Belgium	NA	NA
Czech Republic	766	499
Germany	546	493
Latvia	302	18
Lithuania	123	82
Portugal	99	202
Slovak Republic	114	118

NA – Not analyzed

In several countries. i.e. in Czech Republic, Germany, Portugal, and Lithuania the costs exceed the benefit. In three countries, i.e. Ireland, The Netherlands, and Great Britain the measurements are introduced simultaneously with respect to electricity and gas. In all the cases the expenditures exceed the expected costs.

3. Development of intelligent infrastructure vs. the greenhouse effect

The recommendations [5] indicate that the intelligent networks make a new development stage on the way of enhancement of the rights of consumers, better integration of renewable energy sources with the network and improved energetic effectiveness. The networks significantly contribute to reduction of greenhouse gases emission. A specific feature may be noticed: the countries that consume the highest amount of electric energy are, at the same time, the most extensive sources of CO_2 emission to the atmosphere. This is the case of China, USA, Russia, India, Japan and Germany.

Table 6 presents consumption of electric energy in 2014 and the levels of CO_2 emission of the largest worldwide producers of the electric energy.

CO_2 emission to the atmosphere in European countries is relatively low. For example, in Germany the total CO_2 emitted to the atmosphere from fossil fuels in 2014 amounted to ~36 Gt CO_2 and exceeds the value of 1990 by ~62 percent, while as compared to the value of 2013 it grew by 2.3 percent.

The index of CO_2 emission is also called a carbon trace, the carbonate seal, or carbon footprint (CF). The greenhouse effect is caused not only by emission of CO_2, but also methane, nitrogen monoxide, fluoro-hydrocarbons and sulfur hexafluoride. It is estimated that a statistical Polish citizen (the data from 2013) emits 8 tons of CO_2 yearly. A metric measure is commonly applied to compare emission of various greenhouse gases. The measure is called the equivalent of CO_2 for a definite gas. For carbon dioxide it is equal to 1, for methane 21, nitrogen monoxide 310, for fluoro-hydrocarbons from 124 to 14800, and for sulfur hexafluoride 22800. It means that that, for example, emission of 1 ton of methane is equivalent to emission of 21 tons of carbon dioxide. The gas emission generally may be divided into three categories:

1) the emission coming directly from the activity controlled by producing companies;
2) the emissions caused by consumption of the electric energy;
3) indirect emissions related to goods and services.

Table 6. Consumption of electric energy and CO_2 emission in 2014 in selected countries of the world [a self study]

No.	Country	Consumption of electric energy [%]	CO_2 emission [%]
1	China	~20,0	~25,0
2	USA	~19,0	~18,5
3	India	~0,4	~3,9
4	Russia	~5,7	~5,0
5	Japan	~4,2	~4,0
6	Germany	~2,6	~2,8
7	France	~2,1	No data
8	Canada	~2,6	~1,8
9	The World	100	100

In 2012 the total greenhouse gas concentration converted to CO_2 emission amounted to 435 ppm. In order to refrain the temperature growth below 2°C in 2040 according to 450 scenario, the total carbon dioxide emission must not exceed 3000 Gt. In the first half of 2014 the emission amounted to1900 Gt. Table 7 shows the values of carbon dioxide emission to atmosphere in various countries and continents in 2014.

Most of the countries of the world presented their obligations related to emission of the greenhouse gases. This shall allow to keep the temperature growth under 2°C in 2040 (as compared to 1990) with 50 percent probability.

What concerns the energy storages, their use in the networks at all the voltage levels is now considered as appropriate. In EU countries about 60 percent are low voltage networks, about 37 percent are networks of $1 < U_N < 100$ kV and about 3 percent of $U_N > 100$ kV. The approaches to the energy storage capacity in the USA and EU countries are different. The investment level into power industry development, inclusive of the energy storages by 2035, is presented among others in the World Energy Investment Outlook – IEC 2014. The RES are the sources of unpredictable characteristics. It may be noticed that in Germany the power generated and delivered to the electric power system by the wind power plants and photovoltaic panels changed even 8 times daily [10]. In order to ensure stable operation of the electric power system in Smart Grid mode the energy storages are necessary. What concerns the development of e.g. alternative fuels, the European Union predicts to establish a Trans-European

Transport Network TEN-T. Among the alternative fuels are liquefied petroleum gas – LPG, liquefied natural gas – LNG, hydrotreated vegetable oil – HVO, dimethyl – DME, compressed natural gas – CNG as well as hydrogen and their derivatives, in appropriate cases.

Table 7. Carbon dioxide emission in various world regions in 2014 [a self study]

Region of the world	The level of carbon dioxide emission in [Gt]
North America	6.2
China	8.6
India	2.0
Russia	1.7
EU	3.2
Japan	1.2
Africa	1.1
Middle East	1.7
South America	1.2
Australia and New Zealand	0.4
The countries on the Caspian Sea	0.5
Other Asian countries	1.9

The electric energy enables to improve energetic effectiveness of road vehicles and is conducive to reduction of CO_2 emission. The use of electric energy increases interoperability and e-mobility of the energetic network. The European Parliament issued the Directive [11] aimed at this goal. Influence of electric vehicles on the intelligent energetic network is presented, among others, in [12]. Modern technology is applied also for designing Renewable Energy Sources. It includes application of superconductivity phenomenon to construction of generators used in wind power plants. Liquid nitrogen or helium is used for this purpose. Cryotechnology allows to improve efficiency of the system and significantly reduce the mass of the equipment.

4. Summary

The intelligent metering system is one of many AMI elements of the Smart Grid. Bi-directional communication between final customer and the operator must also ensure proper protection of the data access. The data protection is a process arising already at the design stage. The work [4] determines, among others, such terms as data impact assessment, default data assessment etc. An important element is to use the best available technologies. The concept of intelligent networks in macro-scale should lead to creation of Trans-European Energetic Network, resulting in increased energetic security of the EU countries. The strategy of the European Commission related to the energetic security by 2030 was presented, among others, at the briefing in May 2014 [13].

Unfortunately, it appears that the Commission's plan will be advantageous first of all for the companies having their own gas pipelines or storage facilities/ The RES share in electric energy production is estimated by the European Commission only to 27 percent.

Greenpeace stands for achieving 45 percent share by 2030 and 40 percent improvement of the energetic effectiveness as compared to 2005. The EU countries purchase more than 53 percent of energy raw materials from abroad. Gas imports from Russia is estimated about to 130 billion m^3 yearly. For example, the new gas pipeline Trans-Anatolia (TANAP) could deliver only 10 billion m^3 of Azerbaijan gas yearly. A supplier change will not release the EU countries from "dirty energy sources" and diversification of the supplies. Implementation of the intelligent metering system in Poland finds only 10 percent followers among the customers. Another 40 percent are ready to use these tools free of charge. Fifty percent of electric energy customers have no opinion on it. New technologies, particularly the use of superconductivity phenomenon to construction of generators of the wind turbines and transmission HVDC or LVDC lines, shall enable to increase effectiveness of the investment. The problem of electric energy storage remains unresolved.

Maintaining the emission of greenhouse gases at the level corresponding to the "450" scenario shall result, according to the forecasts [1], in average temperature increase in 2100 about to 2.6°C and 3.5°C after 2200.

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