GDAŃSK UNIVERSITY OF TECHNOLOGY

FACULTY OF ELECTRICAL AND CONTROL ENGINEERING

Student’s name and surname: Michał Andrzejczak
ID: 155694
Undergraduate studies
Mode of study: Full-time studies
Interfaculty field of study: Power Engineering
realized at: Wydział Elektrotechniki i Automatyki, Wydział Mechaniczny, Wydział Oceanotechniki i Okrętownictwa
Specialization: Energy Markets and Systems

ENGINEERING DIPLOMA THESIS

Title of thesis: Analysis of perspectives of Smart Grid technology development and its impacts on power systems and consumers of electricity.

Title of thesis (in Polish): Analiza perspektyw rozwoju technologii typu Smart Grid oraz ich wpływu na systemy elektroenergetyczne i odbiorców energii elektrycznej.

Supervisor	Head of Department
dr inż. Andrzej Augusiak, doc. PG	prof. dr hab. inż. Ryszard Zajczyk, prof. zw. PG

GDAŃSK UNIVERSITY OF TECHNOLOGY

FACULTY OF ELECTRICAL AND CONTROL ENGINEERING

STATEMENT

First name and surname: Michał Andrzejczak
Date and place of birth: 30.01.1995, Gdynia
ID: 155694
Interfaculty field of study: power engineering
realized at: Faculty of Electrical and Control Engineering, Faculty of Mechanical Engineering, Faculty of Ocean Engineering and Ship Technology
Cycle of studies: undergraduate
Mode of studies: Full-time studies

I, the undersigned, agree that my diploma thesis entitled: Analysis of perspectives of Smart Grid technology development and its impacts on power systems and consumers of electricity.
may be used for scientific or didactic purposes.[1]

Aware of criminal liability for violations of the Act of 4th February 1994 on Copyright and Related Rights (Journal of Laws 2016, item 666 with later amendments) and disciplinary actions set out in the Law on Higher Education (Journal of Laws 2012, item 572 with later amendments),[2] as well as civil liability, I declare that the submitted diploma thesis is my own work.

This diploma thesis has never before been the basis of an official procedure associated with the awarding of a professional title.

All the information contained in the above diploma thesis which is derived from written and electronic sources is documented in a list of relevant literature in accordance with art. 34 of the Copyright and Related Rights Act.

I confirm that this diploma thesis is identical to the attached electronic version.

I authorise the Gdańsk University of Technology to include an electronic version of the above diploma thesis in the open, institutional, digital repository of the Gdańsk University of Technology and for it to be submitted to the processes of verification and protection against misappropriation of authorship.

*) delete where appropriate

[1] Decree of Rector of Gdańsk University of Technology No. 34/2009 of 9th November 2009, TUG archive instruction addendum No. 8.

[2] Act of 27th July 2005, Law on Higher Education:

Art. 214, section 4. Should a student be suspected of committing an act which involves the appropriation of the authorship of a major part or other elements of another person's work, the rector shall forthwith order an enquiry.

Art. 214 section 6. If the evidence collected during an enquiry confirms that the act referred to in section 4 has been committed, the rector shall suspend the procedure for the awarding of a professional title pending a judgement of the disciplinary committee and submit formal notice of the committed offence.

ABSTRACT

With continuous growth of electricity demand, efficient energy supply by power systems gains importance. Smart grid technology (SGT) is expected to be one of the foreseen solutions for improved power grid efficiency, reliability and cost reduction.

Advanced metering, monitoring, communication and management systems constitute the bases of the SGT. In the thesis, technologies and devices creating these systems are described and explained. Correspondingly, aspects of their use and choice are considered. The study overviews legal framework of smart grid technology in Poland and European Union. Energy policies and formal regulations are presented. Examples of present implementation projects are mentioned and potential path of future technology implementation is demonstrated.

Analysis of different perspectives of SGT development with research of non-technical aspects have also been performed in the thesis. Points of view of energy companies and energy end-users on SGT uptake are explained. Comparison of benefits and drawbacks for both parties indicates various perceptions of smart grid technology.

As a result, the thesis presents the potential impacts of SGT, explains different viewpoints to the technology and points out the need for deeper social research on its present and future influence.

Keywords:

Power engineering, power system, Smart grid technology, energy-end user

STRESZCZENIE

Wraz z ciągłym wzrostem zapotrzebowania na energię elektryczną, temat systemów elektroenergetycznych zyskuje na znaczeniu. Technologia smart grid (SGT) stanowi rozwiązanie pozwalające poprawić sprawność sieci energetycznej, jej niezawodność oraz obniżyć koszty z nią związane.

Zaawansowane systemy pomiarowe, monitorowania, komunikacji oraz zarządzania są uważane za podstawę technologii SGT. W pracy wyjaśniono działanie poszczególnych technologii i urządzeń pracujących w ramach wymienionych systemów. Aspekty ich wykorzystania i wyboru są uwzględnione. Praca stanowi również przegląd ram prawnych dotyczących technologii typu smart grid w Unii Europejskiej oraz Polsce. Przedstawiono podejście polityki energetycznej i cele ustanowionych regulacji prawnych w tym temacie. Podane są przykłady projektów wdrożeniowych. Potencjalna ścieżka wdrożeniowa technologii jest nakreślona.

Analiza różnych perspektyw rozwoju SGT wraz z prześledzeniem aspektów nietechnicznych została przeprowadzona w ostatnim rozdziale. Przedstawiono punkty widzenia firm energetycznych i odbiorców energii. Porównanie korzyści i wad dla obu tych stron pokazuje różne postrzeganie technologii smart grid.

W rezultacie, praca przedstawia potencjalne wpływy technologii SGT, istotę różnych podejść do tej technologii oraz wskazuje na potrzebę przeprowadzenia głębszych badań dotyczących społecznych kwestii zagadnienia.

Słowa kluczowe:

Energetyka, system elektroenergetyczny, inteligentna sieć energetyczna, końcowy odbiorca energii

TABLE OF CONTENTS

LIST OF IMPORTANT SYMBOLS AND ABBREVIATIONS

AMI	–	Advanced metering infrastructure
AMR	–	Automatic meter reading
CEN	–	European Committee for Standardization
CENELEC	–	European Committee for Electrotechnical Standardization
CIM	–	Common information model
DC	–	Data concentrator
DER	–	Distributed energy resources
DSM	–	Demand side management
DSO	–	Distribution system operator
ETSI	–	European Telecommunications Standards Institute
GPRS	–	General Packet Radio Service
GPS	–	Global positioning system
IC	–	Integrated circuit
ICT	–	Information and communication technologies
IEA	–	International Energy Agency
IEC	–	International Electrotechnical Commission
IHD	–	In home display
LV	–	Low voltage
MDMS	–	Meter data management system
MV	–	Medium voltage
PLC	–	Power line carrier, Power line communication
PLL	–	Phase locked loop
PMU	–	Phasor measurement unit
RAM	–	Random-access memory
RES	–	Renewable energy sources
RF	–	Radio frequency
RTC	–	Real-time clock
SCADA	–	Supervisory Control and Data Acquisition
SET	–	Strategic Energy Technology
SGT	–	Smart grid technology
SGTF	–	Smart Grid Task Force
SM	–	Smart meter
SoC	–	System-on-chip
XML	–	Extensible markup language

1. INTRODUCTION. OBJECTIVES AND AIMS OF THE THESIS

Along with growing population rises the demand for electricity. Everyday life requires more and more advanced energy-powered technologies. Energy producers often meet problems with providing good quality, clean and sufficient energy to every end user. Energy providers aren't able to maintain the power grid in good shape and to anticipate a demand because of lack of information. In traditional power grid the flow of information between distributor and customer is insignificant. Hitherto supervising of the grid was restricted in many ways.

Smart grid technology (SGT) creates new improved electricity grid that provides wide visibility and control of services. It is requisite that the grid will be able to recreate its state after system anomalies. Its role is also to make both-way transfer of energy possible on a large scale, engaging stakeholders to communicate with each other as well as with utility companies [1].

Smart grid technology can be divided on 3 main working areas. Data acquisition, sustained by smart meters placed on ends of the grid and by Phasor measurement units (PMU) in the midst of the power grid, refers to first sector. Data transmission technologies are the second area and aspects related to data storage and processing gathered information shape third part of SGT. Advanced metering infrastructure (AMI) gathers all of these technologies as far as it is directly related to customers.

Conception of the SGT is not a mention nor distant future. There are completed projects of implementation of technology into areas of residence and a lot of programs are performed all over the world at present. It is open to the public that European Union encourages modernization of power grid in a way that support deployment of distributed energy resources (DER) and improve energy efficiency [2].

Implementing this particular technology requires over and above development of existing grid and its equipment. There are substantial non-technical aspects that have to be precisely researched. Different perspectives of smart grid technology can be distinguished. Power grid users are concerned about safety of their personal data likewise power system could be more exposed to cyber-attacks due to computerized and automated network alongside developed flow of information. Perception of smart grid can significantly differs among end users, system operators and energy undertakings. Every side see various benefits and threats, thus many approaches have to be analyzed.

The main goals for this thesis are focused on analysis of perspectives of smart grid technology development and its impacts on power systems and customers (as in title). Technical and non-technical issues will be acutely discussed in the following three main chapters. Closure is intended to summarize the study and draw conclusions directed towards society including in particular end-users and energy producers.

2. SMART GRID TECHNOLOGY

2.1. Data acquisition

The base of the contact between end users and the power grid is found in electric meters. However in traditional grid a role of these meters is strongly limited. Periodic view of electricity consumption is doubtless not enough information about ends of branches of the network. The same applies to the power lines including whole range of voltages. Vision through the middle of the classic grid is narrow, meaning that the quality of provided electricity is often unknown. The smart grid technology concept grants wide spectrum of possibilities for energy distributors who needs essential knowledge in order to maintain high network efficiency.

The infrastructure of segment responsible for information measurement and metering can be divided on:

- smart metering, enclosing appliances of end users,
- smart monitoring, established by sensors and Phasor Measurement Units,
- data concentrators, gathering information from numerous devices.

2.1.1. Smart metering

Electric meters allowing two-way communication between the central system and end user are identified as a smart meters (SM). Despite real-time measurement of energy consumption of customers these should be able to capture voltage, frequency and phase angle [3]. All of the measurements are considered to be taken automatically in specified periods of time. Mentioned features are obligatory part of Advanced meter infrastructure (AMI) system which can be considered as improved, extended version of Automatic meter reading (AMR) system. Other technologies and features that are handled by AMI will be discussed in further part of the study. AMR is known power measuring technique that is used in traditional power grid. Application of AMR is justified by substituting utility providers' physical periodic trips to read a meter by doing it remotely. Another important detail that SM supplies to AMI is measurement on-demand. That helpful element gives energy provider a possibility to check selected parameters from a particular meter at any time.

All of the values collected by SMs are directed towards energy distributors, where local authorized workers have access to data. System arranged for managing these valued is called meter data management system (MDMS). The access is granted by Supervisory Control and Data Acquisition (SCADA) system that is computerized control system architecture using usually network communication and graphical user interface for bringing a vision of the process on the screen and programmable controllers for interaction with the actuators and meters.

Smart meters are crucial part of advanced metering infrastructure (AMI). AMI consists of data measurement topology including communication paths and data management applications. Fig. 2.1. presents basic blocks building AMI system. Customers are equipped with smart electric meters which are connected to AMI host system through data transmission network based on power line carrier (PLC) or radio frequency (RF). Data sent to AMI host system is redirected to the MDMS afterwards [4].

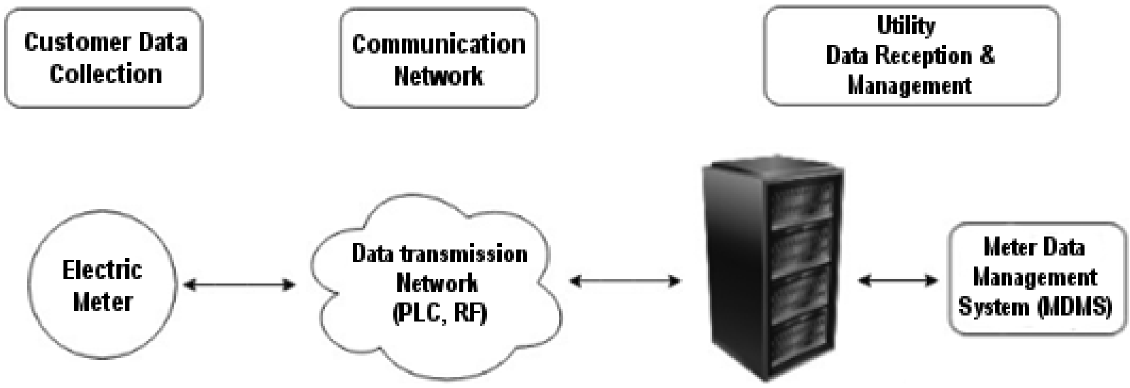

Fig 2.1. AMI building blocks [4]

Worth mentioning is equipment occurring with or as a part of SMs. In home display (IHD) appliance controller is a device designed for users to allow them to get information about some of measured parameters or signals coming directly from the utility provider e.g. tariff type, real-time price of energy, scheduled power outages.

Metrology integrated circuit (IC) ensures that SMs make measurements with certain accuracy. According to [5] it can be equipped with such metrological solutions as analog-front-end (AFE), system-on-chip (SoC) or smart applications-on-chip (SaoC). Specifications of smart meters are defined by imposed standards. International Electrotechnical Commission (IEC) standards, European Directive on Measuring instruments (MID) and European cooperation in legal metrology (WELMEC) standards are fundamental in the EU. These existing norms are able to define necessary functions for SGT deployments but still some important aspects being real-time data control functions, power quality assessment, data storage, support tariffication facility, data security and consumer privacy are skipped or underdone [5]. Although the market contains of complete SMs combining metrology, security and communication. For an example in 2012 American company Maxim Integrated introduced Zeus, complete SM with SoC with multiple ADC (analog to digital converter) channels offering high sampling rates, flash and RAM memory, Real-time clock, LCD driver and other features [6].

2.1.2. Smart monitoring

Moving on deeper towards center of the grid, where voltage level grows, smart grid technology should provide power grid parameters. On-site measurement of power quality is significant for system operators to maintain the network during unforeseen disturbances or launch of new energy sources, especially renewable energy sources (RES).The basic concept of getting this kind of information involves phasor measurement unit (PMU). PMUs are devices able to measure electrical waves using time source for synchronization, which means that multiple devices make synchronized measurements at the same time. *Synchrophasor* is commonly used word for describing an occurrence of phasor measurements done at the same time. This feature of PMU is key to get valuable information about power quality. Values recorded by PMU are magnitude, phase angle, hence frequency, all from the sine waves found in electricity. According to research work [7] this comes to simultaneous record of:

- three phase voltage magnitude,
- voltage phase angle,
- three phase current magnitude,
- current phase angle and
- frequency

what gives 9 samples of data. PMU synchronized with global positioning system (GPS) records time stamp for each sample to have reference point for comparison with measurements from other network points, thus it equals 18 variables for each measurement of PMU. The number of data obtained from one PMU device is enormous when sample rate of 30 samples per second is set. This gives the result of nearby 2.6 million data samples coming from only one device for each day, where one sample delivers 18 variables. Managing this amount of data can be very problematic. Further development of the aspect comes in data storage and processing chapter.

PMU device consists of receivers, filters, GPS unit, phase locked loop oscillator, analog to digital converters and processor which prepare a sample for transmission. An important part of PMU is phase locked loop (PLL). PLL is an electronic circuit (based on feedback loop) which generates a signal that is related to measured input signal. Signal going through filter and voltage controlled oscillator is modulated until it reaches signal identical to sine wave in the power line. Following figure explains basic model of PLL idea.

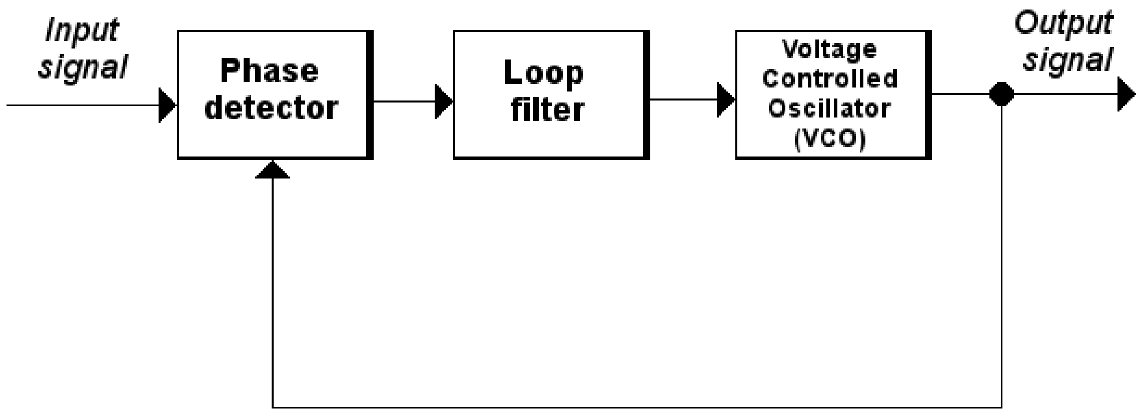

Fig 2.2. Basic PLL building blocks

Considering ability of monitoring the power grid using PMU technology, there is exceedingly important aspect that is needed to be discussed. The placement of PMU devices, seemingly simple, but in fact complicated issue, is key for getting appropriate vision of power system. Best vision would be provided with high density of placement of devices, but against that comes out economy of smart system. Also other criteria such as accuracy of estimating a state of power grid or clarity of measurements affect the choice. The grid made of PMU should be also designed the way that allows neighboring devices to control each other in case of error and disturbances in measurement of single sensor. These opposing approaches forms a decision problem, which can be solved using known optimization methods and known software such as Matlab. The [8] study sets itself main objective as *the placement of a minimal set of phasor measurement units to make the system measurement model observable.* Using mathematical formulation (binary integer linear programming) for the problem authors make simulations in Matlab software on simple 7, 14, 30, 57 and 118-bus system with different methods of placing PMU modules. 2 scenarios were considered: without loss of any PMUs and with loss of some device. Figure 2.3 shows exemplary 14-bus power system (IEEE standard) on which simulations were done.

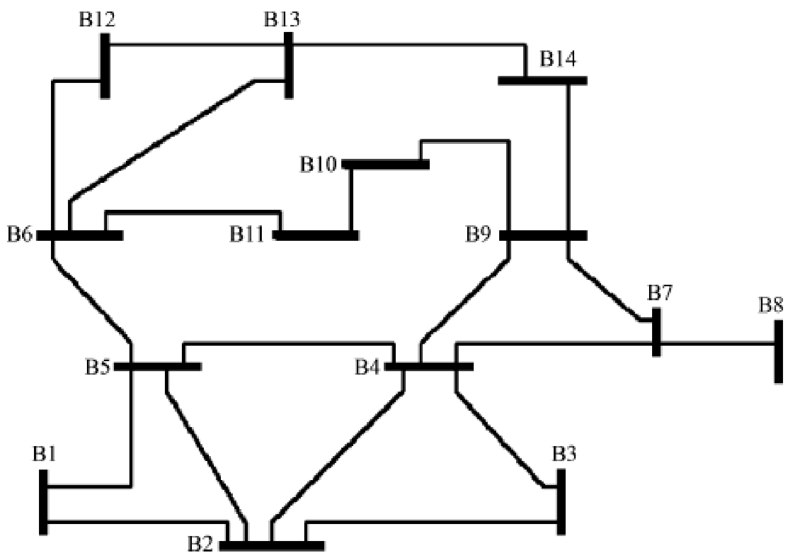

Fig 2.3. IEEE 14-bus system [8]

Results of the simulations for this model are good cases to analyse. Assuming that none of PMU will be damaged during work there are 4 devices needed for full vision of the grid, placed on buses no. 2, 6, 8, 9. Looking into the case, by placing devices on mentioned buses every branch of the grid is visible for system operator. Although if any PMU fails the vision is limited. Simulating situation when single PMU can fail and vision is undisturbed gives result of 9 devices needed on buses no. 2, 4, 5, 6, 7, 8, 9, 11 and 13. Taking a note of different cost of a module because of required channels (e.g. PMU on bus #1 – 2 channels, PMU on bus #2 – 4 channels) setup of devices on buses no. 2, 6, 8, 9 taking 13 channels is more advanced, hence more expensive from setup on no. 2, 8, 10, 13 taking 10 channels. Going further this way of thinking, most economically would be to place PMU on bus no. 2, 6 and 9, what gives best vision on the grid (only dropping the least significant bus #8) with costs reduced to minimum.

2.1.3. Data concentrators

Besides making measurements SGT should provide the power grid with devices able to gather samples from numerous instruments. This concept doesn't require that system operator has communication link with every smart meter, but only gets packages of information from data concentrators (DC). Therefore density of needed relations in the power grid is lowered and cost of SGT construction is also reduced if DC substitutes adequate amount of connections.

DC consists of microcontroller able to process and regroup collected data, regarding constraints of encrypting all samples. Device needs enough memory for preserving data during intervals between data forwarding. Communication with concentrator is provided by different technologies depending on system architecture. Modules working with RF, GPRS on GSM and PLC are most commonly used. Often microcontrollers are equipped with Ethernet modular connector or Wi-Fi module. Compulsory is RTC appliance for time-stamping sent packages of data to utility provider. G3-PLC standard, IEEE-1901-2 standard and PRIME standard are mainly supported by today produced data concentrators.

Data concentrators manage to forward condensed data form up to 2000 devices [9], thus their deployment is extremely important in terms of network capacity utilization. According to [10] every smart metering message is send with protocol suites e.g. TCP/IP which add additional 40-60 bytes to the 100-bytes message. In the situation where DC collects multiple data packages and passes on one big package of information, all of additional 40-60 bytes per message can be chop off and one protocol suit can be imposed on one big package. Preceding technique can significantly lower size of transmitted data from DC.

Below scheme of processing data through data concentrator is presented. Idea is divided on messages with and without deadline. As shown, some of packets must be dropped because of missed deadlines or missed time-stamps, which are different from others.

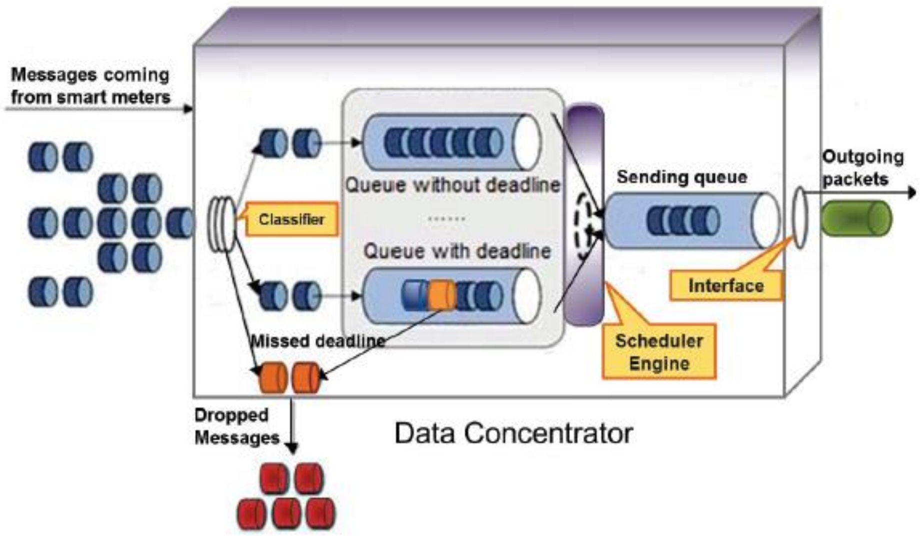

Fig 2.4. Idea of data concentrator's work [10]

Issue of data concentrator placement is easier comparing to deployment of PMU modules. Most reasonable is to locate them beside LV transformers. Locations of LV transformers are forced by electricity demand, hence often number of households. Installing DC at the same place as transformer matches adequate area supported by one device. The only issue related to the placement of DCs is a result of overlapping of working areas. Every meter should be specified to connect with only one data concentrator in order to avoid sending duplicated samples, and every data concentrator should be programmed to collect one package of data only once per at the specified time.

2.2. Data transmission

To accomplish smart grid technology features communication between each device must be granted. Data collected through smart meters or PMUs have to be delivered to utility providers, and the other way, information from provider should find its path to reach devices. Looking at AMI, there are two basic connections: between SM and data concentrator and between data concentrator and operation center. Figure 2.5. illustrates basic communication architecture supporting AMI. As main goal for this part focuses on communication, operation center with surrounding manage systems will be discussed further.

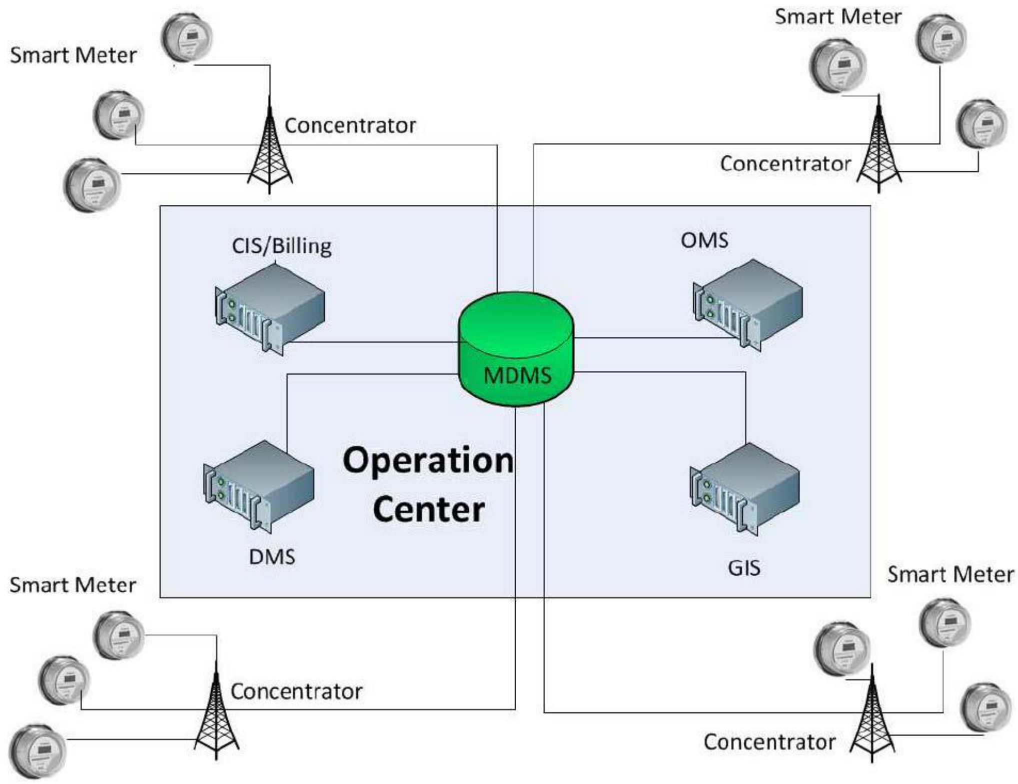

Fig 2.5. AMI communication architecture [11]

Starting with classification of available technologies it is well-known that transmission can be wireless or wired. According to [12] wireless technologies can be divided on:

- Wireless Mesh Network,
- Cellular Communications,
- Cognitive Radio,
- IEEE 802.15,
- Satellite Communications,
- Microwave and Free-Space Optical Communications,

while wired technologies aren't so spread and include only 2 feasible ones: Fiber-Optic Communications and Power line Communications.

Wireless Mesh Network

Communication network built up of radio nodes coordinated in the way creating mesh topology. This concept effectively fits into the SGT architecture, where meters can be considered as access points of the mesh. Access points communicate with each other wirelessly based on IEEE 802.11 standard. Depending on operating frequency, needed throughput, modulation method and maximum range there are different physical layers: 802.11b 2.4 GHz, 802.11g 2.4 GHz, 802.11a 5 GHz, and 802.11n (draft) 2.4 and 5 GHz. The latest standard 802.11n approved in 2009 provides theoretically bit rate up to 600 Mbps, but practically maximum comes to 150 Mbps. Such high speeds are possible because of Multiple Input Multiple Output (MIMO) technology that uses many antennas for sending and receiving signals.

Cellular Communications

Cellular communications include Global System for Mobile Communications (GSM), 3G or even 4G (standing for third and fourth generation of wireless mobile telecommunications technologies). Cooperation between SGT and radio network can save many funds for building communication structure. Existing cellar communication systems coverage large geographic areas and are available mainly everywhere. Most common technology – 3G provides at least data rate of 2 Mbps and usually operates on the 2100 MHz frequency band, while gaining popularity 4G sets peak speed up to 1 Gbps (for stationary clients). In this scenario SGT devices will be considered as users of separated part of GSM and will be given Subscriber Identity Module, widely known as SIM card. Data will be transmitted towards operation center through radio towers located on the way. This concept doesn’t require usage of data concentrators, since their function is to collect measurements and forward them in condensed form further.

Cognitive Radio

It is wireless technology that is meant to be configured dynamically to use always best possible channel of communication to avoid interferences of other signals. This specification of technology is challenging for SGT application, because of cognitive nature and delays caused by dynamic, sensing radio searching for new available channels. However method proposed in [13] describes use of IEEE 802.22 standard (standard designed for wireless regional area network (WRAN)) that operates in available TV broadcast bands called white spaces in frequency spectrum. In addition, as a solution for continuous searching for channels and causing delays, authors of [13] suggest *dual-radio* architecture, where one radio constantly checks channels, and second radio chain is dedicated only for data transmission. The *dual-radio* idea can find application of Cognitive Radio for smart grid technology communication networks, which doesn’t require capital funds for licensed spectrum.

IEEE 802.15

IEEE 802.15 is working group for Wireless Specialty Networks (WSN). Usage of 802.15.4 standard to reach wireless communication proposed in [12] focuses on three technologies which are ZigBee, WirelessHART and ISA100.11a. The 802.15.4 defines operation of low-rate wireless personal area networks (WPANs) with basic range of 10 meters and transfer rate of 250 kbps, whilst newest fourth amendment provides higher rate of 2 Mbps. Most popular of these technologies – ZigBee is meant to be used as communication for smart meters in Home Area Network (HAN), because of its short range, low bit rate, very low power consumption, security of connection and low overall cost.

Satellite Communications

Transmitting data using satellites can be exploited in situations where no other communication infrastructures are available in vicinity of devices monitoring power grid. Connecting with satellites isn't requiring complicated equipment and can bring many advantages, such being failure-proof and accessibility from every point on the ground. It is mentioned [12] that satellite communications can be great substitution form communication technologies during their and system failures. Also their features can find application in transmitting data between distant from urban networks e.g. wind farms and operation centers. Mentions not standing for using satellites as main communication technology point out significantly higher delays comparing to other technologies and possibility of fading signals due to bad weather conditions on the way towards a satellite.

Microwave and Free-Space Optical Communications

Microwave technology is used for transmitting signals on long distances between two points with directional antennas on a line of sight. Specification of transmission is similar to satellite communication, but difference is direct broadcast. Free-Space optical communication technologies use light propagation for sending data between two locations. These two technologies are similarly secure because of directionality of signal beams, however optical in contrast to microwave solution can be used in urban areas, where high density of interferences affects negatively on microwaves signals. Again these solutions are good application on more opened areas like rural ones but are highly affected by environment and weather conditions e.g. fogs, hard rains, thunderstorms.

Fiber-Optic Communications

Optical fibers are flexible, transparent fibers that are constructed to transmit light between two ends of the connection. They allow to transmit data with high data rates over long distances. Their undeniable, important advantage is immunity for all electromagnetic and radio disturbances. These features make the solution ideal for transmitting data around the power grid, despite the cost of fiber installment. However the technology is spreading rapidly among types of the Internet connections, which marks definitely good perspective for future SGT wired connections.

Power line Communications

In abbreviation PLC, is technology that uses an existing electric grid as a data carrier simultaneously, where supply voltage at 50 Hz or 60 Hz doesn't interfere with high frequency communication signals. It is known solution, which is used by utility providers for load control and metering or to gain Internet access by broadband over power lines (BPL) technology. Since narrowband PLC application for smart metering infrastructure is well-known and can be easily adapted, broadband PLC at high voltages and longer distances causes more problems. With increasing connection range, PLC signal is fading and disappearing in disturbances. Although frequencies of voltage and information signals differ and these two are filtered, hence separated, data signal needs to be modulated and afterwards its accuracy must be verified.

Main premise for using PLC as communication technology is no necessity for creating new infrastructure, since PLC works on existing power grid, what strongly affects save of costs. However on long distances, investment into repeaters of signal is needed. Signals meeting transformers and substations on their way can be significantly disturbed. In addition, heavily-exploited grid causes more disturbances than new-build one, what should be considered before an implementation of the technology. Another disadvantage of PLC solution is possible loss of communication if power line is damaged. In this scenario power supply and data transmission are lost at the same time.

Transmitted data format

Selection of most suitable communication technology should rely not only on distance, land specification, network layout, susceptibility to damage and interference or costs, but also number and size of data. To achieve best possible efficiency in transmitting data, it has to be properly prepared. It is important to keep connections not overloaded to maintain communication reliable and stable. Investigating further the issue, preparing data doesn't close in compression data to lower its size, but also the frame of data package to provide standardized format to read for data concentrators and management systems.

Such message framework for PMU communication is included in IEEE C37.118.2 standard [14]. The document presents both measurement and data transfer requirements. Focusing on formatting, standard describes examples for overall message, data frame, configuration frame and command organization.

Figure 2.6. illustrates exemplary order of transmitted message according to C37.118.2 framework. SYNC 2-bytes field is responsible for synchronization and is first to be sent. Then comes information about total size in bytes of the frame – 2-bytes FRAMESIZE. IDCODE is 16-bit number which labels the message for identification. Next field to be transmitted is SOC (second-of-century) which stands for timestamp and uses 4 bytes. FRACSEC keeping 4-bytes of information about time of measurement or time of frame transmission, hence quality and CHK is small field for 16-bit cyclic redundancy check used to verify if data is not corrupted. Right before CHK comes characteristic fields containing data, configuration or command.

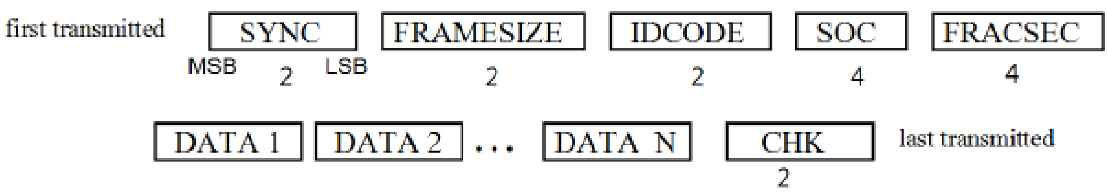

Fig 2.6. IEEE C37.118.2 frame order for message transmission [14]

Mentioned DATA fields cover bytes of measurements of phasors and frequency and also status of the device. Values can be integer, binary or in IEEE floating-point format. For example status of PMU about data error can be described in 2 bits, as a comment towards data frame STAT field for [14] includes:

> *Bit 15–14: Data error:*
> *00 = good measurement data, no errors*
> *01 = PMU error. No information about data*
> *10 = PMU in test mode (do not use values) or absent data tags have been inserted (do not use values)*
> *11 = PMU error (do not use values)*

Substantial part of smart grid technology data is produced by AMI structure. Measurements taken by smart meters make enormous data volumes. Independently from communication technology and provided bit rate, data has to be compressed. It affects communication network load, hence decreases costs. Considering compression algorithms the criteria of lossless method is required, meaning none of values is being corrupted. Two scientific institutes in Germany has worked on a way to choose optimal algorithm for smart meter data. Taking compression rate and process speed into account, result of the research [15] points out two algorithms: Adaptive Trimmed Huffman coding (ATH) and Lempel Ziv-Markov Chain Huffman coding (LZMH). First one besides lowest compression rate, comparing to other analyzed methods, with maximum of 63% is fastest algorithm with the average processing time of 52 ms/KB of data. Thus ATH shows best features when there is a necessity of fast transmission e.g. on-demand measurements. Second, LZMH algorithm fits requirements for overall data transmission with very high compression rate between 75% and 95% near good estimated execution time of 150 ms per kilobyte.

2.3. Data storage and processing

Large quantity of measurements from smart meters, PMU and other sensors does not guarantee increase of knowledge about grid load or power quality. Raw data is useless, when devices take measurements with high sampling rate, thus important incidents disappear among dense and crowded database. Information management and clear data representation is key to make SGT genuinely smart. These aspects also refer to storage of data, its methods and time of access to specific details. Storing all collected data is practically impossible, so there is needed application of algorithms deciding about importance of data, what information should or shouldn’t be stored. Different approach is required for analyzing system history, and other for user history, since utilization of this data varies – first is important for system visibility and second is used for demand side management, forecasting and bills. Keeping in mind objectives of SGT implementation, part of data should be available for end users, hence some information should be processed into an easily readable format. Influential technology connected directly with data processing is cloud computing, which is service assured by cloud providers who have possibilities of computing and storing large amount of data and share this services through network for clients e.g. utility providers. Cooperation between power grid operators and cloud providers can bring many benefits for both sides.

Going along path of SGT data, after taken measurements and transmission, samples has to be filtered, grouped and stored. Basic approach predicts application of servers located in operation centers managed by energy provider. Management structure with only one big center server is not recommended, since single failure could cause data loss.

Different storage platforms are available such as MySQL database, PI database, Oral database, Microsoft SQL Server. Choice between them refers to its performance and access ability with the connection to other management units and customers. It is important that data is simultaneously readable by human and machine. Such storing solution is proposed in [16] article, where measurements from the grid are fused in method based on Common Information Model (CIM) standard and Extensible Markup Language (XML) language. CIM responsible for managements of elements in IT environment, their set, connections between them and XML as set of rules for making document human and machine readable can be certainly helpful to constructing a framework for storing and processing obtained information. The fusion of grid data relying on gathering same type of information or data collected from a certain area, using CIM/XML method can be advantageous in terms of fast access, easy transform and scaling.

Table 2.1. presents exemplary data table model holding e.g. PMU device records. Conception of the table based on [16] examples of line-based storage structure.

Table 2.1. Table model example for PMU data storage

Field Name	**IDOf PMU001**	**Location OfPMU001**	**TimestampOn PMU001**	**VoltagePhase1 PMU001**	**VoltagePhase2 PMU001**	**…**	**Frequency PMU001**
Info	ID number	Geo. loc.	-	-	-	-	-
Record1	-	-	Value11	Value12	Value13	…	Value1N
Record2	-	-	Value21	Value22	Value23	…	Value2N
⋮							

Different devices should have their own files, since there can occur problem in this kind of solution when different devices provides varying measurements and length of their records differs. Making statistics and graphs in this kind of register solution is easy and does not expect any advanced processing and programming. Mapping every device and its every value is significant in further accessing and processing data Access to database of every device should be properly secured, for example by demand of username and password. Obtaining certain value by operator from PMU001 measurements should be possible by filtering and searching services. Moreover, comparison of values e.g. in graphs should be available on-demand.

In AMI end users should have access to interactive web application that allows users to monitor their energy consumption and to check statistics from past periods. There is no need to arrange direct connection between costumer and server database. Instead cloud computing can act as intermediary and be a security barrier for database, so only authorized persons could connect directly to the server.

Storage time of measurements depends on many things. First is type of measurements. Voltage value on the substation can has different priority than power line frequency, thus ones ought to be stored longer than the others. Another thing is destination of data processing. Some records are going to be used in short-term load forecasting, some can be used in long-term statistics and other are taken only for state-monitoring.

Crucial part of data processing is filtering data through the analyzing process. Filtering allow to significantly reduce load of database by cutting off unnecessary measurements. However this reduction is proceeded in a way that won't cause any lack of information about the power grid state. Described process mainly concerns data collected by PMU devices, because of the character of taken measurements. PMU delivers high volumes of data but most of it occurs to be redundant. It doesn't mean that PMU sampling rate should be lowered so database won't be littered. Frequency of sampling is required to be high for the vision and control of the grid to be continuous.

The only solution to this problem is mentioned filtering. Whole issue comes to deciding algorithm of removing appropriate records. 'R' programming language is assumed as very suitable for analyzing PMU data, since his features fit statistical computing and visualization of results [7]. The research suggests method for analyzing PMU data from 6 locations in Great Britain by presenting simulation. Good example of filtering can be shown on frequency measurements. Greater part of records are frequencies around standard value of 50 or 60 Hz. Values closest to the standard one can be ignored, as they don't bring any needed information e.g. about disturbances. In mentioned work [7], this kind of segregation results in leaving 7700 observations instead of all 4.5 million by dismissing measurements between 59.96 Hz and 60.04 Hz. A similar approach can be used for analyzing voltage or current. Only uncommon rises or downs of magnitude, interpreted as special events, should be registered, and relatively stable measurements around standard values should be dismissed. Every of this special events should be distinguished in processing so the needed automatic or manual action would be performed.

There are two possible ways of using 'R' programming language for data processing. First, less effective, is filtering data after its save in main storage system. It means, that at first large space of available memory of database is locked by massive data volumes and processing gradually clears it, leaving only meaningful information. This way database has to be ready to handle a way more quantities than in second approach. This one requires additional transitory memory such as RAM (random-access memory) placed before main database in the process. RAM would store data only on the time of filtering and further transmission towards main server would hold only useful records. Although another transient database is needed, main servers' load will be reduced, what results in better efficiency of processing.

Using proposed algorithm can be useful in catching disturbances in continuous delivery of data. Cases of missing packages of information should not be ignored and registered likewise as potential failure. However, sensitivity on this empty records should be constrained, since single packages of data can be missing due to transmission disturbances.

Data analysis doesn't close in monitoring smart grid technology state, registering disturbances and further related activities. Very influential for energy production as well as for all users is load forecasting. Its meaning rises with network size increase. With the possibility of correct prediction of power consumption, the management of power generation can be more effective, allowing renewable energy sources (RES) to take part in production and reducing surplus of generation, what converts into lowering costs. Providers' savings also relate to potential users' savings. Along the drop of overall production cost, transmission costs are also predicted to become lower, since forecasting will allow to maintain grid in best shape, suitable to expected load.

Basing on history of gathered SGT data there can be done predictions for further consumption. Comparing power load in specific days during the year (with comparative weather conditions, week time etc.) we can easily guess energy demand in similar days. To achieve most accurate electricity forecasting more than single power consumption criteria on the background of weather conditions should be considered. Analysis should combine criteria of outside temperature, number of living people in the area, humidity and time [17]. Mentioned research discuss variables selection for prediction of electricity consumption. Against popular premises that consider environmental factors as most significant ones for forecasting, the survey proved that forecast with the lowest prediction error was accomplished by taking into account only time and number of people variables. Concluding, people's daily life data has bigger importance in short-term load forecasting than weather conditions.

Besides research of potential analysis methods and data storage options, cooperation between these services and energy producers, distributors, end users must be considered. It is known that adequate access should be provided to every energy market participant. However, there is certainly need for scalable system architecture for management of collected data, especially in this SGT section covering active influence of users. In previous subchapter referring to data transmission AMI communication architecture with the operation center was mentioned. The operation center is exactly system responsible for managing data. The system should have distinguished unit that is able to read and store data, as well as point its further way in the process of analysis and access. That unit called meter data management system (MDMS) is predicted to cooperate with other support management systems:

- consumer information system (CIS),
- outage management system (OMS),
- distribution management system (DMS) and
- geographic information system (GIS) [11].

Every of listed system has separate objectives and they shouldn't be mixed, since their individuality ensure best effectiveness by focusing on single tasks. CIS regulates billing information and other messages sent to customers, deriving from data analysis and forecasts. OMS encloses aspects related with power outage and potential failures and its prevention. DMS basing on gathered data should be able to control power quality and GIS provides localization information about data or event source. Moreover systems should work with relevant priority.

Events registered in OMS should be investigated at first, when work of CIS among with DMS should be assured as continuous.

Depending on scale of supported grid, there can be one operation center as well as few smaller ones. It is important to provide scalable data management system to allow growth of smart grid technology without losing ability of efficient data processing.

3. IMPLEMENTATION OF SMART GRID TECHNOLGY

3.1. Legal framework of smart grid technology in Poland and EU

Objectives of smart grid technology implementation are strongly related to increase of energy consumption caused by technological progress and population growth, necessity of efficiency improvement due to economics, protection of environment by use of renewable sources and many others. Researchers, scientists and technicians, all over the world, are meant to be focused on development of SGT technologies. The application of developed scientific know-how requires a lot more. The scale of SGT is at least agglomeration-size and deliberately should enclose countries and even continents. This kind of issue's dimension has to involve government, as the ones imposing directions towards project implementation. To gain full functionality of SGT, authorities should commit to cooperation and establish agreeably rules of conduct. In the subchapter attitude of EU authorities and specifically Poland will be discussed.

European Union as a group of countries sets main objectives in politics, to achieve best performance for example in the industry, amongst the competition that are other continents. Energy industry in the EU is differential, depending on land specification, climate and local fuel sources. However, European Commission proposes solutions for improving power grids efficiency that are more or less universal.

To support cooperation between countries three European Standardization Organizations: European Committee for Standardization (CEN), European Committee for Electrotechnical Standardization (CENELEC) and European Telecommunications Standards Institute (ETSI) work on smart grid technology set of standards that states for guidance of standards selection for EU members' power grids [18]. The document gathers suitable technological standards (already available and coming ones) including: European Standards (maintained by these three organizations), separate ETSI security and AMI standards, ENTSO-E (European Network of Transmission System Operators for electricity) propositions for market solutions, IEC, ITU (International Telecommunication Union) and well-known ISO (International Organization for Standardization) standards. CEN-CENELEC-ETSI association besides research on: measurement technologies, transmission standards, data storage and data management issues and security challenges, describes conceptual models of SGT highlighting four domains that are: grid users, markets, operations and energy services. By working with standardized technologies systems are scalable and connection of several grids with maintenance of SGT features is possible. As the listed document mentions, the framework's goal is upholding interoperable solutions, that are the key of smart operation of the system.

Setting legal framework for smart grid technology implementation requires some basis of defining concept and goals. The first step to this direction was committed by United States Congress in The Energy Independence and Security Act of 2007 [19], where the official definition and characterization of smart grid has occurred. Increase use of information, improvement reliability and security, deployment of distributed generation, integration of appliances and consumer devices are only a few of features mentioned in the document. The same time Smart Grid Task Force (SGTF) has been established, as the group of designated employees responsible for development of smart grid technology, coordination of diverse activities and assurance of awareness.

Europe hasn't stayed behind for long, when at the end of 2009 Smart Grid Task Force was set up by European Commission after two years from proposal of the Third Energy Package framework in 2007. Objectives of the formed group are similar to the one operating in US area, however in Europe there are international coordination issues, hence framework has to be comprehensive. The specified mission of SGTF is described as advisory for the European Comission on policy and regulatory plans accordingly on European level for making first steps into the smart grid technologies implementation and assistance in the identification of common interest projects. Operation time of the task force was set on the 2012-2020 period [20].

International Energy Agency (IEA), associating countries from all continents, constructed Technology Roadmap for smart grid technology development [21] in 2011, where SGT deployment vision is discussed. Worth a mention is an invention of universal smart grid (in context of electricity grid) definition, that would be understood by everyone and could be reused afterwards:

> *A smart grid is an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users. Smart grids co-ordinate the needs and capabilities of all generators, grid operators, end-users and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimising costs and environmental impacts while maximising system reliability, resilience and stability* [21].

These kind of documents, because of its versatility are meaningful not only for coordinators of local smart grid technology implementation projects, but also state authorities and society, since its comprehension is better than purely technical standards.

The Third Energy Package which is legislative documentation aimed at gas and electricity markets in EU consists of two important Directives 2009/72/EC and 2009/73/EC, repealing Directives from 2003 and three Regulations repealing two old Regulations and one new one establishing an Agency for the Cooperation of Energy Regulators. 27th point of the 2009/72/EC Directive informs about obligation to strive for better energy efficiency by development of existing networks through the implementation of SGT [2]. Also in the same place the encourage for building up decentralized generation through the modernization process is mentioned. The second chapter of the document which presents *general rules for the organization of the sector* points out exemplary actions that should be taken by State Members towards electricity undertakings to support optimization of the use of electricity. These actions, which are related to SGT features and objectives are effective influence of authorities on the advancement of power grids. Second point of first annex of 2009/72/EC clearly states about countries ensuring intelligent metering systems implementation, that allows consumers to actively participate in the electricity supply market. Approach to this postulate was individual, depending on long-term economic costs. Hence by 3 September 2012 assessment of each Member State has been made and appropriate implementation activates have been set for the target of up to 10 years for each one. European Parliament has set the deadline for positively assessed smart metering projects for equipping at least 80% of consumers with smart meters by 2020. Interoperability of metering systems, as a mutual understanding between different interfaces, devices and systems, should be preserved by observing appropriate standards and cooperation between distribution network operators. Interesting fact is that also in the Directive 2009/73/EC referring to rules of the natural gas internal market, encouragement towards promoting energy efficiency by introducing intelligent systems and grids is included. Not only EU implies on development of electric energy metering system, but energy in the form of fuel such as natural gas should be considered as well during process of projecting advanced, smart measurement devices network.

European Commission has constructed *Set of common functional requirements of the smart meter* in October 2011 [22]. The document describes potential functionalities that should be considered during Smart Metering System implementation process. The workshop includes 13 original functionalities for the customers, for grid and network support, for commercial aspects of energy supply, for security and privacy and one to allow distributed generation. As a part of creating this [22] report, the questionnaire has been conducted among Member States, that have assessed costs and benefits smart meters implementation before. Countries answered about the number of functionalities that they are able to consider before and after getting acquainted with the workshop. It is worth a mention that there is difference between numbers of functionalities considered in questionnaire and after workshop, in favor of the second. It is because of better understanding of smart metering and wider knowledge about its implementation in each of the countries. The results are presented in the 3.1 table. Assessment of the numbers were accordingly assigned to: 1 when answer was 'yes', 0.5 if answer was 'partly' and 0 for the answer 'no'.

Table 3.1. EU Members State's answers about number of functionalities considered [22]

			Number of Functionalities Considered	
Country	**Electricity**	**Gas**	**Questionnaire**	**After Workshop**
Austria	✓		10.5	10.5
Belgium	✓	✓	8	8.5
France	✓	✓	10	10.5
Ireland	✓		10.5	11
Netherlands	✓	✓	12	12
Norway	✓		8	8
Poland	✓		11	11.5
Portugal	✓		11.5	12.5
Slovenia	✓		10	10
Sweden	✓		4	10.5
United Kingdom	✓	✓	13	13

Reasons of these answers are mainly connected with advancement of made assessments of profitability, but also previous development of smart metering technologies and willing for further rapid improvement of existing systems and their projects. Through the process, statistics were also noticed. Every of proposed smart meter functionality got its own ‘consensus level’, what means about approach of countries to specific features, their importance and impact they bring after implementation. Providing secure data communication and allowance of remote reading are the only features that are 100% considered by every of participating country. Least promising occurred energy supply by pre-payment method and on a credit and also functionality of providing monitoring of power quality.

Implementation of smart grid technology, or even smart meters separately, is investment that has to be planned and thoroughly discussed. Precise research on technologies and standards to be used, defining the process, assessment of costs and profits are unavoidable, but more than this has to be done. Impacts of SGT implementation are not only technical, but in considerable part they relate to how the whole energy market works. All decisions has to be taken considering society and environmental aspects. Moreover, the process of power grid improvements is definitely long-term and involves a large number of institutions. Concluding, the strategy is needed.

Besides European Directives that only give the point of view, which should be kept by Member States, Integrated Strategic Energy Technology (SET) Plan is the pillar of innovation and research activities in EU of effective acceleration of transformation of the EU’s energy system. The steering group of the plan, chaired by the European Commission, secures equivalent development of technologies, preserves priorities and sets targets for key actions. When in 2007 the Commission of the European Communities created statement towards SET-plan, conclusions were aimed mainly on renewable energy sources while only mentioning the need of development of ICT and interaction between customers and operators [23].

Over time, awareness of technological progress and need for more advanced communication has increased, hence in 2015 new integrated SET-plan was established [24]. The new document, focused on transformation of energy system in cost-effective way, discuss more specific empowering the consumer in new smarter system and energy efficiency issues besides renewable technologies and lowering emissions. With experienced gained by running SET group in 2007, improved, more integrated approach is used in latest plan as well as management and targeting objectives are being more transparent.

Overview of legal framework and approach of European Union to smart grid technology implementation can’t omit official 2020, 2030 and 2050 Energy Strategies. First, the nearest 2020 Energy Strategy, written down in 2010 [25], priorities reduction of gas emissions by at least 20%, achievement of energy savings of 20% or more and most important, increase a share of renewable energy to at least 20% of consumption. Referring to perspectives of SGT development, smart meters are mentioned as key to *full exploitation of the potential for renewable energy and energy savings*. European Commission sets goal of establishing clear policy and common standards for smart grid technology and metering system technologies before 2020. To achieve this, mentioned before Smart Grid Task Force was set to lead the implementation process of smart grid technology in Europe. Energy strategy for 2030 that was set in 2014 includes mentions on further emphasis of 2020 strategy objectives with higher requirements, with maintenance of smart grid policy [26]. However, as an extension, the document points out that secure and sustainable energy should be supported by deployment of SGT as links between Member States to urgently ensure equivalent advancement levels of electricity interconnections that will meet at least 10% of their installed production capacity. The longest vision of EU energy strategy reaches year 2050 [27] and consists of main dominance of RES share in energy consumption of 75% (with 97% coverage for electricity) with obligatory infrastructure supported by monitoring, metering and information systems. By this time SGT should be implemented and provide high energy efficiency together with unlimited possibilities of deploying new renewable sources.

With continuous development of the smart grid technology concept European Union has to face its tempo and be prepared to make changes into approach. Current Directive 2009/72/EC could be possibly repealed shortly, since European Comission in early 2017 set a proposal of new directive [28]. The change includes removing, rewording and adding some points to customize to energy market evolution. Added statements claims that consumers should benefit from direct participation in the energy market through, ensured by Member States, smart metering system. Assurance of access for consumers to their consumption data and other metering services is mentioned as well as using these features as incentives for energy savings. Issues of cybersecurity were not skipped, since transparent rules for data access and highest level of data protection should be provided by Member States, as the document points out. Moreover, EC proposes that smart metering functionalities should be also included in the new directive, after discussing it in *Set of common functional requirements of the smart meter* in October 2011 [22].

The EU legal framework of SGT contains of multiple documents, roadmaps and plans that are made for group of Member States and support balanced development emphasizing cooperation of power systems. Although, every country establish their own framework and strategy that comply with EU statements. Poland, as Member State not developed as good as other countries but with one of the fastest growing economy is a place where implementation of SGT is possible and being considered in close future.

On 10th of November 2009 significant document was established by the Council of Ministers in Warsaw, that declares Energy Policy of Poland until 2030 [29]. However, directly there are no mentions of a strive to smart grid technology implementation by the Polish authorities, since the document has been made in the same year as European Directives concerning common rules for internal markets in electricity and natural gas has been updated. Polish government was not entirely acquainted with upcoming issues of modernizing power grid and did not include it in 2030 strategy. Although, in the appendix to 10 Nov 2009 document describing action plan for years 2009-2012 [30] there is mention of applying Demand Side Management techniques, which include introducing an obligation of using electronic meters enabling transmitting of price signals to every end-user and also creation of digital communication standard for ensuring conditions for solid, homogeneous system of radio communication for power sector's needs of data transmission. Another little step towards smart grid technology is point of mentioned appendix that presents wish of introduction of national standards for electronic meters' technical features with rules of installment and read of meters.

In June 2015 Poland followed the path of European Union approach and set project of Energy Policy of Poland until 2050. In the first appendix of the document, the assessment of realization energy policy to 2030 is included, where there is undeniable mention of the national legislation lack for the smart metering technology development what is significant hindrance to SGT implementation [31]. Moreover, created regulations obligating power system operators to introduce more advanced metering systems haven't been implemented what causes further delay of SGT advancement. Preceding lack of actions is also putting Poland in bad position as EU Member State, since smart meters ideology was suggested by European Commission in Directive 2009/72/WE.

Energy Policy of Poland until 2050 [32] sets Poland on the right way to achieve efficient and modernized power grid. One of the declared projecting priorities is development of smart power grid, what convinces of better knowledge of the issue. Ministry of Economy claims that the priority should embrace especially smart grid technology construction together with smart metering systems, what allows management of direct interactions and communication between consumers, undertakings and energy providers. In addition, enhancement of energy awareness and ability of proper use of smart meters are considered as necessary. Polish authorities realized that all mentioned actions affect effective housekeeping of electricity, through making an impact on consumers and possibility of better and more directed network management keeping power grid safer, more integrated and cheaper in operation. In the perspective of 2050, the goal is to make all networks intelligent, and being able to cooperate with other Member States' systems.

Despite poor action plan for years 2009-2012 [30], third annex of Energy policy until 2050 which is plan for present period of 2015-2018 [33] is much more promising. One of mentioned movement is elaboration of new both technologic and market roadmaps of energetics development, including solutions defined as “smart grid ready”. Establishing legal regulations of obligatory implementation of AMI systems and creation of operator of gathered data is another point. Need for analysis of substantiation of development smart technologies and its direction is considered in the document. Power system operators are also pointed out as responsible for realization of SGT concept by managing demand side and creating new, compatible energy storages.

Environmental impact assessment of document "Polish Energy Policy until 2050" [34] drawn up as another appendix convinces that every action taken towards improvement of power grid efficiency by implementation of smart technologies bring no negative impacts on the environment. Even the strategic judgment of the project marks positive influence, since actions are designed to support renewable energy sources without excessive use of nature goods.

3.2. Smart grid technology projects and programs – an overview

Directives and regulations of European Commission are legal framework that creates a basis for application of technologies. European Union as association of states provides financial and management support for implementation of projects and researches. According to the report [35] there are 950 registered projects within 50 countries that are related to smart grid technology issue, of which 308 are ongoing projects. The figure 3.1. presents map of smart grid projects running from 2009. Every dot is one project, where red dot stand for demonstration stage of innovation and green dot is stage of research & development. Substantial part of performed projects is taken in Central-Western Europe. The highest density is in Germany, Denmark, United Kingdom, France, Netherlands, Belgium, Switzerland, Austria and Italy. Significant gaps can be noticed in Eastern Europe and Balkans, where level of technological development is lower.

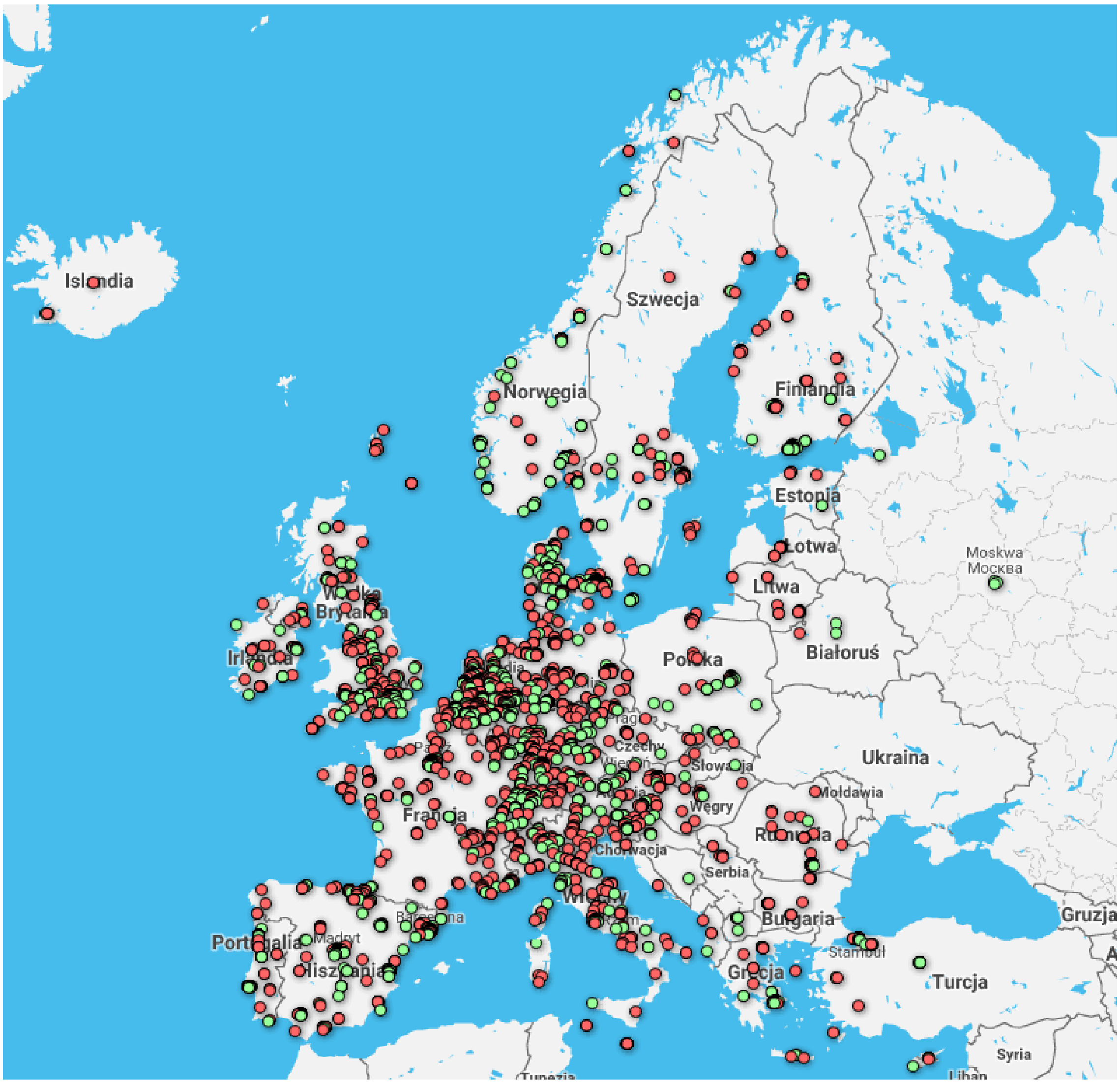

Fig 3.1. Smart grid technology projects map (since 2009) [35]

Establishing a new directive in 2009 concerning common rules for the internal markets in electricity and natural gas and also institutions set up with the directive were the start point for most of projects caused by high increase in not only common interest but also active actions on the smart grid technologies. With the development increases the desire to continue the work with higher involvement. It propels economy and technologic progress. The 3.2. figure presents chart of cumulative data of the budget for smart grid projects in Europe in all countries. Assuming that project budget is allocated in the starting year, the highest growth of total budged starts around year 2009. There is noticeable poor interest until 2007, what can be caused by insufficient information about the issue. The period between 2009-2015 has brought five times of budget increase reaching €5 billion total for smart grid technology development. Worth mentioning is higher focus on demonstration projects than projects of research & development. It can be reasoned by need of working systems and infrastructures that have their own application, since researches, allowing implementation process, are already done.

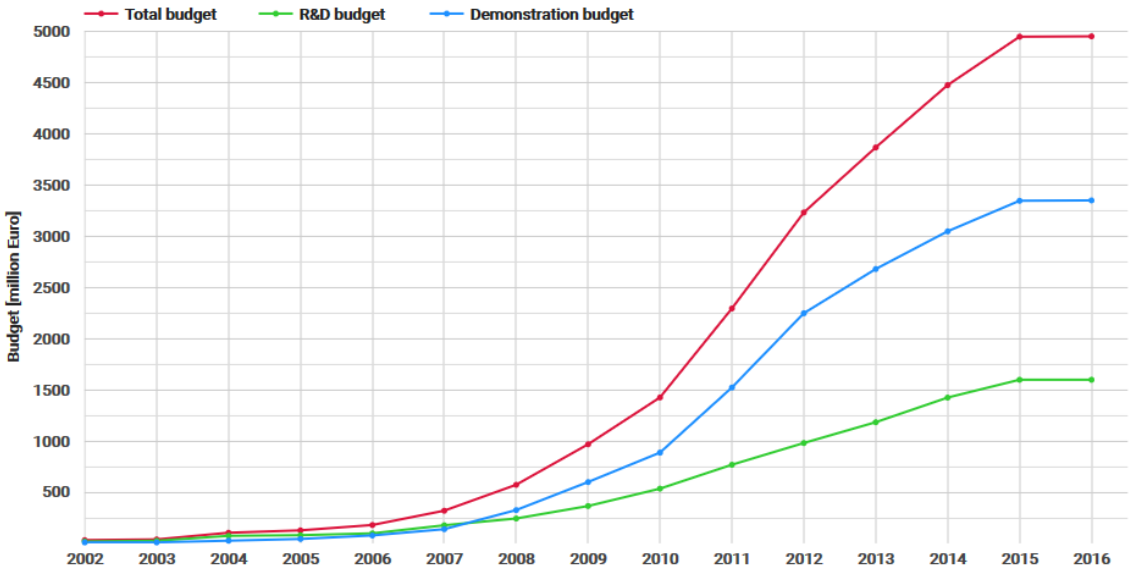

Fig 3.2. Budget of smart grid technology projects in Europe [35]

For further investigation of real progress of SGT implementation policy in EU, overview of few projects is needed. Descriptions of 5 chosen reports will be presented, what will provide transparent look on the topic.

EU-DEEP, which is one of older projects, was running from 2004 to 2009 on territories of the majority of Member States and was coordinated by GDF-SUEZ in France. Project, funded under the European Commission Sixth Framework Programme (FP6), embraces the birth of European Distributed Energy Partnership aimed to help largescale implementation of distributed energy resources (DER). Project was initiated by European energy utilities, due to desire of removal of most barriers (technical and non-technical) that prevent easy and numerous deployments of DERs in Europe. Hence, main goal was design of effective methodology basing on requirements of future energy market and developing innovative solutions for enhanced distributed energy resources deployment. Results of EU-DEEP shows that, dispersion of sources is possible with the support of ICT, thus smart meters and sensors with communication and data treatment provided [36]. Knowledge, produced within the run of the project, embraces ways to shape business platform for effective DER units participation in energy markets.

Moreover, EU-DEEP proposed future frameworks for further development, support and enhancement of DER expansion. These are: future technology standards, the needs for future larger scale experiments and recommendations for future novel regulatory regimes. Meaningful is the part of the work, which was messaged to the every stakeholder directly (policy makers, investors, system operators, energy producers, consumers, regulators and manufacturers) containing key conclusions and recommendations for future demonstration projects and experiments.

Next interesting project refers to interaction between smart houses and smart grid technology to achieve *next-generation energy efficiency and sustainability*, simply called SmartHouse/SmartGrid [37]. Project, funded under seventh framework programme, run in 2008-2011, was field tested in three countries: Germany (coordinator), Netherlands and Greece. Mission of the project was to make a positive influence on energy efficiency, increase a share of renewable sources and diversify Europe's energy mix, through connection smart home systems with broader, intelligent power grid. Thus, work was focused on information and communication technologies to be used for collaborative interaction with customers and energy devices. Vision of SmartHouse/SmartGrid was unique, because of division on particular levels of technologies:

- intelligent customer-interactive in-house technology,
- interface technology, which aggregates smart houses into larger local networks,
- agent-based distributed control of power grid technology, and
- electric market, forecasting and operation optimizing technologies.

Hence, three concept technologies, managing demand and supply, were created within these levels: the PowerMatcher developed in the Netherlands, Bi-Directional Energy Management (BEMI) developed in Germany, and Multi-Agent Intelligent Control (MAGIC) system developed in Greece. Summarizing, these three technologies were various approaches to the coordination of pricing services with energy management in decentralized way. As the project was not only analysis but also active research, after trials and measurements, mass-scale viability of SmartHouse/SmartGrid solutions simulations was done. For example, simulations based on scenarios of 2040 Dutch network, scaled to the number of 3000 households, resulted in positive application of PowerMatcher technology, since it brought significant flexibility of demand and supply, by utilization greater part of energy produced by renewables in the cluster and also reduction of cable losses, due to lowered surplus of energy.

Concluding the results of the research:

- application of extra hardware for smart grid technology energy management turned out as no solution for a large-scale implementation,
- more detailed research should be done onto customer behavior,
- strong need for the definition of standards used in devices manufacturing and
- analysis of technological smart grid technology practices is key to achieve efficient solutions.

GRID4EU is another considerable project, because it's the biggest one realized in Europe so far. It was embracing 27 organizations from 15 countries that were working during 51 months from 2011 to 2016 [38]. With total cost of over €52 million and half funded by FP7, GRID4EU was aimed to *large-scale demonstration of advanced smart grid solutions with wide replication and scalability potential for Europe.* Innovative approaches of: improvement of MV and LV network automation technologies, optimization and integration of DER, balance of intermittent energy sources, assessment of islanding technique and also increase of use of active demand evolving customers' behavior were proposed as actions taken under this project. The reason of GRID4EU high importance is testing developed solutions in real size areas located in Germany, Sweden, Spain, Italy, France and Czech Republic. Demonstrations in these countries included such cases as outage detections, automatic grid recovery, customer engagement, voltage control, demand response, islanding operation, peak demand reduction and others. After experimentation of these cases, demonstrators performed Cost Benefit Analysis (CBA) of solutions and most of the results were assessed as positive and cost efficient. Numerous technical results and conclusions were drawn from an implementation of solutions proposed within realizing project's goals, what provides solid help and basis in further attempts of SGT development. Furthermore, massive information about customers behavior, management of the grid, environmental and social impacts were obtained due to years of research. For example around 80% of the participants in the Customer Engagement Spanish programme have changed their consumption habits. French demonstrator performed assessment of impacts on climate change as well as on human health. Curiosity, wish of participation, indifference and serious concerns were registered analyzing approaches of customers, employees and local population.

Another project concerning a field of a "small power industry" of households and distribution networks is Smart Consumer - Smart Customer - Smart Citizen (S3C) [39]. However this one, more precisely has described behavioral issues of inhabitants and researched on guidance to achieve best effects of smart solutions implementation among developers and public on territory of 7 EU Member States. The project set to run in 2012 and ended in 2015, had an objective to *foster 'smart' energy behaviour of households and SMEs*[1] *in Europe via active user participation.* Main reason of running this project was significant lack of research projects focusing behaviour of end users on the background of smart grid technologies roll-out, in the midst of high intensity of researches on technologies development. With the end of the project, S3C team has set a practical toolkit (containing 50 tools and guidelines) on dedicated website to support further implementation actions by sharing gathered knowledge with recommendations for local authorities, associations of consumers and industries, policy makers as well as curriculum developers. S3C has brought useful conclusions about users' engagement in SGT implementation and has filled the gaps between consumers' approach and policy of undertakings concerning development of smart grid technologies and their roll-out.

Last of discussed projects is still ongoing, since it has started in 2015 and will last until end of 2017. UPGRID [40] is the project, funded under Horizon 2020 programme, that involves solutions of enabling active demand and distributed generation integration for low and medium

[1] SME - Small and Medium-sized Enterprise

voltage distribution grids in Portugal, Poland, Spain and Sweden. Main objectives of the project are not only technical (improvement of operation of LV grid, active demand integration, DER manageability) but also economic like increase of LV infrastructure capabilities, definition of business models and social objectives including creation of conscious consumers behaviour, improvement of services and customer engagement for active participation in energy market. Within the scope of the work, network monitoring services, advanced metering infrastructures, data management systems, Outage Management System and others are tested in real field. Polish demonstration covers advanced monitoring and control of low voltage network using the AMI structure on the area close to the city center of Gdynia with characteristics of approximately 14.700 consumers, 55 secondary MV/LV substations and 107 km of LV overhead and underground lines. As the results of the implementations, it is expected to gain knowledge about requirements and expectations of distributed energy operators for best usage of technical and management solutions. Moreover, real improvements of power grid will get their applications, what improves ability of distributed sources roll-out. UPGRID project, as well as other ones, is great opportunity for local institutions to get familiar with division of responsibilities during implementation processes, since for example Polish demonstration area organizes DSO, university, research institute and IT capital group with separate tasks.

3.3. Directions of smart grid technology development

The topic of improvement of existing power grids with ‘smart’ solutions is relatively new. At least 10 years of consecutive research of the topic has developed numerous different thoughts about technology choice, management, customer and undertaking approach, economy and impacts of SGT implementation. Except that, many attempts of certain technologies application in real life, outside laboratory, have been made. All these actions with the one objective of finding best possible solutions for best efficiency resulting in increase of possibilities, interoperability, information, quality of services, reliability and safety, while minimization of costs and errors of energy network. Analyzing further, the objective has not been achieved yet, since researchers are still working on the topic, searching for better, meeting all requirements solutions.

The vast majority of countries strive for at least one of following targets:

- independence from fossil fuels,
- ability of DER deployment,
- improvement of transmission efficiency,
- reliability of power grid work,
- demand side management,
- diversity on energy market, or
- better quality of customers service.

Hence, the struggle of smart grid technology implementation is prevalent on every continent, with various reasons, but with the same final goal. Europe, as the area embracing many small states, with separate legal systems and policy, need SGT as the way to successful integration between separate power grids, creating one big smart network. Further motivation for the Old

Continent is included in EU policy and concerns saving the environment and maintaining energy market competitive. USA, covering half of Northern America, bothers with relatively frequent blackouts problems over last years [41]. Brazil, with biggest energy market in Southern America, manages with long distances of connection lines with high transmission and distribution loses and furthermore is threatened by eventual droughts scenarios, affecting power supply. India, has similar problem of high losses on power lines, and bothers with demand peaks and energy shortages, not excluding high dependence on fossil fuel and partial lacks of electricity access. Every of these difficulties can be eliminated, or at least decreased, by smart grid technology solutions. But the question is how to perform and manage the roll-out. Following, where today's solutions are heading, so the technology would bring long-term profit.
Taking into account criteria of benefiting from 'cost avoidance' caused by modernizing the power grid, some scenarios has been considered in the research made for Oman area [42]. Proposed scenarios were presented as follows:

- Minimum Smart – introduction of basic technologies: Energy Management System, DSM Tariff System, smart meters (automatic meter reading and monitoring),
- Recommended DSM – based on study done for Kuwait [43], economical application of small practices not requiring big investments from the utility or customers, such like change of thermostat settings, application of high efficiency lighting, use of improved air conditioning systems
- Distributed Generation – proper preparation of the grid, then after 5 years deployment and integration of distributed sources (assessment with photovoltaic panels),
- Hybrid – connection of Recommended DSM and Distributed Generation scenarios, most advanced and costly case.

The analysis resulted in straight answer, that Recommended DSM is most profitable solution for the case, having best benefit-cost ratio. However, this suggestion consists of improvement of consumers' appliances, what actually can bring big savings and reduce demand peak on the large scale, but it doesn't deliver SGT features, such as use of smart metering, advanced ICT, reliability of supply and power quality, integration and others essential characteristics that are expected. Minimum Smart Scenario, resulted in second best profitability, showing that investment in AMI systems, with focus on smart meters and tariffs management, is beneficial from both: economic and technological side. More advanced scenarios of Distributed Generation and Hybrid solution occurred less profitable, since they require much more investment capital and slowly bring profit. Concluding this research, results showed, that the smart grid technology implementation (in analyzed Oman case) should be initiated with small investments in metering systems and DSM technologies.

Coming back to European approach, interesting plan has been introduced in 2013 for Slovenian distribution networks [44], presenting proposal for SGT concepts deployment with the focus of financial aspects. Necessity of the implementation reasoned by aging infrastructure, growing demand peak, requirement of better quality of power and need for DER. First step of the plan was identification what features of smart grid technology (advanced metering, DSM, operation of distributed generation, power quality management, storage, electric vehicle infrastructure) have impact on particular fields: technology, sociology, economics and regulation. These features, taken as ‘project clusters’ was further analyzed and their cost and benefits were assessed, showing that advanced measurement of household customers brings highest financial profit by lowering significantly costs of meter reading and commercial losses. One of conclusions of the Slovenian implementation plan survey is that despite high investments needed for implementation of SGT at the beginning, further maintenance costs of the modernized network are lower than yearly investments in existing grid. That means that the plan not only provides higher power supply stability, better quality of service on other features but also is economically profitable in long-term analysis. Discussed research presents that dividing smart grid technology implementation on clusters and treat them as separately investments is right thing to do considering costs and benefits assessment clarity as a criteria.

Preparing for the process of smart appliances deployment, which should be gradual basing on discussed studies, one should follow some path, clear plan. EU Member States can treat European Commission’s directives and other documents as a kind of guideposts, while other countries can use of Technology Roadmap for smart grid technology development constructed by International Energy Agency (IEA). However, every project of implementation of smart grid technology should be preceded by plan creation. Hassan Farhangi, the director of the Smart Microgrid Applied Research Team at British Columbia Institute of Technology and adjunct professor at Simon Fraser University, points out the importance of making maps for development of system in two publications [45], [1]. Proper division on the fields and matching them with specific approach, supporting technologies, costs and their impacts can be very supportive in planning grid modernization. In the article [45] the concept is explained as layers of fully integrated system, where SGT functions are crossing through layers of utility structure. The approach of splitting smart grid technology on parts that are providing different characteristics brings clear view on the project topology. This way, priorities are easier to be found and roll-out process can be more effective, since it lets to stay more focused on next particular tasks.

Discussion about potential strategies of SGT implementation is not intricate, since majority of researchers come to similar conclusions. Transforming traditional power network into a smart one is hard to be performed in one rapid process, that modernizes whole infrastructure at once. The process should be gradual, allowing for spread of investments and assimilation of all energy market users with changes. The research [1] presented a way of smart grid technology evolution that was considered at the beginning of introduction of these technologies and aspects. At first, electromechanical meters should have been deployed, then Automated Meter Reading (AMR), next transitioning to Advanced Metering Infrastructure (AMI), and at last complete interconnection of systems creating SGT. However, change from AMR to AMI occurred not fluent, because of need of complete abandonment of working reading system and installment of new AMI system, for transforming one-way communication infrastructure to both-way one. Figure 3.3 presents discussed case of potential evolution with omitting step of AMR system application.

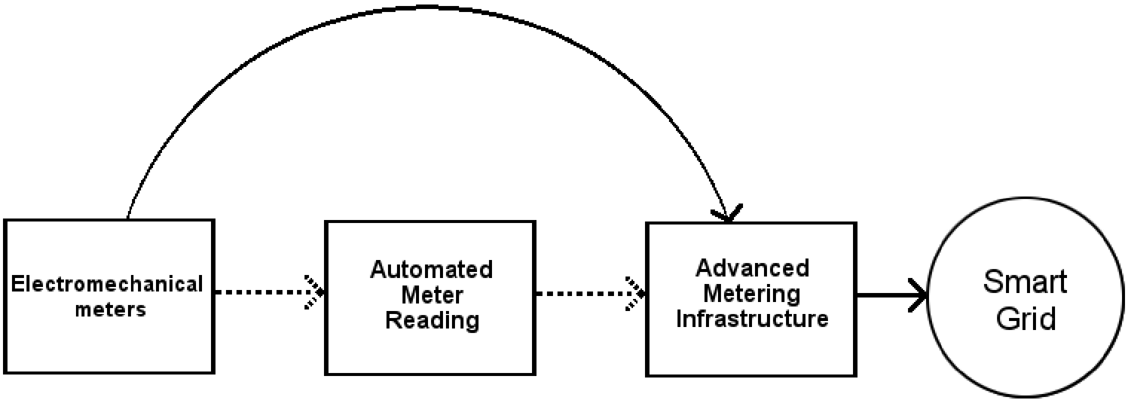

Fig 3.3. Simplified block diagram of metering technologies evolution into a smart grid

In addition to strategy of evolution and deployment of particular technologies in fine order, defining of more general look over the topic can be useful. Two main possibilities are discussed nowadays, from which first is deployment of one big “smart” network at once and second consider conception of microgrids and their further integration. First solution seems better for interoperability, because of unity of used technologies and standards, but it’s roll-out is complicated in management and simultaneous cooperation between all system operators, energy producers and authorities is difficult. On the other side, second strategy of implementing small grids and afterwards connecting them is looking more possible to accomplish. The key is establishment of unique standards, which would be used in every technology deployment, so the further integration of systems would not be hindered. Separate steering groups can be set for every implementation plan, making their management more direct and transparent. European Union in its policy has a tendency of second solution usage, where Member States’ grids are treated as micrograds and future plan consists of their integration to create one big cooperative European system.

Together with the grid modernization by deployment of sensors, meters, communication connections, restructuring of existing power lines can be needed. The problem concerns distribution grid – medium and low voltage, because transition to SGT affect it the most. Distributed energy resources, smart metering devices, energy storages and even electric vehicles charging stations may be requiring upgraded power connections. Moreover, new connections ensure higher density of the grid. This kind of links redundancy positively influences on safety of energy supply. The survey [46] investigated different strategies of evolving distribution grid and subsequently their features have been compared. Through solutions of assortative, disassortative, in triangle, by least distance and random connection of nodes few has been chosen as best ones, taking into account optimality between number of relations in the grid and provided stability of connection. It occurred, that randomly added connections between nodes in power grid provides best results for robustness of connection. Secondly, assortative solution, which consists of connecting nodes of the same degree starting with the highest degree, scored also very good. Comparing two of them, proposing random method of modernizing the grid to utility providers sounds not serious, whilst assortative approach is well-organized one.

For better view on the implementation process, defining the stage of advancement can be helpful in order to inform outside stakeholders about progress. Standardized assessment should be based on reports of particular features and technologies. As the exemplary solution definition of Characteristic Evidence Indicators (CEIs) is proposed for rating maturity of smart grid technology model [46]. First right key features should be identified as CEIs, that would be controlled systematically. As the article mentions, objective evidence of implementing outage management system can be functional description of restoration after the outage. Power quality monitoring can be evaluated by number of provided measurement points and its accuracy. These SGT functionalities should be assessed in the same way, so the comparison between different systems could be possible.

Some general proceedings at design stage and implementation afterwards should be applied, to keep best efficiency of the process and ensure proper work of developed technologies.

At first, every action related to implementation of smart technologies should be designed with long-term prediction. Today is the time, when most of countries are modernizing existing power grids and probably there will come another such moment in the future. Constructing new power grids, based on SGT, developers should take care of maintaining ability of further advancement of the grid, without complete makeover. Prospect of continuous development is one of the crucial features.

During the process of evolution of the power network, stakeholders (distribution and transmission system operators, utility providers, consumers, authorities) should cooperate with each other. Every has its own point of view, opinions, preferences for particular functions, although smart grid technology concerns all. It is important to take all statements into account in order to create universal and favorable system.

As far as possible, in European Union (according to EU policy), development of national grids should be consulted with neighboring countries. One of the far reaching objectives of SGT deployment is ability of effective, free electric energy exchange between state boundaries. Performed projects under policy frameworks of EU satisfyingly fulfill their tasks in this aspect, by integrating institutions from different Member States.

4. NON-TECHNICAL ASPECTS OF SMART GRID TECHNOLOGY

4.1. Different perspectives of smart grid technology development

Smart grid technology development brings not only transformations to technical structures of power systems, but first and foremost significant changes to their operation and control.

As a result, smart grid technology development concerns equally: energy companies and energy end-users. However both parties emphasize different features of SGT. Benefits for one party can be perceived as drawbacks by the other. The following chapters aims at showing advantages and disadvantages of smart grid technology for energy utilities and their customers as well as understanding differences in the perception of SGT.

Energy companies, as any other entrepreneurships, have income oriented perspective. They wouldn't strive for SGT development, if the technology doesn't bring benefits to them. The values foreseen by the companies include, but are not limited to the following potential profits:

1. improvement of power grid reliability, by means of monitoring, emergency and management systems,
2. enhancement of energy end-use planning, with support of advanced metering infrastructure and communication connections,
3. acceleration of energy-use billing, through efficient transfer of data provided by smart meters and data transmission technologies with dynamic and automatic post-processing of information,
4. decrease of O&M costs, by improvement of power network efficiency and better deployment of distributed energy resources,
5. extension of grid's lifespan, due to keeping power load more balanced,
6. creation of new energy services, due to new technological and organizational capabilities.

The process of smart grid technology implementation cannot omit end-user's point of view, since energy supply is one of the most important factor for a citizen today. Investigating an attitude of energy end-users to smart grid technology indicates that their approach is influenced mostly by concerns about potential risks associated with SGT implementation.

Perspective of energy end-users to smart grid technology development include, but is not limited to the following aspects:

1. threats to health and wellbeing, due to expected extension of electromagnetic waves to be produced by new devices,
2. difficulty to understand the devices because of their advancement,
3. uneven position to negotiating energy-use contract rules, due to unequal access to energy-use data,
4. exposure to cybersecurity threats,
5. exposure to loss of privacy.

The above mentioned features do not exhaust differences in the perception of smart grid technology by the two involved parties.

4.2. *Why energy companies can be interested in SGT?*

Energy companies, like undertakings from every other industry, are associations that provide goods and services to their customers – they supply energy to the end-users who consume it. Their existence and functioning are conditioned by the demand of electricity. With continuous technological progress, demand for energy is rising, but so do requirements of the end-users. Hence, functioning of energy companies is also dependent on energy users' satisfaction. Undertakings, managing to implement smart grid technology, should carefully consider benefits for their clients, so the investment would occur profitable.

SGT is meant to be improvement of existing power grids due to new solutions, devices and connections between them. That's why reliability is a feature to be improved due to SGT roll-out. Maintenance of continuous information flow makes connections more visible for system operators and provides better, autonomous control of devices. This feature significantly enhances ability of regeneration after power outages and damages on the grid [47].

Greater density of connections, including power lines and communication links, influences constancy of supply. During the case of emergency, when power outage has already happened, monitoring systems can automatically send a signal towards distribution stations to take actions to avoid further failures. For instance, phasor measurement units located on the grid, provides precise information about electricity signal. Gathered and analyzed PMU data can be valuable for system's health and quality of generated power.

Concluding, from the end-users' point of view, smart grid technology ensures more stable energy supply, by more efficient dealing with damages and failures. As mentioned in previous chapter, it can be great solution for consumers from USA, Brazil or India, since their systems are bothering with frequent, short outages due to their power grid structure [41].

One of objectives of advanced metering infrastructure (AMI) and communication development is ability of demand side management (DSM) method usage. DSM is a method of changing consumers' energy demand. It involves engaging to use appliances that consume a lot of electricity in other time of a day (or time of a week) through changes of energy pricings [48]. With the goal of peak-shaving a load during the day, costs of energy can be lower during load valleys, and higher when load is too high. Solution affects end-user's consciousness of energy consumption and encourage for better use of energy resource.

Deployment of smart meters enables receiving signals from utility provider about pricings. End-users can respond to them with proper actions – limiting or reallocation in time some energy-consuming activities. As the survey [49] presented, user's actions enclose mostly in flexible activities like run of a dishwasher, vacuuming or washing machine. Activities of cooking, using electric water heaters or every leisure time activity are hard to be moved in time. However, DSM has higher potential with future technologies including electric vehicles or electric heating. Their high consumption of electricity means high possibilities of reducing power load at the time.

Connection of smart meter with Home Area Network (HAN) can bring new experiences within the technology, supporting a creation of smart home. Automatic control of electrical home appliances power supply can be possible due to signals from operators about pricing and their processing through smart meter and then through ‘smart plugs’ to home devices [50].

Another point of smart grid technology, that affects end-users is way of getting energy-use billings. The process of settlement of energy consumption can be faster and more friendly. Automatic transfer of data to energy company and meter data management system, the settlement process can be non-invasive, hence more efficient.

Moreover, energy end-users will have provided access to information about their energy consumption (or generation in cases of being a prosumer), statistics or even predicted consumption. Such features can be realized by computer or mobile applications run by energy company. Due to faster preparation of energy billings, as well as better developed metering technology, chances of energy theft will be lowered. Anomalies in operation of metering device can be diagnosed through safety monitoring systems working with a meter. Comparison of bills between different meters, or previous settlement done automatically is also proposed method of tracking potential energy thefts [52].

Despite the fact, that smart grid technology implementation requires deployment of brand-new hardware and software, maintenance cost of properly working SGT can be lower comparing to traditional power grid, due to its autonomous character. Mentioned before, Slovenian implementation plan survey, proved that in long-term analysis SGT can be economically profitable [44], what can be seen in figure 4.1.

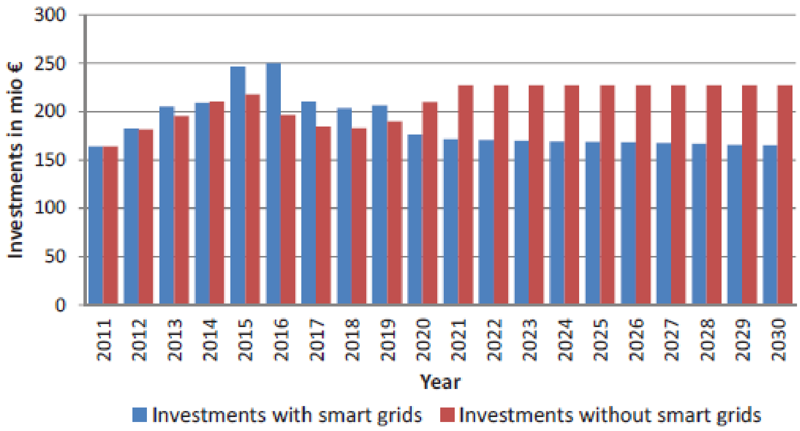

Fig 4.1. Investments of Slovenian power distribution grids with and without smart grid technology [44]

Accordingly, costs of electricity should decrease with a time lapse after deployment of smart grid technology. This affects availability of electric energy for people, that could not afford it before, or who used to limit their consumption due to high prices. In addition, DSM method have potential of further savings, by planning on consuming electricity during off-peak time, when pricing will be lower.

By several reasons, smart grid technology will extend the power grid’s lifespan. Discussed reduction of load during short periods of time during day, called peak-shaving is most economical method of keeping load on restrained, reasonable level. Maintenance of stable load of the network, does not strain power lines, generators or transformers. Deployment of distributed energy resources (DER), that is favored by European Union policy, changes whole structure of power generation in the system. DER conception is meant to be realized in the area of distribution network (MV/LV) and consists of small sources of energy like renewables or micro heat and power generators.

Coordination of distributed energy resources, through use of SGT features and proper algorithms can decrease a percentage of distribution network power losses [51]. Furthermore, displacement of energy generation from distant power plants, towards bunch of small sources that are located nearby clusters of receivers can significantly lower losses related to energy transmission. Summarizing, this solution can contribute to elongation of grid's life.

Rarer events on a grid or needed modernization, caused by poor state of network equipment, also can mean lower costs of maintenance and energy prices. But, despite economic aspects, it is another point for stability of energy supply. Functional status of the grid will last longer, because of less frequent repairs. And at last but most important, extending lifespan by smart grid technology, affects users' feeling about it. Raising sense of reliability and safety of presented solutions is strong impact on trust. Energy-end users, as a people signing a contract with undertaking, demand receiving best possible services and safety of their supply. Reasons to trust increase acceptance of users on new, not entirely known, technology [52].

Development of smart grid technology is complex process, because of its arrangement in time, covering long periods. Moreover, diversity of considered technologies of measurement, transmission and data processing makes SGT development a project requiring lot of work. It means, that new workplaces have to be organized for activities of:

- researching new technologies,
- their deployment in life,
- developing new control systems,
- operating these systems and
- servicing implemented devices.

Besides predicted reduction in jobs related to manual read of energy consumption, overall employment can rise, concluding all employees needed for development and operation of smart grid technology [53].

4.3. Why energy end-users can be afraid of SGT?

End-users, as the opposite to the energy companies, are meant to receive smart grid technology and not take part in its development. As a customer of every other services, energy users require good quality of supplied goods, that is electricity and related services. However, implementation of new technologies and devices, especially ones expected to be installed at end-user's house, can cause concerns. Issues of origin and importance of users' fears should be investigated among the development of technologies, because of their influence on the level of acceptance on SGT deployment.

Consumers can be concerned about influence of smart grid technologies on their health and other home appliances. Nowadays with a large number of electric devices, people gives more attention to their possible impacts on other areas of life. It's no other in the issue of development of power system, since it includes great amount of modernizations of old and introductions of new technologies.

People's fears can be based on high density of communication network or even potential negative influences of metering devices. Electromagnetic waves coming from smart meters can be suspected as a source of discomfort and illness. Depending on transmission technology of measuring devices, these can emit signals with different frequencies in a range of radio frequencies and microwaves spectrum. Despite lack of studies performed on health risks of smart meters, different researches have been done to the effects of exposure to electromagnetic field, which have shown potential to be considered as harmful [54]. Feelings associated with negative influence of these devices are justified. Symptoms like headaches, dizziness, weakness, sleep disturbance or memory impairment are known from other technologies basing on high density of signals transmission [55].

Implementation of smart grid technology requires more contribution of energy end-users in power system. Interaction between them and utility providers is more noticeable, due to more communication-structured system topology. AMI system cause, that more information between operators and users is exchanged, whether they want it or not. However, when SGT is understood by engineers and researchers that are responsible for its development and construction, end-users may struggle with understanding its essence and provided features.

Smart meters, may introduce functions, that are not known by consumers. Instructions provided by energy companies may be unclear and confusing. In addition, whole conception of implementation new power grid technology may be not explained enough for people to understand. Risk, associated with difficulties of understanding technology and its good interpretation, should not be neglected, because it is believed to be one of the most important factors on end-users acceptance of SGT [56]. Educating people about smart grid technology lets them to assimilate with unfamiliar devices, what makes them feel more secure. It is expected, that forcing the adoption of devices and systems, without explanations can intensify the sense of fear. Informing people about smart grid technology seems to be necessary, if implementation is meant to be successful.

In traditional power grid, energy companies are responsible for energy distribution to end-users, settlements of energy consumption and customer services, like tariffs changes or complaints cases. Smart grid technology introduces solutions that require much more interest of utility providers. Besides responsibilities relating to security of transmitted data and operational safety of new technologies, energy companies have to partially care for load control, using demand side management (DSM) methods. As mentioned in previous subchapter, DSM is method of controlling consumers' energy demand by engaging them to consume energy at specific time. Although, discussed benefits are not the only impacts that can be seen with use of DSM.

Despite the fact of relating to energy consumption, DSM is directly affecting behaviour of end-users. Changing prices of energy on specific time of a day forces user to take a decision.

One could want to engage in energy saving and consume energy at other time with lower price. Another would prefer to stand aside of response and be charged with higher cost of energy consumption.

From the energy end-user's point of view, undertaking that is using DSM wishes to change lifestyle of their clients, by engaging them to use appliances that consume a lot of electricity in other time. Hence, the issue concerns more than power supply, that is lifestyle and habits.

Interesting can be fact of compliance of these actions with the regulations of the state level and with contracts that are signed between end-user and energy company. A research done for Kuwait [57] has concluded that lack of policy on DSM can be considered as a threat for grid users and energy companies. Possibility of violating rights of energy end-users may not convince them to approval of demand side management among smart grid technology. Furthermore, needed changes in contracts may cause objections and encounter denials.

Introduction of new technologies to the energy system may make it more exposed to dangers, especially cyber-threats, due to high density information and communication technologies. It is assumed that ICT may can provide an easy access to other functionalities. Breaking into a connection can result in loss of data, blockage of access to other services, energy, falsification of transmitted data and theft of software data [58]. The number one priority, during the development process, should be security of connection.

Cyber-attacks are believed to be one of the most dangerous events, because they can be performed from any place on the world which is connected to the particular network, mostly through the Internet. In addition, one cyber-attack can be performed simultaneously from several places, or even it can concern several objectives at once [59].

Despite all safety and security systems that are responsible for defending information and communication systems, some gaps may be found. Security gaps are the ways of potential attacks coming from hackers. The crucial issue with security systems is that because of their complexity, security gaps are not usually known until a moment of intrusion. This means that discovery of a threat can occur after the fact and after a receive of damage to the system.

Investigating character of potential cyber-attacks, in most cases they may affect energy end-users, intentionally or unintentionally. Attacks can have different origin and various objectives. Attack performed by particular group, intending to shut down the power supply of some enormous area, causes long and extensive lack of electricity. But more than this, it may arouse public panic due to suspicions even about e.g. war outbreak. From the other side, more petty case of fired worker wanting a revenge and unrevealing some crucial information about database of the energy company is also a big threat of upcoming attacks. Concluding all cases, risk associated with exposing power network to cyber-threats by deployment of smart grid technology affects security of power supply and reliability aspects of SGT.

Investigating data transmission technologies, energy end-users can also feel suspicious about reliability of connection between their home appliances and the database. End-users would like to hear that their data is transmitted directly to the provider's database without any interruptions. Devices like data concentrators can raise objections towards implementation of advanced metering infrastructures. Probably their activity isn't known for daily electricity users, if at all people came across the term of data concentrator. Also service of cloud computing of gathered data, discussed in previous chapter, can raise doubts about credibility of this technology, because of its external character. All these fears are caused by exposing to loss of privacy by smart grid technology.

According to [60], smart meters has 4 purposes, that are 3 intended: billing, value-added services and operations, and 1 unintended which is invading a consumer's privacy. It is definitely true statement, as it was mentioned before that information about user's consumption bring a lot more than energy consumption. Behaviour and habits of energy end-users can be read through analysis of the data. Particularly 'dangerous' can be reading of real-time data flow. Information about the current consumption in a household clearly can be transformed to knowledge about number of people in the house and their activities.

To outline the problem more precisely and present the threat of the issue, proper research has been performed. Experts in Germany showed that, with the access to the data transmitted from smart meter with a sample rate of 0,5 s^{-1}, it is possible to reveal what TV channel is displayed at the moment in the household [61]. Also high-resolution information about consumption data can carry and information about house equipment type e.g. refrigerator, oven, TV set, toaster. These arguments prove that smart meter and information flow are serious threat for end-user's privacy. Users have rights to be seriously concerned about the technology, that is intended to be deployed among European Union, as well as in other countries.

4.4. Why energy companies tend to neglect risks that energy end-users do perceive?

Smart grid technology can be received in many different ways, depending from the point of view. Attitude of consumers definitely varies from the one of energy providers. This means that smart grid relate to multiple fields of life and there is no universal estimation method of the features and its impacts. Every of these sides has own thoughts about new technologies, and see benefits and drawbacks only for themselves.

Risks, created with smart grid development, are assumed to be specific values, describing level of the threat of particular functionalities. However from unscientific point of view, assessment of the risk is not based on any analysis but mostly on feelings about concepts. People, not introduced in smart grid technology topic, aren't usually familiar with an objective approach to the subject. Their statements depend on suppositions and speculations. Very often opinion of the one affects another's opinion, creating sometimes chains of false information, what spreads misleading perception.

As survey [62] presents, there is a considerable relation between end-users' perception and their knowledge of electric energy. Unawareness of energy end-users may also contribute to creation of concerns about risks, that even were not considered by any engineer or researcher working on particular technology. Good example is potential impact of electric meters on health, mentioned in one of the previous subchapters. People unfamiliar with basic knowledge about some technologies may come up with various hypothesis, that from the other point of view can be even called ridiculous. It is known phenomenon, that people tend to fell suspicious and scared of new technologies, which affect them directly. It is no different in the case of SGT, that is meant to be a part of energy consumers' closest surroundings.

Expanding the topic of approach of "normal people", that are not part of energy industry and don't have any deep knowledge about technology, their statements not only differs from attitude of the industry, but they can vary from each other. Point of view on the smart grid technology can be other whether person is considered as a consumer, citizen or member of society. Presented division, that has been proposed in [52], where issue of influence on technology acceptance was analyzed, embraces 3 particular attitudes.

1. Customer's point of view, is based on personal benefits and threats, mostly related to the money savings on the one side, and privacy concerns on the other.
2. Attitude of citizen, usually cares about integration and benefits for local gatherings of people, but also can oppose for changes in surroundings. Citizen, identifies as a member of the group with specific obligations towards the group.
3. The attitude of a member of big society can be considered as a matter of *sociopolitical* acceptance or refusal [52]. It concerns changes in policy, for example establishing new rights that responses on national or even international events.

Energy companies as establishments consisting mostly of employees with technical education see smart grid technology differently. Efficiency and reliability improvement, management of demand, lowered costs of maintenance are some points that are considered as benefits for undertakings. Risks of the technology perceived by experts, are assessed through specific algorithms and mathematical models. End-users rate the technology by comparing benefits (most influential are financial profits) to risks that come with the new technology [63].

Moreover, energy companies are the ones in control of the development of smart grid technology and are aware of every issue, while users have negligible impact on the SGT features. This can cause differences in technology perception, since being in charge of something give sense of security.

All risks, that cause social threat are dependent values. From the power system's point of view, threats that are crucial for end-users can be negligible for system operators at the same time. For example, intrusion into the smart meter with the objective of private information theft does not affect work of the grid. This event can be ignored in operation centers, that have goals of maintaining the grid's state in best condition and coordinate its performance. However, energy end-users don't seem to worry about health of specific power line, as far as power supply is continuous and energy prices stay the same.

With various perceptions of the smart grid technology of energy end-users, energy companies may struggle with understanding needs and especially fears of users. Experts rate risk and assign its real level, hence they aren't able to perceive risk without comparing to other risks, basing on facts – rational evaluation [64]. Once more, energy end-users, without a knowledge, estimate risks by emotions. However, these approaches should not be divided on one correct and second wrong, because there is no solution of changing one of them.

The issue of smart grid technology end-users' perception should be given more attention. There is significant lack of social research among papers in scientific databases. Investigating socio-economic features of smart grid focuses mainly on costs, slightly less on cyber security and regulation, least on privacy while last on consumers' perception [65]. It creates a problem, because end-users have important role in the energy market and with SGT roll-out their value grows.

5. SUMMARY

Smart grid technology is meant to create set of technologies used to form more developed power grid. Main objectives of an implementation plan of the technology are related to increase of grid efficiency, expansion of the grid state preview, better reliability of electricity supply and growth of knowledge of network state. Metering, monitoring, communication, management systems can be distinguished as a part of SGT.

Technologies, which are expected to be used as the basis of the smart grid technology, have been presented within the thesis. Method of data measurement depends on placement in the power network. Smart meters are responsible for consumption/production of end-user, while phasor measurement units measure parameters on the power lines and characteristic points. Devices serve also for sending and receiving signals to and from energy undertakings and system operators.

Process of data transmission can be accomplished by several of different solutions. Wireless technologies have a big potential of use, since their deployment does not require additional infrastructure. Wired communication through optical fibers may be considered for good perspective for future SGT modernization. PLC technology usage, despite existing infrastructure, requires a lot of effort, due to disturbances and signal loss issues. Achievement of best efficiency of data transmission depend on choice of technology and appropriate formatting of data presented in second chapter.

All measurements sent towards operation center have to properly processed and stored. Filtering is first stage of data processing and involves cutting off unnecessary records, on the way of analyzing their importance. Before final storage of data, they should be grouped in order to provide best transparency of information. Post-processing, analyzing of stored data can be used in load forecasting, what has been discussed. Cloud computing as external service can also find an use in data processing in SGT.

Smart grid technology is relatively new issue, hence regulations of its development have been established recently, or are in the process of forming. Legal framework in European Union and Poland separately, has been overviewed. European directives informing about strive for better energy efficiency or need for more renewable sources points SGT as supporting utility. Energy policies, action plans of both - EU and Poland, declare implementation of smart grid technology solutions in following years.

Projects and programs performed in the European Union are representing active actions relating to SGT implementation plans. With financial support, they cover over 300 ongoing researches and implementation attempts of the technology. For better understanding 5 projects have been described in the thesis, explaining their goals and results.

Analyzing different approaches to implementation of smart grid technology, attempt of forming universal path of development has been described. Despite specified features of SGT, various motivations for its deployment can be seen all over the world. Success of SGT implementation depends on following clear plan and communication between participating parties. Standardization of solutions is believed to be the key for cooperation between different power systems.

In last chapter, analysis of non-technical aspects of smart grid technology has been done. SGT relates to energy companies and energy end-users equally. Different perspectives have been pointed out, showing advantages and disadvantages of smart grid technology for both parties.

Energy companies have income oriented perspective, since they wouldn't participate in SGT development if it doesn't bring benefits. Improvement of power grid reliability, decrease of O&M costs, creation of new energy services are some profits that are foreseen by entrepreneurships. However, these affects energy end-users as well, what have been presented along description of energy companies' interests.

Energy end-users' point of view has been also deeply discussed, since energy supply is important factor for a today citizen. Smart grid technology can be perceived as a source of various threats. Risks related to SGT influence on users have been presented in the document. People are afraid of the new technology and point cybersecurity threats, possible loss of privacy, negative health impacts and other, as reasons of concerns.

At the end, differences between perceptions of smart grid technology have been explained. Risks assessed by experts in energy companies aren't understood in the same way by energy end-users. Engineers use algorithms and mathematical models for risk assessment, while users follow feelings. Level of people's awareness of electric energy has impact on their perception of power system. There has been distinguished a need for social research around the SGT topic, since it is ignored in most of studies.

BIBLIOGRAPHY

[1] H. Farhangi, “The path of the smart grid,” *IEEE Power Energy Mag.*, vol. 8, no. 1, pp. 18–28, 2010.

[2] European Union, “Directive of 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,” *Off. J. Eur. Union*, vol. L211, no. August, p. L 211/55-L 211/93, 2009.

[3] Y. Kabalci, “A survey on smart metering and smart grid communication,” *Renew. Sustain. Energy Rev.*, vol. 57, pp. 302–318, 2016.

[4] S. Nimbargi, S. Mhaisne, S. Nangare, and M. Sinha, “Review on AMI technology for Smart Meter,” *2016 IEEE Int. Conf. Adv. Electron. Commun. Comput. Technol. ICAECCT 2016*, pp. 21–27, 2017.

[5] K. Sharma and L. Mohan Saini, “Performance analysis of smart metering for smart grid: An overview,” *Renew. Sustain. Energy Rev.*, vol. 49, pp. 720–735, 2015.

[6] “Maxim Integrated’s Complete Smart-Meter System-on-a-Chip Combines Metrology, Security, and Communication,” 2012. [Online]. Available: https://www.maximintegrated.com/en/aboutus/newsroom/2012/enproducts1680.html. [Accessed: 14-Oct-2017].

[7] S. M. A. Bhuiyan, J. F. Khan, and G. V Murphy, “Big Data Analysis of the Electric Power PMU Data from Smart Grid,” pp. 3–7, 2017.

[8] N. H. Abbasy and H. M. Ismail, “A unified approach for the optimal PMU location for power system state estimation,” *IEEE Trans. Power Syst.*, vol. 24, no. 2, pp. 806–813, 2009.

[9] S. T. August, “Data concentrators and the Smart Grid,” pp. 1–6, 2015.

[10] B. Karimi, V. Namboodiri, and M. Jadliwala, “On the scalable collection of metering data in smart grids through message concatenation,” *2013 IEEE Int. Conf. Smart Grid Commun. SmartGridComm 2013*, pp. 318–323, 2013.

[11] R. Q. Hu, J. Zhou, R. Q. Hu, and S. Member, “Scalable Distributed Communication Architectures to Support Advanced Metering Infrastructure in Smart Grid Scalable Distributed Communication Architectures to Support Advanced Metering Infrastructure in Smart Grid,” vol. 23, no. 9, pp. 1632–1642, 2012.

[12] X. Fang, S. Misra, G. Xue, and D. Yang, “Smart Grid — The New and Improved Power Grid: A Survey,” *IEEE Commun. Surv. Tutorials*, vol. 14, no. 4, pp. 944–980, 2012.

[13] A. Ghassemi, S. Bavarian, and L. Lampe, “Cognitive Radio for Smart Grid Communications,” *2010 First IEEE Int. Conf. Smart Grid Commun.*, no. November 2010, pp. 297–302, 2010.

[14] IEEE, *C37.118.1-2011 - IEEE Standard for Synchrophasor Measurements for Power Systems*, vol. 2011, no. December. 2011.

[15] M. Ringwelski, C. Renner, A. Reinhardt, A. Weigel, and V. Turau, “The Hitchhiker’s guide to choosing the compression algorithm for your smart meter data,” *2012 IEEE Int. Energy Conf. Exhib. ENERGYCON 2012*, pp. 935–940, 2012.

[16] H. Lyu, P. Li, Y. Xiao, H. Qian, B. Sheng, and R. Shen, “Mass Data Storage Platform for Smart Grid,” 2016.

[17] H. Yang, P. Li, A. Masood, Y. Xiao, B. Sheng, and Q. Yu, “Smart Grid Data Analysis and Prediction Modeling,” no. 1, pp. 6–9, 2016.

[18] CEN-CENELEC-ETSI Smart Grid Coordination Group, “Smart Grid Set of Standards Version 3.1,” p. 259, 2014.

[19] U.S. Congress, “Energy independence and security act of 2007,” *Public Law*, pp. 1–311, 2007.

[20] EU Commission, “European Task Force for the implementation of Smart Grids into the

European Internal Market. Mission and Work Programme," no. June 2011, pp. 1–15, 2012.

[21] International Energy Agency, "Technology Roadmap - Smart Grids," *Current*, p. 52, 2011.

[22] European Commission, "A joint contribution of DG ENER and DG INFSO towards the DIgital Agenda, Action 73: Set of common functional requirements of the SMART METER," no. October, p. 82, 2011.

[23] Commission of the European Communities, "A European strategic energy technology plan (SET-PLAN)," no. 2006, p. 14, 2007.

[24] European Commission, "Towards an Integrated Strategic Energy Technology (SET) Plan: Accelerating the European Energy System Transformation," *Igarss 2014*, no. 1, pp. 1–5, 2015.

[25] European Commission, "Energy 2020. A strategy for competitive, sustainable and secure energy," *Https://Ec.Europa.Eu/Energy/En/Topics/Energy-Strategy/2020-Energy-Strategy*, p. 21, 2010.

[26] European Commission, "A policy framework for climate and energy in the period from 2020 to 2030," *Https://Ec.Europa.Eu/Energy/En/Topics/Energy-Strategy/2030-Energy-Strategy*, p. Brussels, 2014.

[27] European Commission, "European Commission: Energy Roadmap 2050.," no. July, 2015.

[28] European Commission, "Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on common rules for the internal market in electricity," vol. 380, no. 2016, 2017.

[29] Polish Ministry of Economy, "Energy Policy of Poland until 2030," *Energy Policy*, no. Appendix to Resolution no. 202/2009 of the Council of Ministers of 10 November 2009, pp. 1–27, 2009.

[30] Polish Ministry of Economy, "ACTION PLAN FOR THE YEARS 2009 – 2012," no. November 2009, 2012.

[31] Ministry of Economy. Energy Department, "Annex no. 1 to Polish Energy Policy until 2050. Assessment of implementation of Polish Energy Policy until 2030." pp. 1–54, 2015.

[32] Polish Ministry of Economy, "Energy Policy of Poland until 2050." Warsaw, 2015.

[33] Polish Ministry of Economy, "Annex no. 3 to Energy Policy of Poland until 2050 - action plan for years 2015-2018." Warsaw, 2015.

[34] ATMOTERM, J. Jaśkiewicz, A. Bartocha, M. Rosicki, and A. Tyszecki, "Environmental impact assessment of Polish Energy Policy until 2050." 2015.

[35] F. Gangale, J. Vasiljevska, F. Covrig, A. Mengolini, and G. Fulli, "Smart grid projects outlook 2017: facts, figures and trends in Europe, EUR 28614 EN," 2017.

[36] European Commission's primary public repository, "EU-DEEP Final Report," p. 231, 2011.

[37] A. Weidlich *et al.*, "Deliverable D5.5: Public Report on SmartHouse / SmartGrid," p. 70, 2011.

[38] ERDF Technical Committee, "GRID4EU - Final report," no. 268206, p. 246, 2016.

[39] E. Laes *et al.*, *Deliverable D7.4, S3C Final Summary Report*. 2015.

[40] R. G. Sainz-Maza and Á. D. Gallo, "UPGRID Report Summary for period 1," 2016. [Online]. Available: http://cordis.europa.eu/result/rcn/193671_en.html. [Accessed: 18-Nov-2017].

[41] M. A. Ponce-Jara, E. Ruiz, R. Gil, E. Sancristóbal, C. Pérez-Molina, and M. Castro, "Smart Grid: Assessment of the past and present in developed and developing

countries," *Energy Strateg. Rev.*, vol. 18, pp. 38–52, 2017.

[42] A. S. Malik, M. Albadi, M. Al-Jabri, A. Bani-Araba, A. Al-Ameri, and A. Al Shehhi, "Smart Grid Scenarios and their Impact on Strategic Plan—A Case Study of Omani Power Sector," *Sustain. Cities Soc.*, 2017.

[43] A. N. Al-enezi, "Demand side management (DSM) for efficient use of energy in the residential sector in Kuwait: analysis of options and priorities.," no. October, p. 203, 2010.

[44] B. Blažic, I. Papic, J. Kosmac, and G. Omahen, "Smart grids implementation plan in Slovenian distribution networks - 22nd International Conference on Electricity Distribution," no. 1219, pp. 10–13, 2013.

[45] H. Farhangi, "A road map to integration: Perspectives on smart grid development," *IEEE Power Energy Mag.*, vol. 12, no. 3, pp. 52–66, 2014.

[46] N. Rajagopal and K. V. Prasad, "Process framework for Smart Grid implementation," *2013 IEEE Innov. Smart Grid Technol. - Asia, ISGT Asia 2013*, pp. 1–5, 2013.

[47] K. Moslehi and R. Kumar, "A reliability perspective of the smart grid," *IEEE Trans. Smart Grid*, vol. 1, no. 1, pp. 57–64, 2010.

[48] W. Y. Chiu, H. Sun, and H. V. Poor, "Energy imbalance management using a robust pricing scheme," *IEEE Trans. Smart Grid*, vol. 4, no. 2, pp. 896–904, 2013.

[49] R. Smale, B. van Vliet, and G. Spaargaren, "When social practices meet smart grids: Flexibility, grid management, and domestic consumption in The Netherlands," *Energy Res. Soc. Sci.*, vol. 34, no. June, pp. 132–140, 2017.

[50] M. S. Hoosain and B. S. Paul, "Smart homes : A domestic demand response and demand side energy management system for future smart grids," *2017 Int. Conf. Domest. Use Energy*, 2017.

[51] L. McDonald *et al.*, "Minimisation of distribution network real power losses using a smart grid Active Network Management System," *Univ. Power Eng. Conf. (UPEC), 2010 45th Int.*, pp. 1–6, 2010.

[52] N. M. A. Huijts, E. J. E. Molin, and L. Steg, "Psychological factors influencing sustainable energy technology acceptance: A review-based comprehensive framework," *Renew. Sustain. Energy Rev.*, vol. 16, no. 1, pp. 525–531, 2012.

[53] J. C. Stephens, T. R. Peterson, and E. J. Wilson, "Socio-Political Evaluation of Energy Deployment (SPEED): A Framework Applied to Smart Grid," *Ucla Law Rev.*, vol. 61, no. 6, pp. 1930–1961, 2014.

[54] P. S. Namkung, "Memorandum of County of Santa Cruz, Health Services Agency, Attachment B: Health Risks Associated With SmartMeters." Santa Cruz, pp. 257–266, 2012.

[55] L. Hillert, N. Berglind, B. B. Arnetz, and T. Bellander, "Prevalence of self-reported hypersensitivity to electric or magnetic fields in a population-based questionnaire survey," *Scand. J. Work. Environ. Heal.*, vol. 28, no. 1, pp. 33–41, 2002.

[56] C. Park, H. Kim, and T. Yong, "Dynamic characteristics of smart grid technology acceptance," *Energy Procedia*, vol. 128, pp. 187–193, 2017.

[57] R. Alasseri, A. Tripathi, T. Joji Rao, and K. J. Sreekanth, "A review on implementation strategies for demand side management (DSM) in Kuwait through incentive-based demand response programs," *Renew. Sustain. Energy Rev.*, vol. 77, no. February, pp. 617–635, 2017.

[58] K. Billewicz, "Problematyka bezpieczeństwa informatycznego w inteligentnych sieciach," pp. 115–120, 2011.

[59] W. F. Boyer and S. A. Mcbride, "Study of Security Attributes of Smart Grid Systems – Current Cyber Security Issues," *Contract*, vol. 215, no. April, pp. U212–U212, 2009.

[60] M. R. Asghar, G. Dan, D. Miorandi, and I. Chlamtac, "Smart Meter Data Privacy: A

Survey," *IEEE Commun. Surv. Tutorials*, vol. 19, no. 4, pp. 1–1, 2017.

[61] U. Greveler, B. Justus, and D. Loehr, "Multimedia content identification through smart meter power usage profiles," *Comput. Priv. Data Prot.*, p. 2010, 2012.

[62] G. S. Guthridge, "Accenture end–consumer observatory on electricity management: Understanding Consumer Preferences in Energy Efficiency," 2010.

[63] A. Mallett, M. Jegen, X. D. Philion, R. Reiber, and D. Rosenbloom, "Smart grid framing through coverage in the Canadian media: Technologies coupled with experiences," *Renew. Sustain. Energy Rev.*, no. xxxx, pp. 0–1, 2017.

[64] P. Stankiewicz, "What We Talk About When We Talk About Risk? Social Perception of Risk in Controversial Energy Investments," vol. 2016, no. 4, pp. 61–82, 2016.

[65] S. Bigerna, C. A. Bollino, and S. Micheli, "Socio-economic acceptability for smart grid development - A comprehensive review," *J. Clean. Prod.*, vol. 131, pp. 399–409, 2016.

LIST OF FIGURES

LIST OF TABLES