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SMART GRIDS FOR DIGITAL SOCIETY

Abstract. This paper begins with an introduction of the basic problems of traditional electric power systems that intend to develop Smart Grids (SG). The characteristics of the SG, as well as those of the new ICT systems and the New Energy Market that accompany the process of SG development, have opened up wide areas of research supported by the EU. An overview of the significant role that the Department of Computer Sciences had in this research, closes the paper.

Keywords: Electric Power Systems, Smart Grids, ICT, new Energy Market, Renewable Energy Sources.

1. INTRODUCTION

During the 20th century the growing power systems were centralized, creating monopolistic systems with millions of reactive consumers all over the world. In the last years of that century a number of problems arose: the growth of oil price, the predicted end of coal reserves, the lack of generation and transmission capacity, blackouts in developed countries, opposition against the construction of new Extra High Voltage (EHV) lines, the necessity of CO_2 generated in coal fired power plants limitations and the development of Renewable Energy Sources (RES). Parallel to the growing electrical energy consumption was the increasing need for its more efficient utilization. All these processes forced the deregulation of the power sector, which opened up new important activities previously unknown within the monopolistic system.

The above mentioned events necessitated the reorganization of the architecture of power systems taking into account RES, in order to develop an Information Communication Technology (ICT) system as a basic communication system enabling the activation of consumers.

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2. SMART GRIDS (SG)

Presently the new approach to Electric Power is to introduce into practice the development of the Smart Grid (SG) idea. Several definitions exist of the SG (Santacana et al., 2010) and in this particular paper the US meaning with the following characteristics will be applied (Matusiak, Zieliński 2011a):
– It is self-healing (from power disturbance events).
– Enables active participation by consumers in demand response.
– Operates resiliently against both physical and cyber attacks.
– Provides quality power that meets 21st century needs.
– Accommodates all generation and storage options.
– Enables new products, services and markets.
– Optimizes asset utilization and operating efficiency.
    In Europe SG is defined as follows (Santacana et al., 2010):
– Flexible in the fulfillment of customers' needs while responding to the changes and challenges ahead.
– Accessible as it grants connection access to all network users, particularly RES and high-efficiency local generation with no or low carbon emissions.
– Reliable as it assures and improves security and quality of supply, consistent with the demands of the digital age, with excellent resilience in the face of hazards and uncertainties.
– Economical as it provides best value through innovation, efficient energy management, and a "level playing field" for competition and regulation.

The SG in China is not defined by what technologies it incorporates but rather what it can to do, according to the nonprofit Joint US-China Cooperation on Clean Energy (Santacana et al., 2010].

Comparing functions from the first definition to functions performed by existing power systems one can see that the SG will introduce new services both for the operation of the network as well for receivers of electric energy. Taking into account the enormous investment expenses necessary for the development of SG, gives rise to a number of questions concerning reason for which a SG is necessary.

The first one is as following: "Do we really need SG for energy efficiency only?" (*EU Information…*, 2009). "The answer is no, as ICT is definitely an enabler of energy efficiency, even without building a SG." But when all functions are considered also containing part of the intelligent functions in TSOs (transmission system operator) and DSOs (distribution system operator) and another players in new energy market (EM), operations based on SG and ICT are absolutely necessary (*EU Information…*, 2009).

A more detailed answer to a similar question: "Why do we need the SG?" can be found in Santacana et al. (2010):

- A specific characteristic of electric energy is its simultaneous generation and utilization because up to date there do not exist any large-scale electric energy means of storage.
- Deregulation has unleashed energy trading across regional power grids with undefined scenarios and uncertainties.
- Increasing RES penetration depending on the number of undefined parameters e.g. wind, solar activity etc.
- The information (digital) society depends on the high quality and high availability of electric energy.
- The threat of terrorist or hacker attacks introduces uncertainties.

Another question concerns differences between existing and intelligent SG grids. Some of the most important comparisons are assembled in Table 1.

Table 1. Characteristics of SG and existing grids

Existing Grid		Intelligent (Smart) Grid	
electromechanical	relays, Meters	digital	relays, meters
One-Way Communication	DSO-Consumer	Two-Way Communication	AMI – Advanced Measuring Infrastructure
Centralized Generation	Power Plants (Coal, Nuclear etc.)	Distributed Generation	RES (Wind, PV, Bio- Hydro, Waste etc.)
Hierarchical	Top-Down	Network	Horizontal
Few Sensors		Sensors Throughout	
Blind		Self-Monitoring	
Manual Restoration		Self-Healing	
Failures & Blackouts		Adaptive & Islanding	
Manual Check/Test		Remote Check/Test	
Limited Control		Pervasive Control	
Few Customer Choices		Many Customer Choices	

Source: Farhangi 2010 (Fig. 1).

Comparing the existing to the SG characteristics in Table 1, one can see that SG has significant advantages over existing grids. Nevertheless it is worth mentioning that the life span of electromechanical devices is longer than that of electronic devices (SEESGEN-ICT 2009-2011).

In Santacana et al. (2010) we can also find very interesting questions accompanied by answers: "What will the Smart Grid be like?" As an answer we find the following features of the SG:

– Tightly Integrated Renewable Energy.
– Proliferation of Energy Storage.
– Growing Mobile Loads and Resources.
– Distribution of Production.
– A New Level of Controllability.
– Real-Time Grid Awareness.
– The Smart Prosumer and the Grid-friendly Appliance.
– The Resurgence of DC.
– Real-Time Distributed Intelligence.

According to Matusiak, Zieliński (2011a) the development of RES (except of wind farms) in Poland is a result of private initiative that has resulted in a number of regionally dispersed generators (DG). Each of these DGs ought to be connected to a distribution network and realize it's private schedule what means that DGs belongs to Virtual Power Plants (VPP).

Individual DGs partnered with virtual power plants and with different technical characteristics, connected to the distribution network, implies serious technical – as well as organizational problems depending on their number, capacity, schedules etc. Introduction of controlling interface between DGs and distribution network will be a valuable solution simplifying the operation of the distribution network. Of course the interface between separate DG and distribution networks is by far too expensive and therefore it is necessary to group together a number of DGs that are located within the same area. When we can collect several DGs with suitable locations, we can compose them in into microgrid.

Microgrids are the interconnection of small modular generation to Low or Medium voltage distribution systems. Microgrids can be connected to the main power network or be operating islanded, in a coordinated, controlled way. Microgrids connected to the distribution network (in the future – smart distribution grids) need the creation of an Active Distribution Network (ADN) passing through the following stages: the remote monitoring and control of DG and RES; accurate information systems management for the consolidation of the great number of DG and RES and full active power management together with real time communication and remote control. More information concerning microgrids can be found in Hatziargyriou et al. (2007), Katiraei et al. (2008) and in Pamuła, Zieliński (2009).

3. NEW ENERGY MARKET

There is no single open energy market model that exists for all countries. In Poland and in Europe, this model should emerge against the background of an already existing market model, including changes in the direction of the SG resolutions.

The current Polish Energy Market model has several crucial elements and functionalities such as:

– Large generation (system power plants) and islanded RES (mainly wind farms, small CHPs) – producing and selling energy on a free market base.
– Controlled market concerning energy transmission and distribution (TSO & DSO).
– Liberalized wholesale and retail market.
– An outdated network infrastructure which has to be modernized towards the use of smart meters and advanced technical sensors.
– The market is moving towards a competitive market through the introduction of TPA rules for all market participants, modifying legal and regulatory solutions that enable a greater variety of financial and legal incentives in order to maintain its development (slow progress has been observed).
– Centralized system design, management of energy flows in the network from top to bottom (i.e. from producer to customer). Poor quality, defects in the management of information (exchange of data between market participants and especially heavy noise levels of real consumption measurements for retail participants).
– Pricing formula (energy price) based of real costs and reasonable regulations for the weakest users (tariffs for small households).
– Lack of a nuclear power plant.
– Weak development of supporting systems for investment initiatives for private investors.

The future energy market model, with SG should consists of Matusiak, Zieliński (2010):

– The network structure built from numerous micro sources and local microgrids – municipal, private, mainly based on renewable sources (RES) and energy storages (ES), distributed generation (DG) and clean coal technologies, where in a significant way, the microgrids as "the islands" became more then self-sufficient and also actively participate in the production of electricity for the system grid.
– Local power management and the harmonization of the central grid and DG (local microgrids for districts and cities).
– Each participant in the market, even the smallest, can actively participate in energy transactions in the market through participating in the aggregation of demand and supply of the microgrid.
– Dynamic grid based on communication between market participants in real time (smart meters, two-way communication, allowing the measurement of energy consumption and demand with the frequency of every 15 minutes or much less).
– Reliable and high quality measurement and billing.

– Flexible demand-side management and value-added services (such as an independent service provider-aggregator in the measured network, who provides new services).
– Ensuring the quality, reliability and security at the all levels for every single market participant.
– Pricing formula based solely on the basis of a competitive market and state support for the development of renewable energy sources to create the legal and financial incentives for micro generation market expansion.
– A strong and longtime supporting system for investment initiatives and private investors.
– Transparent and consistent state policy on energy development.

A part of the energy produced by central power plants should be replaced by distributed generation (minimum 30%), renewable sources and energy storages. Energy trading should take place according to open market principles.

The following tasks need to be performed in order to develop a new active energy market model:
– Build good technical solutions to improve network efficiency and effective implementation of the existing grids for all sources.
– Establishing common standards and protocols that enable the utilization of new devices and exchange of information between vendors.
– Information systems, computing and telecommunications, new businesses with new services development, which improve the energy efficiency.
– Ensuring compatibility between the old and new grid devices to ensure interoperability and full automation.
– Harmonization of regulatory policies and market regulations, to facilitate cross border trade in energy and network services
– Development of new business models (e.g. a place for aggregators of demand at the local level, virtual power plants (VPP), etc.) for the functioning of the new quality economic entrants, taking into account the many possibilities offered by a free and open market based on the smart grid. This is the most important aspect of the economic environment needed for the improvement the power system energy efficiency.

Many developed countries are preparing to upgrade their networks towards SG. Calculations show that the modernization of all the energy networks throughout the U.S. (the implementation of the SG) would save over the next 20 years up to 117 billion dollars (*European Smartgrids Projects*).

In the coming years the SG could be one of the fastest growing sectors of the green energy market, considerably improving energy efficiency. It should be mentioned that many obstacles exist on the road towards the development of the SG network, which have been extensively discussed in *European Smartgrids Projects*, Matusiak (2010), Matusiak et al. (2011a), Matusiak, Zieliński (2011a, b), SEESGEN-ICT 2009-2011 and are dedicated to different EU projects works.

It should also be noted that the current power system investors (beneficiaries) in Poland are not too interested in the development of DG and RES because of a lack of longtime financial background perspectives. Currently challenges in the energy sector revolve around: adequate policy actions, data privacy, security, interoperability, standards and how to finance it all.

The new EM model with a movement towards SG will introduce new market actors. Among the new actors on the new energy market will be the prosumers, the service aggregators or the VPP. In general, the new EM model will be the central space for the creation of new business models and actors and functionalities.

Business models (BM) of the energy market are generically intended as a framework for the management of the commercial relationships among market entities, meant for creating value for the whole electricity market chain (Matusiak, Pamuła, 2010a).

In SEESGEN-ICT EU project, EM is intended as the logic of creating added value, such as profits for the company, tax, income, benefits to consumers, quality power and an improved environment. These also include the description of the stakeholders and of their roles and their most important transactions. The core parts of a business model are: actors, such as different companies involved, and their roles; products and services, such as load modification in certain load area, ancillary services; contractual relationships between the actors, including pricing and penalties; transactions and flows between the actors: energy flow, information flow, economic flow; enabling technologies (non-ICT and ICT), such as sufficient communication links; values/benefits for the actors, such as an ability to integrate distributed and uncontrolled generation and drivers and barriers to the implementation, such as regulatory constraints to their adoption.

One of the new idea of actors on new energy market there are prosumers and virtual power plants (Matusiak, Zieliński, 2011a) or service aggregators (other words: DRSP − Disperse Resources Service Providers). According to the deliverables of the SEESGEN-ICT EU project the prosumer is an active participant of the retail market who can also deliver and use the energy from the grid and who can also apply an Active Demand Side Response Schedule in order to manage your own energy efficiency, requirements and energy usage, according to your own individual schedule. In this sense they can be simultaneously both the producers and the final user.

The aggregator is defined as follows: it is a company that acts as inter mediator between electricity end-users, who − by aggregation − provide energy management and optimization from distributed resources to those power system participants, who wish to exploit these services (VPP can play a role of the aggregator). The main role of the aggregator is to aggregate energy resources (DER) and provide into markets for the use of the other players, and on the other hand providing market access to DER. The aggregator can provide added value to the electrical system (Matusiak, Pamuła, 2010a).

Examples of new products and services on EM with SG are:

– The prosumer delivers energy (so-called colored energy − according to the certificate of origin classification) onto the market with an attractive price for its quality, or uses it for themselves while reducing the load. Through the active demand response it provides for a decrease of the peak load in the power system and reduces the risk of blackouts.

– The aggregator integrates the distributed generation and energy production sources, and on behalf of the prosumer participates in the market, being involved in carries out commercial operations on behalf of the prosumer in the market. Additionally the aggregator manages the energy production, trade and forecasting preparation as well as provides services as the EM manager. The aggregator can be established as an existing entity such as an energy trading company, or a virtual entity which can be such organized thanks to highly specialized ICT systems.

– Energy storage as a service provided by plug-in hybrid electric vehicles (PHEVs) development.

In summary, SG implies development of a new Energy Market model with new business models. The new energy market will be a client-oriented model where there will be space for introducing new business models, millions of active consumers and many other new participants, functions, new services (demand dispatch or price-responded demand, and others), meter access providers and operators, VPPs, islanded and non islanded microgrids, and new RES, with integration and transmission between all EU power systems.

4. PILOTS AND EUROPEAN PROJECTS FOR BM

EU Countries have prepared the legal framework for the new Energy Market, leading the implementation of many pilots, checking economically viable solutions and estimating the effectiveness.

There are approximately over ninety SG pilots currently being implemented around the world today (SEESGEN-ICT). The vast majority of these pilots are primarily focused on AMI. Geographically, there's a concentration of pilots in North America, Europe (France, Spain, UK, Germany, Italy) and Australia, although there is increasing activity in South America, South Africa and Asia (China).

Intensive work on legality, standardization, smart metering, acquisition, storage, sharing and reporting, and management of the measurement data through the ICT systems are currently in progress in Poland (initial part of the project). However pilots are needed to implement, both remote reading (such as the "on ready": The Intelligent Peninsula implementation of the Energa Company: the Converge System, System-Amateur Radio Intrusion) as well as ICT systems for SG.

Moreover, in Poland, in the last quarter of 2010 the Consortium on the Development of Smart Grid had been established and the National Technology Platform to Energy Power had been created. These two initiatives, together with legislative actions of the Energy Regulator and the Ministry of Economy support the rapid development of AMI and SG in Poland, as an initial part of this preliminary projects' works.

It should be also mentioned, that many Polish R&D centers, on topics relating to the power energy market within the FP6 and FP7, dynamically collaborate in European projects such as: ADDRESS, FENIX, EU DEEP (*European Smartgrids Projects*), MICROGRIDS, MORE MICROGRIDS, SYNERGY PLUS, DERLab or SEESGEN-ICT and many others. Many participants of these projects have been devoted to the development of business models for the new energy market in Europe.

The efficiency of business models with combined DER depend on several key parameters related to the technological infrastructure, cost, consumer behaviour, regulatory policies and the market. Identification and classification of these elements is critical to assess effectiveness and stability of the model in different national and network conditions.

For instance, the concept of commercial VPP, with its two scenarios of deployment, was proposed and tested during the FENIX project, taking into account the different economic conditions selected for testing countries.

One of the main results was the working out of three types of business models, which have been tested in five different countries through the implementation of a pilot (in the UK, Greece, France, Spain and Germany).

The aim of the SEESGEN-ICT project was to gather experience and outcomes to determine the current status of the energy sector development in the direction of the SG and to identify barriers to development, that currently prevent further progress in various European countries.

5. THE ROLE OF ICT IN A NEW INTELLIGENT GRID

There is no doubt that ICT solution play significant role in a new idea of Smart Grids in which DG units are predicted to be widely dispersed trough the distribution network that demands bidirectional communications between all players on different levels of the system (Matusiak et al., 2011a).

In fact it is the most important factor that determine its successful deployment. The proper high speed online communication, data transfer and easy access of a new grid elements (physical and logical) are the basic element of the future grid. The management of the SG demands two parallel ways of information exchange. One connected with the technical and the second with economi-

cal perspective. It must be notice that those two types of flow need to be considered at the same time one as power flow, the other as information (and large number of data) flow.

On the technical perspective the power system has to be monitored and managed to distribute the power from generators to consumers what was a general purpose of classic SCADA systems. While the network is moving from classic centralized system towards more and more complex architecture, more data must be managed, more decisions must be made in a real time. As it was mentioned in chapter 2, one of the most important SG functionality is to supply restoration function that is involved after detection of the fault in power system. That demands real time measurement and fault alarm description as well as possibility to send a message to the specific power network device (ex. switch-gear). Traditional SCADA systems were closed, focused on remote measuring of amount of some specific flow/state of the hierarchical grid. Now the system must evaluate to more open solutions providing information of energy flow in a real time to all stakeholders. To supply all foreseen SG scenarios ICT systems must offer a great number of applications for home, building, factory, energy management systems, demand meter readings, demand response systems, electrical grid status monitoring, fault detection, isolation and recovery, manage wide variety of devices, smart appliances and electric vehicles (SEESGEN-ICT). On the economical perspective the new energy market generates a great number of the new stakeholders and new business processes that must be monitored and served by commercial contracts. This moves the system to the service oriented system and demands new ICT architecture ensuring online monitoring and high quality of service. As the most research done by different project shows (ex. SEESGEN-ICT) the recommended technology suitable to managed this type of complex system is Service Level Agreement (SLA). But for the proper use the definition of minimum requirements for SLA design and implementation for all actors and different applications and service performance monitoring need to be established.

The Smart Grid idea is based on active consumers participation in energy market that must be served by suitable ICT systems. Functionality of these systems from End-Users perspective must be considered in different categories like communication, hardware, software, user interface, control logistic and generic. Larger commercial End-Users (mainly from industry) already play an important role in energy market, they have some IT systems. Small prosumers – owners of DER are the beginners on the market. They can play an important role not individually but aggregated into groups. They are the main group needing support of new ICT systems. Dedicated ICT systems must support their aggregation and because of the heterogeneity of those users must be easy to use, flexible and attractive. This type of the system must be strongly demand side oriented.

Internet technology based on its protocols and Service Oriented Architecture is the most often used approach as solutions for supporting this new business. The SEESGEN-ICT project recommends DSSP (Demand Side Service oriented Platform) that combines ICT solutions, architecture and equipment interfaces, good practices, standard and regulatory frameworks (Matusiak et al., 2011a; SEESGEN-ICT). The platform provides infrastructure for end users, Distribution Systems Operator and other commercial intermediaries. The good example of such a Internet platform, already offered as a demonstration kit, is German OGEMA (Open Gateway Energy Management Alliance available at http://www.ogemalliance.org) that uses Java and OSGi as widely accepted software standards that provide a cross-platform execution environment.

The new EM aggregator business role also demand some new ICT tools to support their business ex. price forecasting tools, simulation and optimization tools.

6. SMART GRID STANDARDIZATION PROCESS

Traditional grid was a central controlled system belonging to electric utilities. SG with a great number of new stakeholders generates a problems of ownership of different part of power network and communication infrastructure. The communication network in most cases is independent from power network (although power network can partly play a role of it), so clear rules who pays for what and cost centers has to be established for clearing settlements. The ICT systems must follow the way the business is done in each part of the process and represent all cost in the final invoice of each participant.

The interoperability of the system is a crucial future of the Smart Grid. The great number of diverse components from different vendors in an new network can be managed only if they follow standardization rules. Investing in a new DER and ICT demands proven technologies and clear legal and economical rules. Regarding SEESGEN-ICT project recommends that standardization should concern (SEESGEN-ICT): basic physical and logical connections between systems; different network connections (including Internet to send signals to consumers); data representation to allow message exchange (syntactic level); concept contained in message data structure (semantic level); business procedures and cyber security standards.

There is no in fact standard of SG architecture, there is even no transition plan and clearly defined communication architecture yet, although there is a lot of work done by different standardization and regulatory bodies and other organizations leading to some recommendations towards it. Some of them specify detailed technical specifications and protocols, some present general

technical and market rules, general activities like European Mission Mandate and or specific Roadmaps like NIST Roadmap or IEC Roadmap (Pamuła, 2011). From a large number of those recommendations the most important there are:

– All energy market players must have the same opportunity to do the business no matter what technology and way of communication they use, therefore in most work recommendation the use of open standards and non proprietary solutions is suggested in order to avoid high cost of proprietary right.
– Communication standards should be independent from communication technologies.
– Open source software for the tools for open standards is recommended.
– The complex SG ICT system demands very good communication for critical services and less costly largely available standard for less critical services.
– Similarly to CIM model for electric system (IEC − International Electrotechnical Model 61970/61968) a common descriptive model for distributed grid should be agreed.
– The existing best practices from different countries should be gathered in a reference model system.
– To ensure reliability of the system Cyber Security must be seen as one of the most important SG deployment factor. A lot of sensitive data about consumers and other stakeholders' is going to be present in a modern grid, so Cyber Security standards should be included in ICT solutions considering following aspects: must be design in a way that does not violate privacy; must be design in a way that not cause conflict between Privacy and Cyber Security; ensure network transaction security: integrity, non-repudiation and confidentiality and prevent external attacks and tampering.

Further coordination of standard bodies work on the international level to increase harmonization in standard development and its market deployment is necessary. Developed and agreed standards should be widely promote among all stakeholders.

There are also a lot of work done in the area of ICT for Smart Grids. Some ICT solutions covering for distribution systems are already available like: 4DIAC (http://www.fordiac.org/) initiative that using an open, IEC 61499 standard compliant basis, that gives the opportunity to establish an automation and control environment based on the targets portability, configurability and interoperability, Mango M2M2 for monitoring and SCADA systems (http://m2m2.serotoninsoftware.com), CIMTool is an open source tool that supports the Common Information Model (CIM) standards used in the electric power industry (http://wiki.cimtool.org/index.html) or mySmartGrid is the smart device control for home (https://www.mysmartgrid.de). More analysis regarding current available software and its functionality can be find (SEESGEN-ICT).

7. CLOSING REMARKS

The SG seems be a very attractive idea but because of a lack of experience in developing such a huge projects and costs of the DG implementation, it is not so easy to set timelines. It is also important to remember that a DG in one European country alone cannot be profitable because of connections with power systems of neighboring countries which have no capital. The development of such a massive complex system, as the SG, in which a number of technical and market solutions are necessary for operating in a digital society need to evolve through research undertaken in many countries. This means that the EU will have to maintain control over the development of the SG as well as provide funding for new research projects.

SG in Poland is at its very initial stage, starting with the installation of new intelligent meters in selected region. Research, as is currently being undertaken by the Department of Computer Sciences in the University of Lodz, on new ICT systems and the new Energy Market in SG development is indeed timely.

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