

Smart Grid – the concept, trends and stakeholders' analysis

Carlos Jahn

*Institute of Maritime Logistics
Hamburg University of Technology
Hamburg, Germany
carlos.jahn@tuhh.de*

Jürgen Weigell

*Institute of Maritime Logistics
Hamburg University of Technology
Hamburg, Germany
juergen.weigell@tuhh.de*

Alexandra Borremans

*Graduate School of Business and
Management
Peter the Great St. Petersburg
Polytechnic University
St. Petersburg, Russia
alexandra.borremans@mail.ru*

Aleksandr Lepekhin

*Graduate School of Business and
Management
Peter the Great St. Petersburg
Polytechnic University
St. Petersburg, Russia
lepekhinaalexander@gmail.com*

Abstract— Throughout the last century, global demand for electricity increased, resulting in a growing number of power plants and related infrastructure. Along with this, the demand for modernization and automation of electric networks has risen. Different industrial trends, such as digitalization and integration emerged in various industries, including energy production, result in the creation of the Smart Grid concept. Smart Grid is a term for an intelligent network that extends the distribution and transport system of electricity to optimize ongoing operations and opening new markets for alternative energy. The Smart Grid has different properties, such as increased use of digital and monitoring technologies, demand management, integration of smart metering devices and consumer devices, providing consumers with real time information and management capabilities. Smart Grid is a complex concept, which has to be analyzed for the point of implementation complexity. The key components of this implementation complexity have the technology and the organizational cores. Technological complexity includes component production, technical implementation of networks, reliability and security, and privacy. At the same time, organizational complexity is associated with the interests of a huge number of different stakeholders and their goals. All these points complicate the implementation of technology and the creation of a unified potential implementation framework. This research papers addresses the Smart Grid technology in order to create its comprehensive understanding and develop this implementation framework based on world-wide standard of Enterprise Architecture.

Keywords—*Smart Grid, electricity, Enterprise Architecture, ADM, implementation framework*

I. INTRODUCTION

In many countries, companies in the energy sector are undergoing a period of reform. The ongoing processes of mergers, acquisitions, and changes in the management structure, boundaries of the sphere of activity, and territorial presence compel many former monopolies to seek new models for creating value. The tasks of companies and their business processes are inevitably changing. Market mechanisms are being implemented. Technological changes are required to meet current industry development needs.

Although all these changes vary depending on the location and type of activity of energy companies, innovation will inevitably lead to the transformation of the entire sphere of utilities [1].

One of the main trends influencing the development of information systems in the energy sector is the Smart Grid concept [2].

Energy companies face the need to introduce new standards of operation and maintenance to continually improve the balance between reliability of energy production and costs. Another key task in the energy sector is maintenance and repair. This is due to the large number of parts of equipment distributed over large areas and requiring constant maintenance and repair services. Consolidation of information on the condition of equipment in a single control system with the possibility of its prompt provision to various consumers on the ground can reduce downtime for repairs, reduce costs for spare parts and materials, optimize logistics and workload of personnel. Consumers are also an equally important driving force behind these changes [3]. There is a tendency to move from a process-oriented approach to a customer-oriented one. Increased customer requirements for the level of service inevitably lead to the expansion of the range of services provided by energy companies [4].

This article discusses the main trends in the development of the Smart Grid concept, research areas, as well as the potential for implementation of this concept within the framework of Industry 4.0. based on stakeholders' key goals.

II. MATERIALS AND METHODS

Information and technological support of the organization's business processes is one of the key components of digitalization of organizations in almost any industry.

From the point of view of the US Department of Energy, the following attributes are inherent in Smart Grids:

- ability to self-repair after power outages;

- the possibility of active participation in the work of the consumer network;
- network resistance to physical and cyber intrusion of intruders;
- ensuring the required quality of the transmitted electricity;
- ensuring synchronous operation of generation sources and power storage nodes;
- the emergence of new high-tech products and markets;
- improving the efficiency of the energy system as a whole [5].

According to the European Commission, which is engaged in the development of a technological platform in the field of energy, the Smart Grid can be described by the following aspects of functioning:

- Flexibility. The network must adapt to the needs of electricity consumers.
- Availability. The network should be accessible to new users.
- Reliability. The network must guarantee the security and quality of electricity supply in accordance with the requirements of the digital age.
- Profitability. The most valuable should be innovative technologies in the construction of Smart Grid, together with effective management and regulation of the network [6].

In addition to solving the problems of reducing the environmental burden, reducing energy shortages through the use of renewable energy sources, improving the quality and reliability of the energy system, Smart Grid concepts have another very important aspect: Smart Grid is a catalyst for economic recovery. The implementation of the provisions of this concept will include the development of innovative technologies, the expansion of the production of highly intelligent products, the more intensive use of electric energy in the transport infrastructure, the development of new market relations with the involvement of consumers in the energy sector as active market players [7].

In accordance with the Smart Grid concept, one of the priority areas for the development of IT in the energy sector for the coming years:

1. Widespread implementation of smart measuring tools - smart meters with the function of remote control of the load profile of the measured line and measuring transducers with standard communication interfaces and protocols (including wireless) that comply with information security standards at new and modernized measuring points.
2. Installation at each large facility connected to the power grid (residential area, office center, factory, etc.) of advanced automated information-measuring systems operating in real time.
3. Creation of a wide network of integrated communications based on a variety of communication lines.

4. Implementation of automated systems (AS) of production activity management in energy companies.
5. Creation of integrated interfaces to production management for automatic data exchange with AS of other market participants. At the same time, exchange protocols and information security standards for all categories of market participants should be defined [8].

The cloud platforms used to collect data from connected Smart Grid elements and end-to-end optimization of grid management can be classified into two types: Integration, used mainly for data collection and implementation of the most requested monitoring tasks, in particular, automatic detection of consumer outages and cases of theft of electricity. And analytical, used for optimizing predictive power grid management in real time, including for managing Demand-Response programs and distributed generation facilities [9].

One of the key areas for increasing energy efficiency is equipping consumers with modern electricity metering systems. The key categories of consumers of electricity metering devices are:

- individual houses and apartments;
- multi-apartment residential buildings;
- electric power infrastructure facilities;
- commercial real estate;
- industrial facilities;
- public sector facilities [10].

Equipping consumers with natural gas metering devices is an important area of increasing energy efficiency in the field of housing and communal services, industry, and the commercial sector. Prospects for the development of the market for solutions for smart energy accounting are determined by a fairly wide range of factors, among which are:

- the current level of implementation of metering devices of modern types, allowing their use in multi-level dispatch systems;
- dynamics of volumes of new housing and commercial construction;
- dynamics of the volume of capital repairs of multi-unit housing stock;
- the cost of technological solutions in the field of smart accounting;
- level of tariffs for energy resources.

The simplified Smart Grid model taking into account the use of information and communications technology (ICT) consists of five subdomains, which are considered at three different levels: services/applications, communication, equipment. Each of these three levels spans one or more subdomains:

- power supply (generation, transmission, distribution);
- measuring instruments;

- client subdomain (smart devices, electrical equipment, local networks, etc.);
- communication network;
- subdomain of a service provider (operators, service providers, service market, etc.).

Further the system has five interfaces to be described:

- Interface 1 - between the power supply subdomain and communication networks, allows the exchange of information and service signals between devices in the subdomains.
- Interface 2 - between the measuring instrument subdomain and the communication network (telecom operator), allows measuring information to be exchanged with users (user subdomain) through the telecom operator and with service providers.
- Interface 3 - between the user subdomain and the communication network, allows for interaction between telecom operators and service providers within the service provider subdomain and devices in the user subdomain.
- Interface 4 - between the sub-domain of service providers and the communication network, allows you to communicate with services / applications within the sub-domain of service providers to manage other domains.
- Interface 5 - between the measuring instrument subdomain and the user subdomain through the ESI interface, in particular, the interaction of measuring instruments and user equipment [11].

Smart Grid is one of the components of Industry 4.0 global concept. In the Industry 4.0 paradigm, the vision for the future development of production covers the following areas: new products and services with new added value, new enterprise models, modern industrial design, new production technologies, infrastructure and education, research and development system. Concept Industry 4.0 combines digital technologies and physical objects, creating a fundamentally new domain of scientific and practical activity, which has a significant impact on the economy of various markets, changes the basic processes of enterprises and product life cycles, and is also a trigger for creating new business models and requirements systems to the competencies of specialists. Initially, the term Industry 4.0 appeared as part of the process of development of production and the creation of the concept of "Smart Plant". The scope of this term has changed over time, and such concepts as "smart city", "smart logistics", "smart home", "smart transport" and others have appeared [12] [13]. All these terms appeared as a result of the development and implementation of a system of sensors that made physical objects part of the information space of enterprises. It also means creating an integrated ecosystem of companies that are able to interact within a single space and exchange the necessary data in real time, creating maximum value for the end user, as well as making the delivery process of this value more manageable and transparent. The new concepts are mainly based on the principles of Advanced Industrial Engineering, where the basic principle is the concept of Digital Factory and digitalization. Technologies

like virtual design, digital factory, additive manufacturing / rapid prototyping correspond to modern concepts. New materials are applied, emphasis is placed on intelligent systems. At the same time, Digital Factory will increasingly use renewable energy sources as part of a self-sufficient power supply in addition to the source provided by an external intelligent network [14]. Thus, Smart Grid is an integral part of global digitalization trends. The practical implementation of this technology has to be related with a certain group of stakeholders, which has to be studied.

III. RESULTS

The basis of the goal-setting for the creation and development of enterprise architecture in almost any industry is based on certain driving forces (drivers) arising from the requirements of stakeholders (stakeholders) for the management system, which appear on the basis of the requirements of interested parties. The whole system of motivation, requirements and limitations in the creation and development of enterprise architecture is reflected in the model of motivation extension. Motivation extension is intended for additional structured modeling of factors, goals and objectives that affect the organization in the context of its development. Using the methodology proposed by Lanckhorst for constructing a motivational concept, it is necessary, first of all, to identify key stakeholders in the implementation of Smart Grid technologies [15]. This will allow us to define and more precisely formulate the goals of implementing this concept, as well as formulate goals in the analysis of each group of stakeholders.

To implement the Smart Grid concept, the following groups of stakeholders were identified:

- Energy companies;
- Consumers of energy;
- Governments and regulators of the energy industry [16].

Each of the described groups of stakeholders can have its own set of goals, which subsequently determine the implementation of Smart Grid technologies.

For energy companies, the key objectives pursued by the development of Smart Grid technologies are:

- reduction of energy losses;
- improving the timeliness and completeness of payment for energy resources consumed;
- management of the irregularity of the electrical load schedule;
- improving the efficiency of asset management of energy companies;
- improving the quality of integration of renewable generation and distributed generation facilities in the energy system;
- improving the reliability of the energy system in case of emergencies;
- increasing visualization of the work of energy infrastructure facilities.

The key tasks to be solved by energy consumers in implementing Smart Grid technologies are:

- improving consumer access to energy infrastructure;
- improving the reliability of energy supply to all categories of consumers;
- improving the quality of energy resources;
- creating a modern interface for the interaction of energy consumers with its suppliers;
- the opportunity for the consumer to act as a full participant in the energy market;
- Enhanced opportunities for consumers to manage energy consumption and reduce the level of payments for energy consumption.

Governments and regulators in the energy sector, through the development of Smart Grid technologies, are striving to achieve the following goals:

- increasing the level of satisfaction of energy consumers with the quality and cost of energy supply;
- ensuring a sustainable economic situation for enterprises in the energy sector;
- ensuring the modernization of fixed assets of the energy industry without a significant increase in tariffs.

The described goals can be further analyzed in order to become a basis for architectural development of organizations within Smart Grid concept. In order to develop an Enterprise Architecture of any organization the TOGAF standard may be used. TOGAF framework distinguishes four architecture domains of Enterprise Architecture: Business Architecture, Data Architecture, Application Architecture, and Technology Architecture, which should be created. For further development of the described goals and domains we propose to use Architectural Development Method (ADM). ADM is considered the core of the TOGAF standard and consists of a phased cyclic approach to developing a common enterprise architecture. The figure below demonstrates the structure of ADM [17].

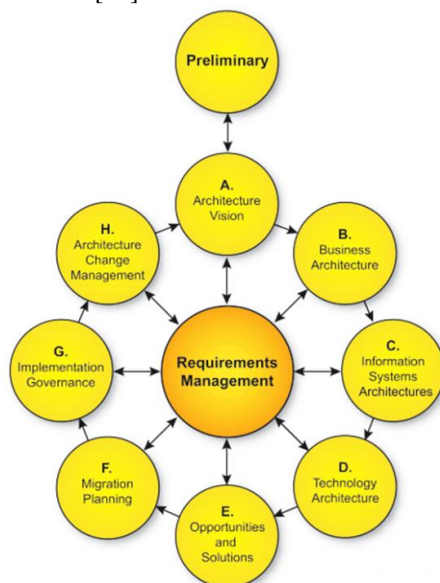


Fig. 1. Architecture Development Method [18]

In the current research we focus on the starting phased of ADM – Preliminary phase and Phase A. According to TOGAF, ADM Preliminary Phase is about defining "how we do architecture" in the enterprise concerned. There are two main aspects: defining the framework to be used; and defining the architecture principles that will inform any architecture work. At this phase we define people responsible for performing architecture work, and their responsibilities. We also need to set up and monitor a process of architecture design and development and other organizational aspects. Phase A is called Architecture Vision. It starts with receipt of a Request for Architecture Work from the sponsoring organization to the architecture organization. On this stage we mainly need to validate the business principles, business goals, and strategic business drivers. Here the described business goals can be adapted in order to move further on the stages C-H.

IV. DISCUSSION

The described approach to Smart Grid implementation, based on stakeholder's analysis and their key goals allows to evolve implementation process in terms of requirements understanding. There are different projects of Smart Grid development and implementation. One of these projects, implemented by the New York Consolidated Edison company (Con Edison) for federal money, implied the development of the compatibility of "protocols and software for connecting various categories of users owning distributed generation facilities, along with an assessment of the demand for the integration of commercial buildings". Con Edison planned to "demonstrate a methodology for interacting with user energy, including combined heat and power (CHP), to create a virtual power plant (VPP)." This was an important project for the people of New York and the entire CHP industry, because it was planned to solve two of the most important problems that impede the development of cogeneration in the Con Edison service area. The first problem was that connecting CHP objects to Con Edison distribution networks was expensive, long, and technically unsafe. The second is that CHP systems rarely provided the same set of opportunities for accessing energy markets and connecting to user programs as other types of generation. Another goal of the Con Edison Smart Grid development program was to develop a power facility interaction scheme that allows you to simultaneously manage user-generated generating systems and networks and direct energy to the distribution network.

One of the first mass projects to equip homes with smart meters called the Telegestore Project was launched by the Italian authorities. Between 2001 and 2006, the number of installed smart meters in the country increased from 150,000 to 29,800,000.

In the Austin, Texas, USA a smart grid was built in 2003. Then a third of simple counters was replaced by smart ones that can exchange information using a mesh network. Today, about 500,000 devices (smart thermostats, smart meters, sensors, etc.) are controlled in real time in the Austin smart grid, and about a million ordinary users and 5,000 enterprises are served. The total area served by smart grid systems and technologies is more than a thousand square kilometers [19].

One successful example is a pilot project in the Netherlands called PowerMatching City. It was established by the Dutch government and implemented by the Norwegian energy company DNL GV in 2011-2013. The project included only 42 houses. PowerMatching participants were able to show in practice the capabilities of Smart Grid similar to those that Con Edison was going to realize in New York. Including the ability to use multi-user software to manage the balance of supply and demand for electricity in real time [20].

The described projects demonstrate that Smart Grid concept has implementation potential on the market. Though, it is important to focus on different aspects, described in existing literature. First of all, it is important to point out the security aspect. The smart grid incorporates many resources, applications, and enabling technologies. Resources are the devices that affect supply, load, or grid conditions, including delivery infrastructure, information networks, end-use systems, and related distributed energy resources. It is important to take into account trust aspects, communication and device security and privacy [21].

Next are environmental issues based on wireless technologies, which have to be considered. Implementation of wireless technology offers many advantages over wired, e.g. low installation cost, mobility, remote location coverage, rapid installation, etc. However, each technology has certain challenges, addressed in existing literature. For example, security and costs issues are addressed [22].

Another important challenge of the Smart Grid implementation is the technological architecture of this complex solution. Current research proposes a heterogeneous communication paradigm based on the requirements of the smart grid network in order to support smart grid applications [21].

In general, the integration of systems in the Smart Grid can be attributed to projects that have a medium- and long-term return on investment horizon. To make the network cost-effective and smart, a set of measures is needed. There are relatively modern networks, there are industrial networks, there are networks of infrastructure facilities, and they are all managed differently. Therefore, despite the fact that different challenges are already addressed, and implementation methods can be potentially developed, it is difficult to immediately evaluate the economic effect. This might be the factor, which can block rapid implementation of the described technology.

V. CONCLUSION

Smart Grid technology is an evolving trend of industrial digitalization. It allows different stakeholders to collaborate within completely new ecosystem based on integration and networking. Today, smart grid projects are being implemented in countries such as the Netherlands, Germany, Australia, Portugal, and Canada. Implementation of such complex technology needs comprehensive analysis of stakeholders and their goals within unified implementation framework. In this research paper Architecture Development Method of TOGAF standard was proposed as a potential tool for architectural planning. For the first stages of ADM the set of key stakeholders and description of their potential goals was propose.

REFERENCES

- [1] R. Wüstenhagen, M. Wolsink, and M. J. Bürer, 'Social acceptance of renewable energy innovation: An introduction to the concept', *Energy Policy*, vol. 35, no. 5, pp. 2683–2691, 2007.
- [2] H. Farhangi, 'The path of the smart grid', *IEEE Power Energy Mag.*, vol. 8, no. 1, pp. 18–28, Jan. 2010.
- [3] W. Su, H. Eichl, W. Zeng, and M.-Y. Chow, 'A survey on the electrification of transportation in a smart grid environment', *IEEE Trans. Ind. Inform.*, vol. 8, no. 1, pp. 1–10, 2011.
- [4] M. N. Q. Macedo, J. J. M. Galo, L. A. L. De Almeida, and A. de C. Lima, 'Demand side management using artificial neural networks in a smart grid environment', *Renew. Sustain. Energy Rev.*, vol. 41, pp. 128–133, 2015.
- [5] S. M. Amin and B. F. Wollenberg, 'Toward a smart grid: power delivery for the 21st century', *IEEE Power Energy Mag.*, vol. 3, no. 5, pp. 34–41, 2005.
- [6] J. R. Roncero, 'Integration is key to smart grid management', in *CIREN Seminar 2008: SmartGrids for Distribution*, 2008, pp. 1–4.
- [7] I. V. Ilin, O. Y. Iliashenko, A. I. Klimin, and K. M. Makov, 'Big data processing in Russian transport industry', in *Proceedings of the 31st International Business Information Management Association Conference, IBIMA 2018: Innovation Management and Education Excellence through Vision 2020*, 2018, pp. 1967–1971.
- [8] C. Cecati, G. Mokryani, A. Piccolo, and P. Siano, 'An overview on the smart grid concept', in *IECON 2010-36th Annual Conference on IEEE Industrial Electronics Society*, 2010, pp. 3322–3327.
- [9] F. Rahimi and A. Ipakchi, 'Demand response as a market resource under the smart grid paradigm', *IEEE Trans. Smart Grid*, vol. 1, no. 1, pp. 82–88, 2010.
- [10] H. Gharavi and R. Ghafurian, 'Smart Grid: The Electric Energy System of the Future [Scanning the Issue]', 2011.
- [11] G. B. Media, '“Умные сети электроснабжения” (smart grid) и проблемы с кибербезопасностью | ITSec.Ru'. [Online]. Available: <http://lib.itsec.ru/articles2/in-ch-sec/umnye-seti-elektrosnabzheniya-smart-grid-i-problemy-s-kiberbezopasnostyu>. [Accessed: 04-Sep-2019].
- [12] C. Prinz, F. Morlock, S. Freith, N. Kreggenfeld, D. Kreimeier, and B. Kuhlentötter, 'Learning factory modules for smart factories in industrie 4.0', *Procedia CIRP*, vol. 54, pp. 113–118, 2016.
- [13] A. I. Levina, A. S. Dubgorn, and O. Y. Iliashenko, 'Internet of Things within the Service Architecture of Intelligent Transport Systems', in *2017 European Conference on Electrical Engineering and Computer Science (EECS)*, 2017, pp. 351–355.
- [14] M. Hermann, T. Pentek, and B. Otto, 'Design principles for industrie 4.0 scenarios', in *2016 49th Hawaii international conference on system sciences (HICSS)*, 2016, pp. 3928–3937.
- [15] M. Lankhorst, Ed., *Enterprise architecture at work: modelling, communication, and analysis*. Berlin ; New York: Springer, 2005.
- [16] M. Hashmi, S. Hänninen, and K. Mäki, 'Survey of smart grid concepts, architectures, and technological demonstrations worldwide', in *2011 IEEE PES conference on innovative smart grid technologies latin america (ISGT LA)*, 2011, pp. 1–7.
- [17] V. Haren, 'TOGAF Version 9.1 A Pocket Guide', 2011.
- [18] A. Josey, *TOGAF® Version 9.1-A Pocket Guide*. Van Haren, 2016.
- [19] 'Smart grid - ot analoga k cifre, ili kak rabotayut umnye seti. Vse o proekte umnye seti', 'Smart grid - ot analoga k cifre, ili kak rabotayut umnye seti. Vse o proekte umnye seti. | iot.ru Новости Интернета вещей'. [Online]. Available: <https://iot.ru/wiki/umnye-elektroseti>. [Accessed: 04-Sep-2019].
- [20] "Istoriya dvuh pilotnykh proektov v oblasti Smart Grid", Portal ob energetike v Rossii i v mire: 'История двух пилотных проектов в области Smart Grid', *Портал об энергетике в России и в мире*, 03-Jun-2016. [Online]. Available: <http://peretok.ru/articles/freezone/12960/>. [Accessed: 04-Sep-2019].
- [21] H. Khurana, M. Hadley, N. Lu, and D. A. Frincke, 'Smart-grid security issues', *IEEE Secur. Priv.*, vol. 8, no. 1, pp. 81–85, 2010.
- [22] A. Zaballos, A. Vallejo, and J. M. Selga, 'Heterogeneous communication architecture for the smart grid', *IEEE Netw.*, vol. 25, no. 5, pp. 30–37, 2011.