INNOVATIVE ENERGY DEVELOPMENT BASED ON THE INTELLIGENT NETWORKS OF SMART GRID CONCEPT

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ABSTRACT

The article deals with modern global energy trends and "intelligent networks" bases. It defines fundamentals of the modern Smart Grid concept and its specific implementation in the leading countries of the world. It also covers the peculiarities of smart grids evolution, advanced forms and directions of Smart Grid development and its implementation.

Key Words: *sustainable development, intelligent energy, Smart Grid, alternative energy, network*

JEL Code: *E 21, E 27, O10, Q 420, Q 430, Q 480*

1. INTRODUCTION

Smart electricity has become a vector of energy policy in many countries. The global competition in the energy efficiency of the economy in recent years has largely passed in the areas of smart grids. Key objectives in the implementation of intelligent networks are energy security, economic growth and environmental sustainability. In the leading countries the intelligent network is an important part of government strategy to achieve the overall objectives of energy security and low carbon economy growth. Intelligent Network is a natural stage of social and economic relations that are embodied in technological concept. Their creation is a modernization of the whole complex of generation and delivery of electricity through the improved management, protection, optimization of power system elements in their relationship - from centralized and dispersed generation, transmission of high voltage electricity, its distribution, automation systems and storage devices to end-users (Varivodov 2011: 5).

The aim of the article is to systematize the main Smart Grid fundamentals, creating "smart" power grids, the major systems of engineering and information resources necessary for the practical implementation of "smart" networks, as well as identifying and forecasting advantages and disadvantages of the concept with a view to possible further analysis of energy system upgrading.

To achieve the aim we put and solved following tasks:

- ❖ Definition of the basic objectives and key requirements of Smart Grid technology energy systems;
- ❖ Examination of trends and economic risks when introducing Smart Grid concept to the EU countries and the USA;
- ❖ Definition of some technical and economic advantages and disadvantages of using Smart Grid technology;
- ❖ The economic assessment of the main effects of Smart Grid concept implementation.

2. THE SMART GRID CONCEPT FUNDAMENTALS

The report of the American Council on energy efficient economy (American Council for an Energy-Efficient Economy, ACEEE) (Elliott at al. 2012) shows that the current level of energy consumption in the United States can be reduced by 22% if introducing a so-called "intellectual energy efficiency". The point is to abandon the approach to energy efficiency in terms of individual devices and appliances, such as a car or a refrigerator and go to complex systems thinking categories (cities, transport systems and other networks), interconnected through the Internet and computer cybernetic technologies. The report draws the conclusions that ancestral energy efficiency methods are fading. Previous achievements in the field of energy saving largely depended on the improving of specific products, appliances and equipment - light bulbs, electric motors and automobiles. The technological upgrade of individual devices will certainly retain its significance. But to meet the future challenges in the energy sector we should look ahead and apply a systematic approach to scaling up energy efficiency. Utilities systems, "smart" cities, transport systems and communication networks based on intellectual performance may become a new reality to support the national economy, ensure its growth and prosperity even in the face of resource depletion (Levchenko 2012: 47).

Smart Grid Technologies provide balance of power generation and power consumption by optimizing the power system management, including cases of emergency outage. This innovative approach in the EU and North America, despite the high cost solutions, is now much better compared with the extensive build-generating capacity.

The term Smart Grid still has no common interpretation. Table 1 shows the main approaches to the definition of «Smart grid».

Table 1. *The «Smart Grid» Basic Definition*

Source	***Defining***
European Technology Platform (2006)	Electrical networks that meet the future requirements of energy efficiency and economic operation of power through coordinated management and using advanced two-way communications between the elements of power networks, power plants, accumulating devices and consumers.
USA Department of Energy (2003)	Fully automated energy system that provides two-way flow of electricity and information between power plants and devices everywhere. Smart Grid through the use of new technologies, tools and methods fills electricity with "knowledge" that can dramatically increase the efficiency of the energy system.
The National Energy Technology Laboratory (2007)	The combination of organizational changes, new models of processes and decisions in the field of information technology and solutions in the field of automated process control systems and supervisory control in electric power.
The Institute of Electrical and Electronics Engineers (2009)	The concept of a fully integrated, self-regulating and self-repairing electricity system that has network topology and includes all generating sources, main and distribution networks and all types of electricity consumers run by a single network of information and control devices and systems in real time.

So Smart Grid is a concept of a fully integrated, self-regulating and self-repairing electricity system that has network topology and includes all generating sources, backbone and distribution networks and all types of electricity consumers run by a single network of information and control devices and systems in real time (Yakimenko, 2012: 5).

The main objectives of the creation and modernization of existing energy systems technology Smart Grid (Gurev, 2015: 69):

1) Reducing energy losses in distributed electrical networks.
2) Increase of energy sustainability system as a whole through the creation of distributed generation.
3) Reducing the impact of accidents in the power system during the interruption of electricity supply.
4) Creating simplified conditions for the admission of new electricity generating entrants (solar and wind power plants, small power etc.) to the wholesale electricity market.
5) Reducing the influence of "human factor" on energy system work etc.

Within the Smart Grid concept the requirements of all interested parties (state, consumers, regulators, energy companies, marketing and public organizations, owners, equipment manufacturers etc.) are reduced to so-called key requirements (values) of a new electric power formulated as:

Availability – providing customers with electric energy without limits depending on when and where they need it, and depending on the paid quality;

Reliability – the ability to withstand physical and information negative effects without total outages or expensive recovery, the most rapid recovery (self-healing);

Economy – optimizing electricity tariffs for consumers and system-wide cost reduction;

Efficiency – maximizing the efficient use of all resources and technologies in the production, transmission, distribution and consumption of electricity;

Organic interaction with the environment – the maximum possible reduction of negative environmental impacts;

Security – preventing situations hazardous to people and the environment.

A fundamentally new here is that all key requirements are expected to be considered as equal ones, and the degree of priority and value level is not common and normatively fixed but can be determined and carried out for each energy subject (power company, region, city, household, etc.) individually.

Within the Smart Grid concept, the key requirements (values) are provided by the development of such functional characteristics:

1) Self-healing at emergency disturbances: the power system and its elements must maintain their technical condition at the appropriate level through the identification of a breakdown, its analysis, control and damage prevention.

2) Motivation of active consumer behavior, enabling individual changes of the volume and characteristics (level of reliability, quality etc.) of received energy based on consumer needs and energy system capabilities, using information about prices, volume, reliability, quality etc.

3) Resistance to negative influences: the presence of special methods to ensure the stability and vitality, reducing physical and information vulnerability of all components of the power system and providing its rapid recovery after the accident in accordance with the requirements of energy security as well.

4) Providing the reliability and quality of electric power by moving from a system-oriented approach (System-based approach) to ensure these properties to a customer-oriented one (Customer-based), and support different levels of reliability and quality of energy in different price segments.

5) The variety of types of power plants and electricity system accumulation (distributed generation): optimal integration of accumulating power and electricity of different types and capacities by connecting them to the grid on standardized technical procedures of accession, and transition to the creation of "micro energy system» (Microgrid) on the part of end users.

6) Expansion of power and energy market to the end user: open access to the markets of electricity for active consumers and distributed generation that increases the effectiveness and efficiency of the retail market.

7) Optimization of assets management: remote monitoring of production assets in real time, integrated into corporate management to improve the efficiency and optimization of operating process, repairing and replacement of equipment, and as a result, providing wide reduction costs

3. PRIORITY DIRECTIONS OF THE SMART GRID CONCEPT DEVELOPMENT

Realization of the pulled out key requirements and implementation of their functional properties are considered within the Smart Grid concept to ensure the identification of basic technological areas and technologies or technological basis that require appropriate innovation.

When referring to a technological base we mean here a set of technologies to provide a coherent structure of intermediate and final products and services at a certain stage of industry development. Forming the Smart Grid technological base, the obligatory attention is paid to right technological succession from an existing base to a new one with the lowest possible cost.

Today in the world there is an opinion that a rapid transition to the ideal (standard) Smart Grid model is impossible. In this regard, there are three generations of Smart Grid provided a consistent move to a target model (see. Figure 1): Smart Grid 1.0 – the state of electric power infrastructure, where individual devices and objects of the system can connect to the network without digital uniform standards; Smart Grid 2.0 – the state of electric power infrastructure where the connection to any system units is possible only with the transition to a single IP-protocol and their inclusion in a single integrated IP-network; Smart Grid 3.0 - a flexible energy system based on the principles of decentralized management and equality of the consumer and the supplier.

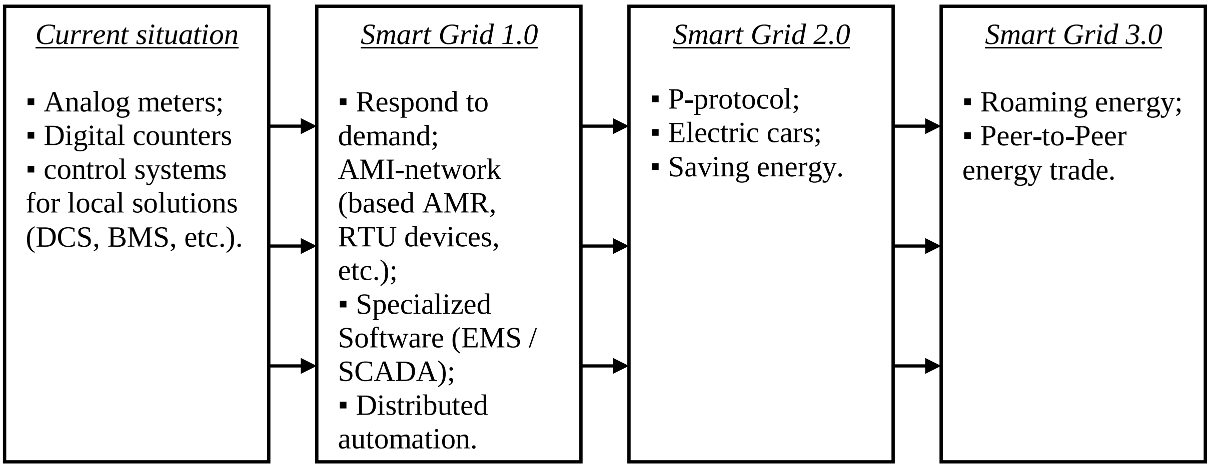

Figure 1. *Smart Grid Generations*

Today there is an actual document entitled 10 Steps to Smart Grids; EURELECTRIC DSOs' Ten-Year Roadmap for Smart Grid Deployment in the EU» (2011). According to this document to implement the intelligent networks in the European market it's necessary to make 10 steps (see. Table 2). They are closely connected and should develop simultaneously. There are three stages of Smart Grid development: promoting national and European levels; deployment in EU member states; large-scale implementation and commercialization at the supranational level (Denisyuk, 2014: 17).

Table 2. *Steps to Smart Grids*

	Step	***2012***	***2013***	***2014***	***2015***	***2016***	***2017***	***2018***	***2019***	***2020***	
Large-scale implementation at national levels	10				Moving to a real consumer participation in Energy market						
	9				The integration of large scale e-mobiles, heating, cooling and storage						
Deployment in states - EU member states	8				Aggregation of distributed energy sources						
	7				The movement to integrate local and central balancing for all types of generation						
	6		Monitoring and management of networks and distributed generation								
	5		The deployment of intelligent measurement - informed customers								
Assistance national and pan European levels	4	Testing with demonstration projects and knowledge sharing									
	3	Setting standards and data protection and confidentiality									
	2	Modeling market									
	1	Ensuring regulatory incentives for investment in innovation network									

The USA positions and develops similar core values and functional properties of the intelligent network. It allocates priorities and sequence of a new concept development based primarily on the specifics of Smart Grid goals and objectives (see. Table 3.). Unlike Europe with its prominent task to find new sources of energy and harmonize major power sector (generation, transmission, distribution and marketing), the US concept of Grid-2030 aims to integrate local companies with a wide range of technological features into a single coordinated grid. This approach can be called as a coherent integration. It develops technologies and mechanisms of power integration starting with the consumer and up to intellectual coordinated management of power system automation technologies through the integration of distribution, transmission and assets management of energy companies. As a part of the Smart Grid concept the United States identifies the following four key priority areas of technology and skills development.

Table 3. *Priority directions of Smart Grid Concept Development in the USA*

AMI Advanced Metering Infrastructure	**ADO** Advanced Distribution Operations	**ATO** Advanced Transmission Operations	**AAM** Advanced Asset Management
Stage of development of technologies and competencies Smart Grid			
I Expands capabilities of a consumer and makes it possible to integrate networks	II Improves reliability and makes self-healing possible	III Allocates overload and integrates with regional distribution companies	IV Helps energy supply companies to reduce costs and work more effectively
Solutions & Technologies			
• Installation of smart meters and software two-way communication • Portal consumer / home network • Data management counters • Consumers informing system • Consumer training	• distribution management system with intelligent sensors and control devices • Demand Management • Automation distribution • Geographic Information System • Work of micro networks • Enhanced "Protection and Control	• Automation of substations • WAMS • High-speed data processing • Tools of modeling, simulation and visualization • Improved digital protection	• «Advanced» Sensors • System Settings • Assets condition • intelligent network integration with other processes • Planning and design • Maintenance • Engineering, design and construction
The expected effects and benefits			
Consumer stimulating expands his opportunities and supports the network	Improved distribution allows self-healing	Advanced transferring system due to deep integration with customers and perfection assets management	The integration of all four phases must significantly increase network effectiveness

4. INTERNATIONAL EXPERIENCE OF SMART GRID CONCEPT IMPLEMENTATION

Currently the work on Smart Grid implementation is rapidly accelerating worldwide. In fact all countries stimulate innovative activity of intellectual energy in the form of public-private partnership. Thus, the state not only forms the favorable regulative field but also gives a considerable financial support to definite programs and projects setting pace and directions for the technological industry updating (Table 4).

In the US, state funding of smart energy development is legislatively a part of the measures on national economy stimulation accepted by Congress. In Canada, the government is actively supporting only a part of Smart Grid technologies that are "clean", renewable energy technologies. At the federal level ecoENERGY is a program for the development of renewable energy (wind, ocean, geothermal, solar, biomass and hydropower) with a budget of about $ 1.5 billion.

Clean energy public-private Fund in the next five years plans to invest in the development of clean technologies $ 795 millions including the federal government support of about 20%.

At the level of the European Union, the adopted R & D program of the pan-European networks development (European Electricity Grid Initiative, EEGI) is co-financed by central funds of the European Union, Member States and the market participants:

- The European Union finances 65-70% of the program in terms of backbone networks development, as well as 30-40% in terms of distribution networks development;
- The EU member states finance 40-50% of the program in terms of distribution networks development;
- Tariff sources of the tariff finance 25-30% of the program in terms of the backbone and 10-30% of distribution networks development;
- Independent market participants' investments account for 5-15%.

Table 4.*Country Case Studies* (**Bennett, 2015**)

	Strengths	*Key Trends*	*Risks*
Canada	• Top Trade Partner. • Policy drivers and facilitative regulations in place. • Market access and high U.S. competitiveness.	• Continued leadership in transition to renewables. • Mature smart meter market with moderate growth. • Opportunities for Time Of Use systems, Demand Response, Energy Efficiency, & other advanced applications.	• Provincial-level regulations are key. • Privacy and cyber security issues currently being addressed.
China	• China's government is making a push to reduce the carbon intensity of its economy, largely through improving energy efficiency • China is planning to install smart meters in every household by 2017 and then institute country-wide time of use pricing for electricity	• Electricity consumption in China is continuing to rise as China's economy continues expanding rapidly, though the nature of economic growth is expected to change, with more growth in the less energy-intensive service industry • China's electricity mix will begin shifting away from coal and toward cleaner energy sources, necessitating the build-out and modernization of grid infrastructure	• U.S. entrants will face a massive challenge in the Chinese market, as local firms supply electricity networks and already have substantial market shares in the smart grid sector
Japan	• The Government of Japan is providing strong support for the development of the energy efficiency, smart grid, and microgrids sectors • Increased amount of renewables in Japan's energy matrix will continue to support the development of smart grids into the future	• The 2011 Tōhoku earthquake and the continued transition of Japan's energy supply mix require electricity management & efficiency solutions • Electricity sector reforms will incentivize utility investment in smart grid and open various segments of the electricity services market to entrants	• Japanese conglomerates and local suppliers already hold strong positions in Japan's smart grid sector • Long project timelines and burdensome technical requirements • Full implementation of electricity sector reforms has yet to be accomplished and there is the risk of diminished achievements.
Turkey	• Electricity demand and grid investment growth • Successful divestment of distribution utilities • Smart Grid working group established as part of Electricity Distribution Services Association (ELDER) with strong commitment to national deployment	• Continued commitment and investment for smart grid and energy efficiency technologies by the Turkish government • Progress towards further energy sector divestment and electricity market reform	• Lack of national coordination in smart grid implementation • Political and economic issues could derail electricity market reform and/or investment

United Kingdom	• Existing regulatory framework facilitates strong funding and returns for smart grid • Government Roadmap in place and commitment and support remain strong • U.S. exporters have already proved highly competitive in U.K. electricity sector	• Smart Meter procurements have begun and major roll-out to begin in late 2015 • Electricity Market Reforms could drive Demand Response and energy efficiency opportunities	• Politics continue to threaten policy and investment in broader energy sector • Potential under-achievement of capacity markets and renewables development • Consumer smart grid adoption and energy efficiency programs could under-perform • Continued delays to UK smart meter rollout resulting from technical issues and public resistance

In addition to European countries, America and Canada and more other states realize the need of radical modernization of electrical networks and are investing significant public funds in their studying and development. Thus, China is seriously concerned about the possibility of creating an effective energy system. JUCCCE Company (China National Cooperative grid) in China is engaged in stimulating interest in Smart Grid concept, plans its implementation and organizes various meetings and symposia.

5. TECHNICAL AND ECONOMIC ADVANTAGES AND DISADVANTAGES OF THE SMART GRID CONCEPT

Considering the above material, there are such advantages of Smart Grid:

- Cuts in expenditure for building new power plants through the significant improvement of the efficiency of existing ones;
- Cuts in expenditure for maintenance and support of existing power networks;
- Reducing downtime in the electric network after emergency situations due to the equipment ability to full or partial self-healing;
- General reliability improvement of the electricity network by increasing its resistance to various kinds of disturbances, such as voltage fluctuations, overload, etc .;
- Decline of electric power losses in transmission lines and increase of its transit volumes without building new infrastructure networks due to the use of electric devices FACTS;
- Providing a more uniform load distribution on power plants (especially during peak electricity consumption time) due to accumulation of commutation devices through the use of distributed generation plants;
- Reducing the negative impact of power grids on the ecological environment;
- Promoting the development and dissemination of environmentally friendly transport technologies – electric cars;
- Promoting the development and dissemination of "smart" home, "smart" cities technologies, etc.;
- Reducing the cost of generation and transmission of electricity to the end users of any scale;

- Enabling to collect as much information about the state of any electrical network node in real time to implement more flexible control and management of the entire electricity system;
- Identifying and prevention of network equipment damage and theft of electricity through monitoring the network in real time.

But we should not forget that the implementation of the Smart Grid concept may also have the following significant disadvantages:

- A significant (30%) increase in the general level of electricity consumption caused by the need for large numbers of additional "smart" equipment (device management, monitoring, collection, storage, data processing etc.).
- Inability to provide full protection of "smart" electrical grid from criminal attacks because of the inability to ensure absolute protection of data transmitted via information network (which is still not safe even with the use of existing protocols and encryption coding);
- Electricity loss in the case of using renewable energy generating sources due to various energy transformations;
- Possible instability in the entire grid, caused by lower volumes of electricity generated by renewable sources, due to adverse weather conditions;
- Considerable expenditures for the concept development in Ukraine (e.g. approximate cost of power equipment purchase for electrical network without increasing power generation is 500 million dollars) (Ivanets, 2013).

6. ECONOMIC ESTIMATION OF KEY EFFECTS OF SMART GRID CONCEPT

Studies show that transformation of the current energy system to the one based on Smart Grid has a number of effects. Estimations of economic and environmental effects of the US Smart Grid energy system in future made by American researchers is presented in Table. 5.

Overall effect and business benefits resulting from the introduction of Smart Grid concept can take many forms:

- A safer production process by increasing the reliability of electricity supply;
- Increasing levels of customer satisfaction;
- Sales growth due to a higher level of customer service;
- Production costs cutting as a result of decreasing number of outages during the power system work failures;
- Reducing of the non-renewable energy source usage;

Table 5. *The effect of Smart Grid Concept Implementation*

Settings	Basis	Energy System without Smart Grid (1)	Energy system based on Smart Grid (2)	Ratio indices (2) to that of (1)%
	2000 year	2016 year		
Energy consumption (Bln. KW • h).	3,800	5,800	4,900–5,200	10–15, decrease
Energy consumption per GDP unit (kW • h. / USD GDP)	0,41	0,28	0,20	29, decrease
Reduced demand at peak loading (%)	6	15	25	66, growth
CO2 emissions (mln. T. Of carbon)	590	900	720	20, decrease
The level of productivity growth (% / year)	2,9	2,5	3,2	28, growth
Real GDP (billion. Dollars).	9,200	20,700	24,300	17, growth
The size of economic business loss (bln. dollars).	100	200	20	90, decrease

- new job creation and GDP potential growth;
- the possibility to modernize energy system based on the integration of energy assets in the field of generation, transmission, distribution and accumulation of electricity;
- promotion of energy efficiency through customers informing programs about the tariff menu;
- reduction of renewable energy sources variability;
- integration of electric vehicles, distributed power sources working due to wind and solar energy and other forms of distributed generation power;
- reduction of workers departures on accident places for a rapid diagnostics and of a number of interruptions and electric power overpayments for automatic disconnecting and reconnecting;
- the transition from scheduled maintenance to the state machinery service through the observation in real time;
- reduction of equipment overloading risk through the use of operative state information network due to Smart Grid monitoring technologies;
- reduction of distribution electricity losses for more than 30% by optimizing the productivity of power plants and balance;
- attracting investment and deep introduction of information technologies in network, thus allowing businesses to use cyber security more effectively;
- increasing network resistance of individual components to external environmental influences, aging conditions or due to intentional damage;
- capability of network components and systems based on information technologies to identify the first signs of intrusion attempts and to notify the organizations responsible for cyber security in real time.

VII. CONCLUSION

The study allowed formulating the following key areas of Smart Grid:

- Realization of state policy in the Smart Grid concept development;
- The "road map" fundamentals of the Smart Grid introduction and its implementation;
- Smart Grid "ecosystem";
- Increasing capacity and efficiency of operating systems;
- Enabling economic and legislative mechanisms to speed up the introduction of advanced concepts, initiatives and solutions at the state level;
- The integration of telecommunications and energy infrastructure;
- Interaction of distribution and transport systems;
- Energy delivery and sales to the end-user;
- Automated measurement, data collection and accounting;
- Data processing technologies in Smart Grid networks;
- Ensuring the confidentiality and security of Smart Grid;
- Distributed and remote data collection and control devices;
- The role of telecommunication operators and machine-machine interaction operators with M2M construction and management of Smart Grid networks;
- Data centers power industry;
- Development of alternative energy;
- Alternative Energy, Smart Grid and Microgrid.

Thus, a predicted cumulative effect of the energy system conversion into intelligent Smart Grid suggests it to become a powerful catalyst for global economic growth and a driver of technological change. While being formed, the IEC should be primarily focused on the requirements associated with neoindustrial development, the appearance of new markets and business models, the formation of a new lifestyle and social practices. Actually forming of a unified technical Smart Grid policy can only occur in constant interaction of various specialists.

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