ТЕХНОЛОГІЇ ТА ОБЛАДНАННЯ В ЕНЕРГЕТИЦІ

TECHNOLOGIES AND EQUIPMENT IN ENERGY

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Y. Rudniev[1], Dr. Sc. (Eng.), Assoc. Prof., ORCID 0000-0002-4236-8407
J. Romanchenko[1], Cand. Sc. (Eng.), Assoc. Prof., ORCID 0000-0001-6579-6474
[1]Volodymyr Dahl East Ukrainian National University

COMPREHENSIVE CONDITION ANALYSIS AND PERSPECTIVES OF ENERGY DEVELOPMENT IN UKRAINE ACCORDING TO THE SMART GRID CONCEPT

The article examines development trends of the energy complex of Ukraine, possibility and prospects of creating a modern energy complex through the use of an innovative technical base for energy management in accordance with the Smart Grid concept. The general properties of Smart Grid technology and its main advantages are given by authors. It is shown that within the framework of the Smart Grid concept, the intelligent electric power system is considered as a single network of information and control systems. The process of electric power industry modernization in the direction of the creation of "smart" power supply networks in a number of European countries, which aims to ensure stable development, economic growth, growth of living standards and protection of the natural environment, is considered. The paper describes modernization methods of the electric power complex of Ukraine based on foreign experience. It is shown that from the point of view of energy security and sustainable development, Smart Grid is able to ensure the operation of the power grid even in case of damage or destruction of one segment, which is a key advantage during post-war reconstruction. They will also make it possible to effectively integrate renewable generation and energy storage systems into the grid, as well as provide auxiliary services for forecasting the power system operation. The paper analyzes the problematic issues of implementing the Smart Grid concept in Ukraine. They include the lack of technological solutions and methods that provide an effective algorithm for determining the state of power networks cyber security; large length of power distribution networks and insufficiently developed infrastructure. A comparative description of the existing energy systems functional properties and energy systems based on the Smart Grid concept is presented in general. An analysis of possible ways of electric power industry development was carried out, which showed the presence of serious limitations of electric power industry development within the framework of the former concept, based mainly on the improvement of certain types of equipment and technologies. It is shown that Ukraine is at the initial familiarization and formation stage of the first organizational initiatives for Smart Grid, namely the implementation of the government-approved Concept of the "smart grids" introduction in Ukraine for the period up to 2035. The purpose and expected results of this Concept implementation are considered.

Keywords: *Smart Grid, power supply, energy efficiency, energy systems, renewable energy sources, intelligent meters.*

Introduction

Currently, there are certain problems in the field of electric power of Ukraine, the main of which is the significant wear of the power network complex, as a result the power networks cannot withstand the load. The high level of wear of main and auxiliary power system equipment and the uneven distribution of the load in the network often lead to emergency situations and power outages.

The modern development of the electric power industry on a global and national scale must correspond not only to the new goals and development trends of the world and national economies of countries in the 21st century, but also to the new types of economy, ecology and social.

Russian military aggression against Ukraine significantly complicates the problems of ensuring regular operation of energy supply systems of enterprises and the population. Thus, during the war, more than 227 enterprises, plants and factories were damaged or destroyed, about 4% of generating capacities were destroyed during hostilities, another 35% of capacities are located in the occupied territories. About 50% of thermal generation, 30% of solar generation, and more than 90% of wind generation were destroyed or are located in the occupied territories, oil refineries were also partially destroyed [1].

After disconnecting in February 2022 from the remnants of the Soviet energy system and joining the ENTSO-E network in March 2022, the transition of Ukrainian energy workers to equipment and management protocols according to international standards has become more relevant than ever. Ukraine's post-war recovery efforts to modernize the economy, decarbonize industry and increase the production and supply of renewable energy to Europe are intended to accelerate this process. One of its key elements is the development of Smart Grid, i.e. "smart energy networks".

Purpose of work

Research and comprehensive analysis of Ukrainian electrical networks development in accordance with the concept of Smart Grid to increase the distribution informativeness, transmission and consumption of electrical energy during the post-war reconstruction.

Research material

Smart Grid is a concept of a fully integrated, self-regulating and self-healing electric power system, which has a network topology and includes all generating sources, trunk and distribution networks and all types of electric energy consumers, managed by a single network in real time. Today, the phrase "intellectual energy" is becoming a term denoting new principles of energy work, both in Ukraine and abroad. Modern electronic, information, telecommunication, computing technologies improve the processes of energy production and energy flows management at the enterprises, make them reliable, safe and efficient, and provide the consumer with new opportunities [2].

Significant changes have taken place in the world regarding the energy development strategy. A set of tasks was defined for different countries to build energy strategies of the 21st century. The main focus is on providing three components: energy supply (uninterrupted supply of electrical energy of appropriate quality), energy availability (energy saving and an affordable price for electricity) and energy acceptability (minimum impact on the environment). These components are considered as the basis for achieving the global goal of ensuring stable development, which guarantees the sustainable growth of the economy, the living standards and environment protection [3].

In a number of European countries, the process of electric power industry modernization in the direction of creating "smart" power supply networks has been going on systematically and consistently for a long time. "Intelligent" management of the power grid provides automation, transmission control in both directions of energy at all stages – from the power plant to the consumer. Today, the largest programs are carried out in the USA, Canada and all the countries of the European Union, especially in Latvia, Italy, France, and Germany [4]. Similar projects will be implemented in large developing countries: India, Brazil, Mexico. It is planned equip all consumers with smart meters in the USA, China, Brazil, and Japan. Smart Metering is a useful element of the "smart energy network" for consumers. They are installed at home or office and can provide near-real-time data on energy consumption, helping to make informed decisions about how much energy to use and at what time. Such meters are able to monitor the energy consumption of each device and maintain certain rules of behavior during peak load hours. Not only consumers can get benefits from this, but also energy companies that are interested in increasing the efficiency of their processes (thanks to remote control of meters) [5].

In Ukraine, work by the implementation of the latest technologies in the national energy system began relatively recently. For example, since 2014, the Belgian company Tractebel has been engaged in the development and implementation of the pilot technologies and Smart Grid projects at the level of the system operator - NEC "Ukrenergo". Distribution system operators are also gradually trying to implement elements of smart electric grids. The Smart Grid project is being implemented within the framework of the Electricity Transmission Project, financed by the IBRD with the assistance of the Clean Technologies Fund. The goal of this project is to reduce CO_2 emissions by ensuring the technical possibility of increasing the generation share from renewable energy sources (RES) in the country's overall energy balance [6, 7]. The result of Smart Grid implementation should be the creation of an energy information network.

As part of the Smart Grid concept, the intelligent electric power system is considered as a single network of information and control systems that provides (Fig. 1):

• integration of all types of generation (including small generation) and any types of consumers (from households to large industry) for situational management of demand for their services and ensuring their active participation in the energy system operation;

• real-time change of network parameters and topology according to current operating conditions, excluding the occurrence and development of accidents;

• expansion of market opportunities of the infrastructure through mutual provision of a wide range of services by market entities and infrastructure;

• minimization of losses, expansion of self-diagnosis and self-recovery upon compliance the conditions of electricity reliability and quality;

• integration of power grid and information infrastructure to create an all-mode control system with full-scale information support.

The following advantages of the Smart Grid infrastructure can be highlighted:

• network infrastructure stability, which continues to work even in case of damage or destruction of one segment;

• development of RES, distributed generation, storage systems and green energy transition;

• Digital Twin technology, which allows modeling and forecasting of modernized network operation;

• a flexible system that helps consumers become suppliers through electricity generated on home solar panels or through used car batteries.

Therefore, from the point of view of energy security and sustainable development, Smart Grid is able to ensure power grid operation even in case of damage or destruction of one segment, which is a key advantage for Ukraine in wartime and post-war reconstruction. They also enable the efficient integration of renewable generation and energy storage systems into the grid, as well as providing support services for forecasting of the power system operation.

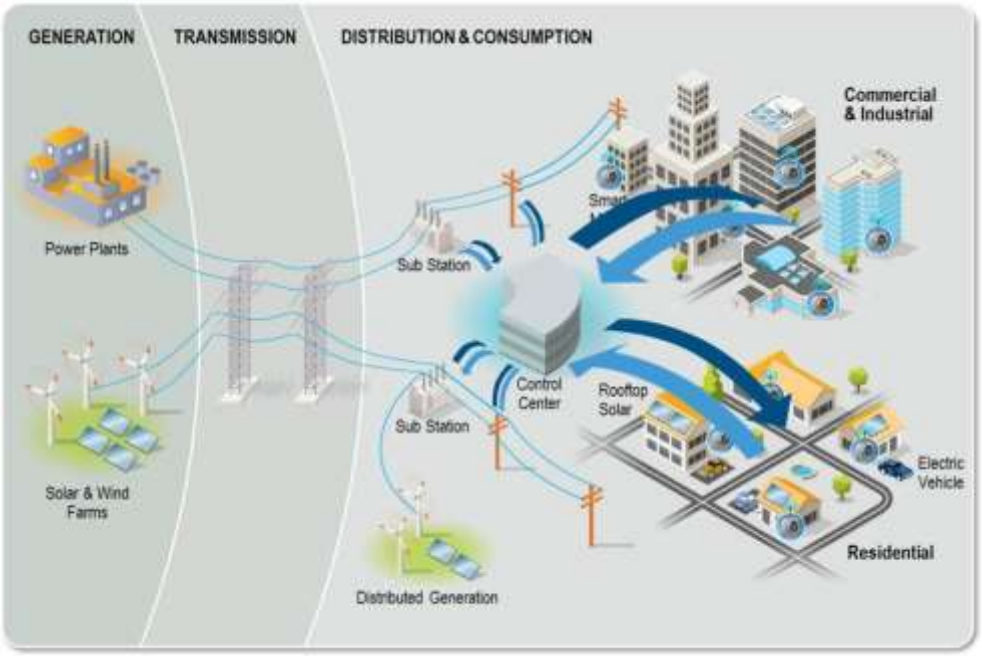

Figure 1. *Intelligent electric power system scheme based on Smart Grid concept*

Problematic issues include the lack of technological solutions and methods in Ukraine that provide for an effective algorithm for determining the state of power networks cyber security, it is also necessary to take into account the large length of power distribution networks in our country and insufficiently developed infrastructure. For the successful implementation of "smart networks", it is necessary to use successful world and European experience, as well as developed and tested standards and recommendations, in particular, of the International Electrotechnical Commission (IEC), the International Organization for Standardization (ISO), the International Telecommunication Union (ITU) and the European Committee for Electrotechnical Standardization (CENELEC).

Currently, significant and rapid changes are taking place in the electricity sector of Ukraine, some of which pose certain threats to energy system reliability and safety. The electric power industry of Ukraine operates within the framework of a market model, where power plants (generating units) are dispatched in accordance with market requirements, and the power grid control center performs a general control role – balancing active power and providing auxiliary services to maintain the reliability and quality of electric power. Table 1 summarizes the comparative characteristics of functional properties of existing energy systems and energy systems based on the Smart Grid concept.

The conducted analysis of electric power industry development showed the presence of serious limitations within the framework of the former concept, based mainly on the improvement of certain types of equipment and technologies. One of the directions of energy sector development is the intelligent systems implementation. It is expected that the development and implementation of the functional properties discussed above will significantly increase the electric power industry efficiency and ensure the expected benefits for all interested parties.

In Ukraine, we can still note the initial stage of familiarization and formation of the first organizational initiatives on Smart Grid, as well as testing of individual technical solutions. However, we already have the first initiatives in this field [8]. Thus, on October 14, 2022, the government approved the Concept of the implementation of "smart networks" in Ukraine for the period until 2035. The document, developed with the support of the World Bank, provides the development of the energy system on modern principles [9, 10]. The purpose of this Concept

is to define directions and tasks, as well as to ensure the coordination of actions for the implementation of "smart networks" taking into account the existing and planned state and regional programs for the development and modernization of the energy sector.

Table I. Comparative characteristics of functional properties of existing energy systems and energy systems based on the Smart Grid concept

Energy system today	Energy system based on the Smart Grid concept
One-way communication between elements or its absence	Two-way communications
Centralized generation – distributed generation with low integration	Distributed generation
The topology, mainly radial	Mostly network
Reaction to accident consequences	Reaction to accident prevention
Equipment operation until failure	Monitoring and self-diagnostics, which extend the equipment operation
Manual recovery	Automatic recovery – "self-healing networks"
System crash proneness	Prevention of the system accidents development
Manual and fixed network selection	Adaptive selection
Inspection of equipment on site	Remote equipment monitoring
Limited control of power flows	Management of power flows
Unavailable or very late information about the price for the consumer	Price in real time

The expected results of the Concept implementation are [9]:

• improvement of the electricity supply reliability and quality, operational characteristics and overall productivity of the entire energy sector;

• increasing of operational efficiency, effective integration of distributed generation, providing remote monitoring and diagnostics, optimization of the use of assets and resources, improvement of the power grids configuration;

• increasing the energy efficiency level, which will reduce networks losses of transmission system operator and distribution system operators, improve the efficiency of load management (active and reactive), reduce the level of carbon emissions (the expected reduction in the level of electricity technological costs by 2030 is at least 30%);

• reduction of frequency and duration of consumer outages;

• providing consumers the opportunity to manage electricity consumption, reduce energy costs (expected reduction of the average duration index of electricity supply long interruptions and the Electricity not Supplied (ENS) index by 2030 in three times).

Therefore, the implementation of Smart Grid technology will significantly increase the reliability and economy of the energy system of Ukraine, and improve the consumers service quality. Today, a large number of green energy projects have already been launched and operating in Ukraine, "intelligent" management systems of energy generation, transmission and consumption are being introduced. Despite the risks connected with the implementation of energy-saving projects, the current legal framework provides investors sufficient incentives and mechanisms to ensure the successful implementation and development of green energy and Smart Grid projects in Ukraine.

Conclusions

The application of "smart grid" technologies will cover the work of the entire energy sector and will have long-term benefits for energy companies and end consumers. Energy companies that will apply "smart grid" technologies will be able to receive significant benefits due to the reduction of capital and operating costs, improvement of the electric energy quality, increase in the level of consumer needs satisfaction and positive impact on the environment.

In addition, the results of the "smart grid" technology implementation are the power grid operation transparency – obtaining data about the entire power system state with the transmission of data from equipment and meters, as well as control commands in real time; ensuring of the power grid operational management; power system automation – quick adaptation to changing conditions with minimal intervention of dispatcher (operator); increasing of the invoicing accuracy, prevention of electric energy theft and fraud, detection of violation cases of legislative requirements; reduction of losses in electric energy transmission and distribution systems due to improvement of system planning and asset management.

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Є.С. Руднєв[1], д-р техн. наук, доцент; ORCID 0000-0002-4236-8407
Ю.А. Романченко[1], канд. техн. наук., доцент; ORCID 0000-0001-6579-6474
[1]Східноукраїнський національний університет імені Володимира Даля

КОМПЛЕКСНИЙ АНАЛІЗ СТАНУ ТА ПЕРСПЕКТИВИ РОЗВИТКУ ЕНЕРГЕТИКИ УКРАЇНИ ВІДПОВІДНО КОНЦЕПЦІЇ SMART GRID

У статті розглядаються тенденції розвитку енергетичного комплексу України і можливість та перспективи створення сучасного енергетичного комплексу за рахунок використання інноваційної технічної бази управління енергією відповідно концепції Smart Grid. Авторами наведено загальні властивості технології Smart Grid та сформульовані основні її переваги. Показано, що у рамках концепції Smart Grid інтелектуальна електроенергетична система розглядається як єдина мережа інформаційно-керуючих систем. Розглянуто процес модернізації електроенергетики в напрямку створення «розумних» мереж електропостачання у ряді європейських країн, який має на меті забезпечення стабільного розвитку, зростання економіки, рівня життя населення та захист навколишнього природного середовища. В роботі описані способи модернізації електроенергетичного комплексу України спираючись на закордонний досвід. Показано, що з погляду енергобезпеки та сталого розвитку Smart Grid здатні забезпечити роботу енергомережі навіть у разі пошкодження або руйнування одного сегменту, що є ключовою перевагою під час повоєнного відновлення. Вони також дозволять ефективно інтегрувати відновлювану генерацію та системи накопичення енергії в мережу, а також надавати допоміжні послуги з прогнозування роботи енергосистеми. В роботі проаналізовано проблемні питання впровадження концепції Smart Grid в Україні. До них належить відсутність технологічних рішень та методик, що передбачають дієвий алгоритм визначення стану кібербезпеки електромереж; велика протяжність електророзподільних мереж і недостатньо розвинена інфраструктура. Узагальнено представлено порівняльну характеристику функціональних властивостей діючих енергетичних систем і енергетичних систем на базі концепції Smart Grid. Проведений аналіз можливих шляхів розвитку електроенергетики, який показав наявність серйозних обмежень можливостей розвитку електроенергетичної галузі в рамках колишньої концепції, заснованої переважно на покращенні окремих видів обладнання і технологій. Показано, що Україна знаходиться на початковому етапі ознайомлення і формування перших організаційних ініціатив по Smart Grid, а саме реалізації схваленої урядом Концепції впровадження «розумних мереж» в Україні на період до 2035 року. Розглянуто мету та очікувані результати реалізації цієї Концепції.

Ключові слова: *Smart Grid, електропостачання, енергоефективність, енергетичні системи, відновлювальні джерела енергії, інтелектуальні лічильники.*

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