UDC 621.316
DOI https://doi.org/10.32838/2663-5941/2022.4/24

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FEATURES OF SMART GRID TECHNOLOGIES INTRODUCTION IN THE ENERGY INDUSTRY

Modern power system technologies offer the integration of renewable energy in electricity grids, smart metering, bidirectional communication between decentralized power generation units and a central control system for energy production and consumption. Moreover, the modern energy system requires control, measurement and cybersecurity of energy processes at every point of the grid. The paper considers the introduction of intelligent smart systems in the future, as it has the ability to protect against cybersecurity by expanding the network system for seamless integration of renewable energy sources such as wind, electric vehicles and battery systems using power electronics, solar, which provides smart metering monitor and control energy by mitigating fluctuations in voltage, frequency and current, creating good harmonization between producers, consumers, network operators and the state. As a result, building a Smart Grid is a complex task, starting with a detailed quantification of system requirements, determining the actual goals and the levels of operation needed to achieve them. This research will be an effective and efficient tool for researchers, engineers, transmitter operators and distributors to transform the classical national energy system into an intelligent energy system. The implementation of the Smart Grid concept is impossible without large-scale physical upgrades of generating and network equipment, ensuring the management of technological processes and economic interactions from the local to the national level. It is in the field of power management and development systems that the largest changes are taking place, which should lead to a qualitative transformation of energy supply conditions by increasing levels of automation, information and intelligence at all levels of power management systems and market operations.

Key words: *Smart Grid, power systems, power grids, intelligent control, power distribution control systems.*

Formulation of the problem. Today, many developed countries are implementing scenarios of the so-called energy transition, in which modern energy is transformed into customer-centric energy systems. There is a transition from traditional models to new ones that use significant amounts of dispersed generation, including renewable energy sources and storage devices. Markets are becoming decentralized, infrastructure is becoming intelligent, and consumers are moving to active, prosumer patterns of behavior. The components of the currently dominant energy paradigm that emerged in the late 1920s are: the dominance of hydrocarbon-based electricity sources; large vertically integrated energy companies; centralized electrical networks; unidirectionality of electricity flows – from the generator to the consumer; simultaneity of electricity production and consumption processes; widespread use of fossil fuels in industry and transport. Components of the future (new) power energy that are currently being formed: "clean energy"; deep decentralization of energy production; increasing the role of electricity in the structure of consumption of fuel and energy resources; decentralized markets, private investment; intellectualization of basic infrastructure, development of Smart Grid technologies; the transition of consumers to active patterns of behavior; energy storage technologies; increasing energy efficiency; increasing levels of electrification of industry and transport. Drivers of new changes are technological advances in other areas, especially in the fields of transmission and processing of information, information and communication technologies, power electronics and modern methods and models of large systems management.

Analysis of recent research and publications. The classic grid infrastructure, from electricity generation to end users, includes several power devices for the safe and efficient transmission of power generated by the power plant to end users. Such power devices are electric generators, transformers, power switches, transmission and distribution lines, utility meters, relays and fuses. Therefore, each of these components has its potential problems due to old technologies. On the other hand, modern energy system technologies offer integration of renewable energy in electricity networks, smart metering, bidirectional connection between decentralized power generation units and central control system for production and consumption of energy. Moreover, the modern energy system requires control, measurement and cybersecurity of energy processes at every point of the grid.

If any classical energy system is integrated with information and communication technology, the electrical network is transformed into a smart grid and provides a two-way connection between electricity generation and the central control system of energy production and consumption. Smart Grid is a kind of sophisticated technology that not only provides two-way communication, but also has several different aspects, such as accessibility, efficiency, accuracy, controllability, economy, flexibility, interoperability, maintainability, measurability, optimality, reliability, stability, stability , security and scalability [1–3]. All these functions of a smart power system make the network quite stable in any power failure, voltage drop, power loss, voltage and frequency fluctuations, overvoltage and current overload. In addition, the smart grid system brings together producers, operators and consumers, as well as energy policy makers. While the classic electricity grid consists only of producers and operators at the national level, the smart grid includes the consumer as a producer electricity.

Thus, all these activities, such as electricity generation, bidirectional communication, integration of renewable energy sources, etc., are in the interests of state technical infrastructures to balance the production and demand for electricity resources.

Power outages or disruptions in the national power system affect millions of people in the country and cause numerous economic losses in terms of business and production, as well as low living standards. In addition, transmission and distribution losses in the world vary from 5 % to 20 % depending on the energy system infrastructure.

Unfortunately, power outages are a common occurrence for Ukrainian consumers. The average duration of scheduled outages for the client in 2019 in our country was 478 minutes. This is three times more than in the European Union. And the average duration of unscheduled outages in our country was 683 minutes, which is 7 times more than in the EU. At the same time, technological losses of electricity for its transmission and distribution in Ukrainian networks amounted to almost 12 % of total output, or more than 1.5 times higher than the European average and more than twice the level of losses in developed countries. The introduction of Smart Grid will help to overcome these and other negative phenomena in the power industry [4].

It is necessary to note the intensive progress in the process of transition to digital, and in fact – to intelligent electricity, which is carried out with the active support of the state in Europe, the United States, Japan and Korea. In particular, new rules are being introduced in European electricity markets, which will further attract RES, increase competition and flexibility of energy systems, increase consumer participation and increase investment [5–10].

Setting objectives. The future introduction of intelligent smart systems is a priority, as it has the ability to protect against cybersecurity, helping to expand the network system for seamless integration of renewable energy sources such as wind, electric vehicles and battery systems using power and solar electronics that enable smart monitor and control energy by mitigating fluctuations in voltage, frequency and current, creating good harmonization between producers, consumers, network operators and the state.

As a result, building a Smart Grid is a complex task, starting with a detailed quantification of system requirements, determining the actual goals and the levels of operation needed to achieve them. This research will be an effective and efficient tool for researchers, engineers, transmitter operators and distributors to transform the classical national energy system into an intelligent energy system.

Presentation of the main research material. The Smart Grid system consists of a bidirectional flow of energy combined with information and communication technologies. All power devices used in the network for monitoring and control are smart and interact with each other.

The structure of the classical power grid (Fig. 1) has four main functions: electricity generation (renewable and non-renewable energy sources, including microgrids), electricity transmission (power transformers, power switches, relays, capacitors, power lines, pylons), power distribution, power transformers, transformers meters, fuses, as well as relays) and electricity consumption (houses, factories, street lamps, electric cars and batteries). All functions have a two-way connection to increase the level of automation, informatization, intelligence at all levels of the power system management system.

In addition, the market and operation are mainly related to government regulation, which takes into account electricity prices, investment, the balance between electricity production and demand, some market standards, the integration of renewable energy systems into the national grid, preferential tariffs and consumer support.

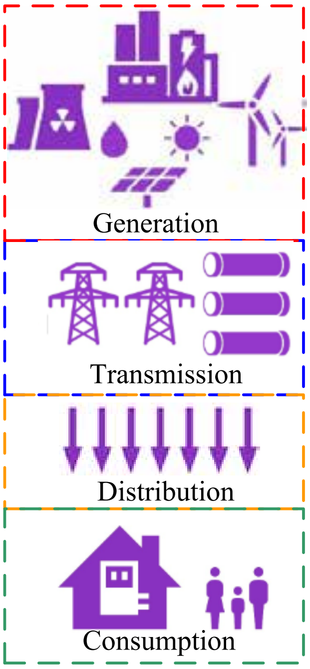

Fig. 1. The structure of the classical power grid

The function of electricity production in fig. 3 has renewable and non-renewable energy sources. Renewable energy sources can be wind, solar, hydro, biomass, biofuels, geothermal, tides and fuel elements, non-renewable energy sources are coal, oil, nuclear and natural gas. However, the concept of a smart grid is to make as more renewable energy sources as possible.

In the current economic conditions in Ukraine there is a significant number of energy-intensive industries, so energy efficiency and energy independence projects are becoming one of the priority areas of development of the fuel and energy complex (FEC) of the country. The unstable situation in the supply and uneven distribution of energy resources, fluctuations in world prices for them leads to the creation of such conditions for the functioning of the fuel and energy sector, which would ensure a stable level of economic growth. Therefore, the strategy to ensure energy independence and reduce energy consumption creates the preconditions for the development and implementation of modern technologies in the fuel and energy sector. Therefore, many studies have been conducted in the literature to include more renewable sources in the smart grid system.

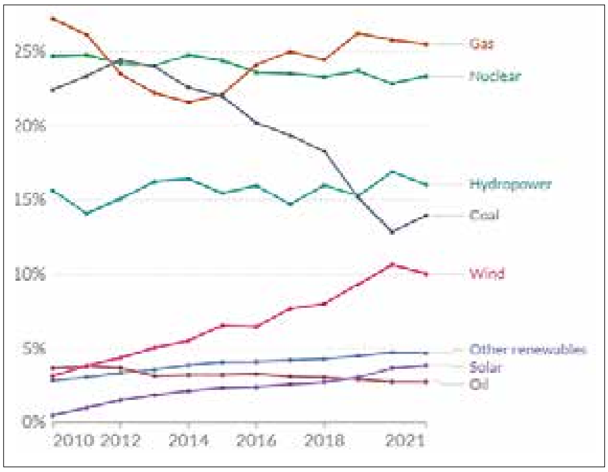

Fig. 2. The share of electricity production in Europe by type of energy resources (2010–2021)

Figure 2 shows the share of electricity production in Europe by type of energy resource. The three main categories of energy for electricity generation are fossil fuels (coal, natural gas and oil), nuclear energy and renewable energy sources. Most electricity is generated by steam turbines that use fossil fuels and nuclear energy. Other power generation technologies include gas turbines, hydro turbines, wind turbines and solar photovoltaic cells [11].

Natural gas remains the main fuel (25%) for electricity generation in Europe, used in steam turbines and gas turbines. Over the last decade, coal has been one of the largest sources of electricity generation, with its share in total production declining from 22% in 2010 to 14% in 2021.

Coal generation is affected by strong price competition from natural gas, wider use of renewable energy sources and, most importantly, new environmental regulations. Currently, new coal-fired power plants are not being built or planned.

Nuclear energy remains one of the main producers of electricity in Europe – 23 %. Nuclear power plants use steam turbines for electricity through nuclear fission.

The largest share of electricity generated by renewable energy sources (34 %) was in hydropower (16 %), the use of wind energy increased from 3 % in 2010 to 10 % in 2021, solar energy (4 %) and others 4 %).

The amount of electricity generated by wind has increased significantly over the last decade. This increase is largely due to the availability of financial incentives and renewable energy targets set by the governments of many countries.

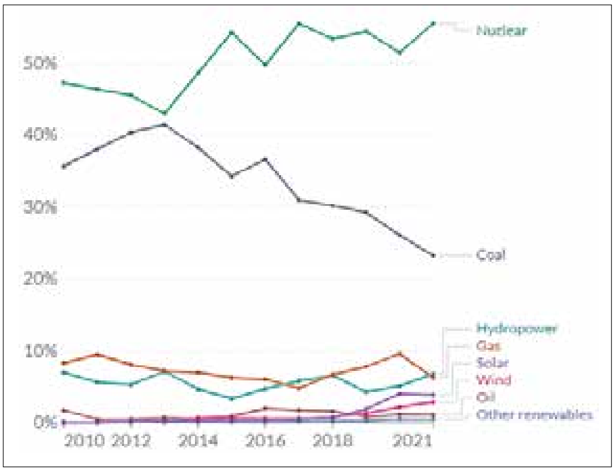

Fig. 3. The share of electricity production in Ukraine by type of energy resources (2010–2021)

In Ukraine, the largest share of produced electricity (Fig. 3) is nuclear (55 %) and coal (23 %) energy. Renewable energy sources are only 14 %. The largest share is hydropower (7 %).

In recent years, solar energy has provided about 4 % of electricity generation in Ukraine. As more and more electricity is generated from renewable sources, the grid must be able to store solar and wind energy. The system must have the intelligence to store excess sun and wind energy for use at night or on cloudy days.

The distribution of electricity for each country by energy source is summarized in fig. 4. It is clear that 42 % of all energy in Europe in 2021 is produced by combustible power plants. Poland and Estonia produce most of their electricity from combustible fuels 83 % and 62 %, respectively.

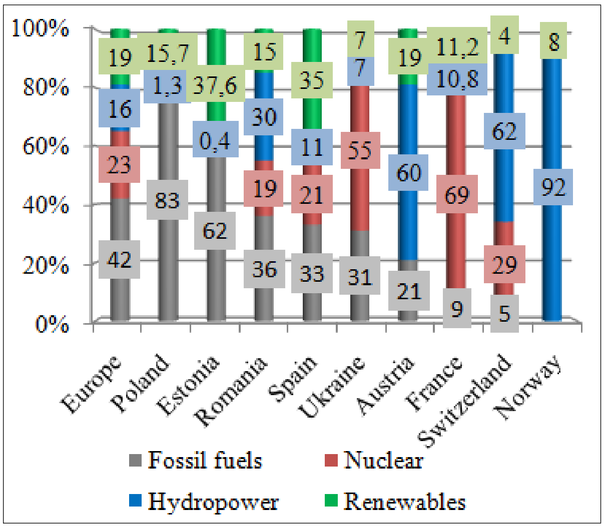

Fig. 4. Distribution of electricity by energy sources, 2021

The second largest source of energy used for electricity generation is nuclear power plants, with a share of 23 %. Its biggest drivers are France (69 %) and Ukraine (55 %).

Hydropower is developed in many European countries (16 %), for example, the share of electricity generated by hydropower in Norway is 92 %, Switzerland 62 %, Austria 60 %, which accounts for more than half of the total distribution of electricity by source in these countries.

Despite the high performance of hydropower in many European countries, the share of renewable energy sources has increased to 19 % in recent years. Estonia (37.6 %) and Spain (35 %) use renewable energy sources to produce electricity, which is a third of the total energy needs of these countries. Also, the use of wind and solar energy increased in Austria (19 %), Poland (15.7 %) and Romania (15 %) [12].

Increasing the share of renewable energy sources in Europe's total energy needs is a way to use natural resources wisely. This is the concern for the health of future generations and the preservation of Red Book plants and animals. Also, these are new highly skilled jobs that will lead to science and education, will create comfortable conditions in a difficult climate without harming the environment. In fig. 5 Renewable energy sources combine several sources of electricity, including hydropower, solar energy, wind energy, geothermal energy, biomass, and waves and tides. It shows the share of electricity generated from renewable energy sources (the sum of all renewable energy technologies) in Europe.

In Europe, in 2021, for the first time, the amount of electricity generated from renewable sources (38 %) exceeded the amount from fuel sources (37 %).

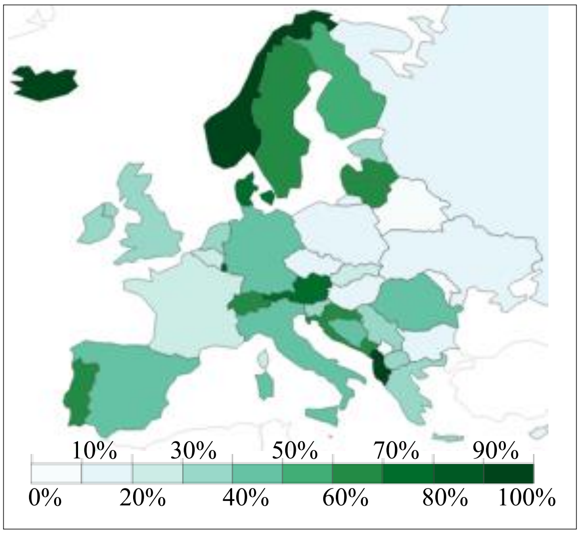

Fig. 5. The share of energy from renewable energy sources in Europe

One-fifth of the EU's electricity has already come from wind and solar systems. The highest percentage was recorded in Iceland (100%), Albania (100%), Norway (99%), Luxembourg (80%), Austria 79%, Denmark (77%), Sweden (67%), Portugal (63%), Latvia (63%), Lithuania (61%).

Europe relies on wind and solar energy to ensure not only the phasing out of coal by 2030, but also the phasing out of gas generation, as well as the replacement of shut-down nuclear power plants and to meet growing demand for electricity for electric vehicles.

In Ukraine, the production and use of energy from renewable sources is much smaller. At the end of 2021, only 7% of the country's electricity comes from solar or wind power. Although the law stipulates that the goal is to receive a quarter of the required amount from alternative energy by 2030, but experts' forecasts are somewhat more modest. It is estimated that at large stations and in private households due to the "green tariff" by the end of its validity will produce from 13 to 20% of electricity [9–14].

The above information and figures underscore the importance of using the Smart Grid worldwide, as many different energy sources are used to generate electricity.

Power transmission systems in fig. 1 include power transformers, power lines, substations, and power switches. The voltage is the highest and the current is the lowest in the transmission lines to reduce costs and losses with thin electrical cables for long-distance power transmission.

As shown in fig. 1, all electricity is transmitted through power lines that can be installed both above ground and underground. The Smart Grid system allows you to measure voltage, current and frequency signals at each point of the power line using voltage and current measuring transformers, as well as a frequency meter for monitoring and control purposes.

The block of distribution of the electric power on fig. 1 starts with a step-down transformer and gives several voltage levels to consumers. All smart meters, ammeters, voltmeters, frequency meters, fuses, switches and relays are included in the electricity distribution. To monitor and control all electrical signals, such as voltage, current, frequency, phase angle, sequence of phases, the distribution unit has several measuring sensors and small transformers. All components of the distribution unit interact with each other.

The unit of electricity consumption in fig. 1 is designed for all types of loads, such as factories, houses, street lamps and electric vehicles. Some consumers may produce their own energy from renewable sources or other types of energy and sell this energy to the grid if the energy produced is not consumed. But in this case, a smart meter is needed to measure the flow of power in both directions.

After providing a brief information about the classic network, it can be combined with communication infrastructures and transformed into a system of Smart Grid, as shown in fig. 6. It consists of a classic network as well as a communication infrastructure that includes wired and wireless technologies to set up a communication system between all electrical units and components in a smart grid. Thus, now the whole system is monitored and controlled from one center. In addition, there is a two-way connection that allows the consumer to be a consumer.

The implementation of the Smart Grid concept is impossible without large-scale physical upgrades of generating and network equipment, ensuring the management of technological processes and economic interactions from the local to the national level. It is in the field of control systems for the operation and development of electricity, the most extensive changes are taking place, which should lead to a qualitative transformation of energy supply conditions by increasing levels of automation, information and intelligence at all levels of control systems and market operations [2].

As explained earlier, the use of smart grids provides a number of tasks for management, monitoring, control, security, as well as simplifies, speeds up and optimizes.

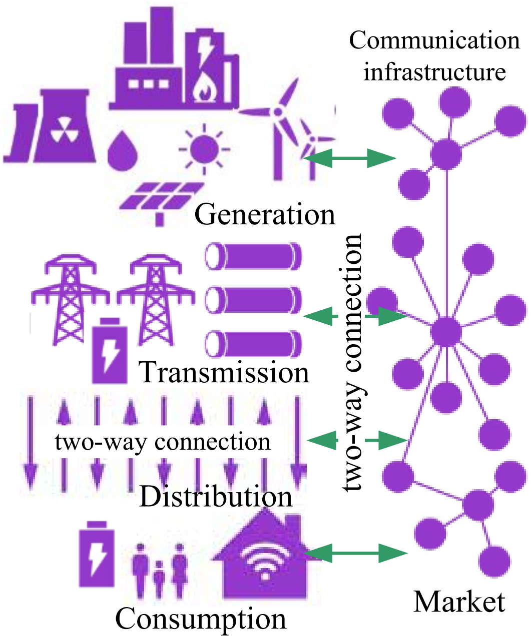

Fig. 6. System of Smart Grid

Conclusions. The value of building energy systems based on the Smart Grid concept is that power companies will be able to "smooth out" electricity needs at peak times, avoid the use of hot reserves and reduce the need for long-term investment in additional generating companies, and reduce the need for other investment.

Key elements of the intelligent power grid: Transparency of work – a complete picture of the state of the power system (data transmission of meters, counters and control commands); possibility of management – transfer of power system to any necessary condition; automation – quick adaptation to changing conditions without user intervention; integration – connection of systems and processes of the electric power enterprise, high intelligence and efficiency of the power system. The presence of these four characteristics, taken together, actually makes the power system intelligent.

Today we can state a combination of three market segments: reliable and flexible networks, intelligent dispersed energy and consumer services. In fact, Smart Grid should be considered as an integrated safe and reliable power system, covering the generation, transport, distribution and final consumption of electricity, the efficiency of which is ensured by operational metering of energy and based on advanced monitoring, communication, analysis and dynamic control. Smart Grid is much broader than technology or hardware, system automation or software development.

The implementation of the Smart Grid concept is impossible without large-scale physical upgrades of generating and network equipment, ensuring the management of technological processes and economic interactions from the local to the national level. It is in the field of power management and development systems that the largest changes are taking place, which should lead to a qualitative transformation of energy supply conditions by increasing levels of automation, information and intelligence at all levels of power management systems and market operations.

Thus, the transformation of a classic network into an intelligent Smart Grid fills its own business areas and provides increased efficiency, loss reduction, flexible price for consumers, safe and stable electricity, as well as reliable and digital infrastructure.

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Лободзинський В.Ю., Бурик М.П., Спінул Л.Ю., Чибеліс В.І., Ілліна О.О. ОСОБЛИВОСТІ ВПРОВАДЖЕННЯ ТЕХНОЛОГІЙ SMART GRID В ЕНЕРГЕТИЧНУ ГАЛУЗЬ

Сучасні технології енергосистеми пропонують інтеграцію відновлюваної енергії в електричних мережах, розумне вимірювання, двонаправлений зв'язок між децентралізованими силовими агрегатами генрації електроенергії і центральною системою керування виробництвом і споживанням енергії., запобігання відключенням електроенергії, стійких та безпечних джерел енергії, а також енергоефективність. Більш того, у сучасній енергетичній системі потрібен контроль, вимірювання та кібербезпека енергетичних процесів в кожній точці електромережі.

В роботі розглянуто впровадження інтелектуальних розумних систем в майбутньому, оскільки вона має здатність захищати від кібербезпеки, сприяючи розширенню мережної системи для плавної інтеграції відновлюваних джерел енергії, таких як вітер, електромобілі та акумуляторні системи з використанням силової електроніки, сонячна, що забезпечує розумний облік, дозволяє спостерігати та контролювати енергію, пом'якшуючи коливання напруги, частоти та струму, створюючи гарну гармонізацію між виробниками, споживачами, операторами мереж та державою. Як наслідок, побудова Smart Grid постає як складне завдання, що починається з детальної кількісної оцінки вимог до системи, визначення фактичних цілей і необхідних для їх досягнення рівнів функціонування. Це дослідження стане ефективним та дієвим інструментом для дослідників, інженерів, операторів передавачів та розподільників, щоб перетворити класичну національну енергосистему на інтелектуальну енергосистему.

Реалізація концепції Smart Grid неможлива без масштабного фізичного оновлення генеруючого і мережевого устаткування, забезпечивши керування технологічними процесами та економічними взаємодіями від локального до національного рівня. Саме у сфері систем керування функціонуванням і розвитком електроенергетики, відбуваються найбільш масштабні зміни, які в результаті мають привести до якісної трансформації умов енергопостачання споживачів за рахунок підвищення рівнів автоматизації, інформатизації та інтелектуальності на всіх рівнях систем керування функціонуванням енергосистеми і ринковими операціями.

Ключові слова: *Smart Grid, енергетичні системи, електричні мережі, інтелектуальне керування, системи керування розподілом електроенергії.*