Possibility Implementation Analysis of the Smart Grid Network in a Current State Conditions of the United Energy Systems of Ukraine

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Abstract

The paper analyzes the current state of the energy system of Ukraine and the efficiency of generation and transmission of electricity. The analysis of the best world practices shows that the active development of modern technologies of energy accounting allows: to bring to a fundamentally new level the quality of data collection and analysis of consumers' energy consumption; increases the efficiency of operational management of energy assets; promotes the active involvement of energy consumers in the processes of regulating their own energy consumption. Ukraine's energy system has been in operation for quite a long time, and it is difficult for it to withstand the load of modern times. The high level of wear of the main and auxiliary equipment of the power system and the uneven distribution of load in the network often lead to emergencies and power outages to consumers. Undoubtedly, increasing the efficiency of electricity generation and supply is an important and urgent task for Ukraine's energy sector. One of the modern and innovative concepts that can significantly affect the quality of electricity transmission is Smart Grid technology. This technology and its capabilities are not new. But the problems that accompany the widespread introduction of Smart Grid in the energy market of Ukraine do not have an unambiguous and effective solution. In this regard, this paper proposes to consider and discuss several scenarios for the implementation of Smart Grid in Ukraine, with an overview of their advantages and disadvantages. In particular, this is a scenario of monitoring and point-by-point implementation of certain Smart Grid technologies; scenario of development of existing and creation of new competencies in the field of Smart Grid; scenario of development and re-implementation of a comprehensive national program of innovative development of electric power on the basis of the Smart Grid concept. The ways of mathematical formulation of the Smart Grid optimization problem using the Data Science approach based on the machine learning system and neural networks are determined separately. These include Big Data processing methods, Data Mining, statistical methods, artificial intelligence methods, and Machine Learning. Data Science includes methods of designing and developing databases and application software. The main practical purpose of the scientist's work is to extract useful information for business from large arrays of information, identify patterns, develop and test hypotheses by modeling and developing new software, and therefore are necessary and sufficient conditions for theoretical justification of practical implementation of Smart Grid in Ukraine.

INTRODUCTION

Increasing the reliability of electricity supply is one of the most important conditions for improving the economic efficiency of the united energy system (UES) of Ukraine. Prospects for sustainable development of Ukraine, as well as other developed countries, are associated with the introduction of a new model of "inclusive" economy, based on the concept of Smart – the basis of scientific, technical

and innovative transformations. The most significant factors that determine the priority development of Smart-technologies are [1–3]:

- full automation of technological processes and production;
- large-scale and prospects for the development of computer technology;
- emergence of new technologies, materials, devices that provide an increased level and comfort of life;

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- the need to comply with environmental standards, reduce the impact on the environment, including in the field of electricity generation: wind power plants (WPP), solar power plants (SPP), power plants based on biofuels and others).

Based on this, the implementation of Smart Grid technology in electricity is one of the most important stages of energy efficiency management, as intelligent networks allow more effective control of energy use depending on peak loads, which confirms the relevance of the chosen research topic and its practical significance for Ukraine's energy saving [4].

Improving the efficiency of electricity generation and supply is an important and urgent task for Ukraine's energy sector. According to the latest data from Interfax-Ukraine, electricity consumption in the UES of Ukraine increased by 7.2% (by 1 billion 21.4 million kWh), while at the same time electricity production from non-traditional sources (WPP, SPP, biomass) has almost doubled to 10 billion 841.2 million kWh. In this regard, it is extremely important to provide the energy system of Ukraine, which is under the influence of sharp variable loads, with reliable sources of electricity generation.

Aim of the work is to analyze the power system and develop a plan (scenario) for the possible implementation of Smart Grid technology in the Energy System of Ukraine.

Research objectives:

- on the basis of the analysis of the existing power supply system to analyze the volume of electricity consumption in general;
- explore the features of the Smart Grid system;
- to assess the state of the power system of Ukraine after the implementation of the Smart Grid system.

ANALYSIS OF THE CURRENT STATE OF THE ENERGY SYSTEM OF UKRAINE

The peculiarity of the United Power System of Ukraine (UES) is the excess of base and the deficit of shunting capacity. According to the Ministry of Energy and Coal Industry of Ukraine, the total installed capacity of power plants in the country as a whole was 54.5 GW, of which (Table 1) [5]:

- 51% is accounted for by thermal power plants (TPPs);
- 25% is nuclear power plants (NPPs);
- 10% is hydropower and storage power plants (HPPs and StPPs);
- 12% is thermal power plants (TTPs), block stations and other facilities;
- about 2% for renewable energy sources, such as wind (WPP) and solar power plants (SPP).

The total length of power transmission lines of all voltage classes (Table 2) is 934,710 thousand km, main transmission lines with a voltage of 220–750 kV – 22923.07 km. The length of main and interstate overhead power transmission lines with a voltage of 35–800 kV JSC NPC Ukrenenergo is given in Table 3.

Ukraine's energy system has been in operation for quite a long time and it is difficult for it to withstand the load of modern times. The high level of wear of the main and auxiliary equipment of the power system and the uneven distribution of loads in the network often lead to emergencies and power outages.

In Ukraine, one of the highest in Europe indicators of the duration of emergency blackouts: 696 minutes per year on average in the country. An important point in the work of Smart Grid is the possibility of efficient integration of power plants based on renewable energy sources [6]. One of the key stages is the decarbonization of energy, ie the reduction of the share of power plants that burn coal, gas and fuel oil. An effective way to decarbonize – the development of green energy – is solar, wind and hydropower. Also, the Smart Grid system – is able to respond quickly to virtually any change or deviation in the power supply. And to ensure uninterrupted power supply to electricity consumers.

According to the Ministry of Energy of Ukraine, in January-August 2020, the volume of electricity production by energy generating companies that are part of the UES of Ukraine reached 96337.5 million kWh, which is 6759.0 million kWh or 6.6 % less compared to the corresponding period of 2019.

At the same time, TPPs and CHPs generated 31212.4 million kWh of electricity, or 18.2% less than in the corresponding period of 2019, which amounted to 38180.3 million kWh. Nuclear power plants generated 51,135.6 million kWh [5, 6].

Compared to January-August 2020, NPPs reduced electricity production by 3406.5 million kWh, or 6.2%. Electricity production of HPPs and StPPs amounted to 5016.9 million kWh, which is 12.1% less (or 689.5 million kWh) than last year. For 8 months of 2020, RES (WPP, SPP, biomass) electricity production amounted to 7657.0 million kWh, which is 4130.4 million kWh, or 117.1% more than in the same period last year.

Electricity production by power plants of other types (block stations and other sources) compared to the same indicator in 2019 increased by 174.5 million kWh, or 15.3% and amounted to 1315.6 million kWh.

In August of the current 2021, the total production of this type of energy resource reached 11346 million kWh. As of August 31, 5941.7 million kWh of electricity were generated at the NPP.

Table 1. The largest power plants in Ukraine

No	Power plant	Power of turbo generators, MW	Number of turbo generators	Installed power power plants, MW
Thermal power plants				
1	Vuglegirsk TPP	300/800	4/3	3600
2	Zaporizhzhya TPP	300/800	4/3	3600
3	Kryvyi Rih TPP	282	10	2820
4	Burshtyn TPP	185/195/206	3/8/1	2321
5	Zmiiv TPP	175/275/325	6/3/1	2200
6	Ladyzhynska TPP	300	6	1800
7	Trypillya TPP	300	6	1800
8	Starobeshivska TPP	175/200/215	4/5/1	1915
9	Prydniprovsk TPP	150/285/310	4/3/1	1765
10	Luhansk TPP	175/200/210	2/4/1	1360
11	Kurakhiv TPP	200/210/222/225	1/3/1/2	1502
12	Zuevskaya TPP	300/320/325	2/1/1	125
13	Slavic TPP	80/800	1/1	880
14	Dobrotvirska TPP	100/150	212	500
15	Kyiv TPP-5	100/250	2/2	700
16	Kyiv TPP-6	250	2	500
17	Kharkiv TPP-5	110/250	2/1	470
Nuclear power plants				
1	Zaporizhzhya NPP	1000	6	6000
2	South Ukrainian NPP	1000	3	3000
3	Rivne NPP	415/420/1000	1/1/2	2835
4	Khmelnitsky NPP	1000	2	2000
Hydraulic power plants				
1	Dnipro HPP	65/72/2/100,8/112,5/120	3/6/1/2/5/1	1513,1
2	Dniester HPP-1	117,0	6	702,0
3	Kremenchug HPP	52,08/60	11/1	632,9
4	Kaniv HPP	18,5/22	16/8	472
5	Kyiv HPP	18,5/22,0	3/17	429,5
6	Dniprodzerzhynsk HPP	44,0/48,4	4/4	369,6
7	Kakhovka HPP	55,8/50	5/1	329,0
8	Kyiv StPP	37,0/41,5	3/3	235,5
9	Tashlyk StPP	151	2	302
10	Dniester StPP	324	1	324

Table 2. Information on the length of the transmission line of Ukraine of different voltage classes

Voltage, kV	Length, th. km
800 (DC)	0.10
750	4.12
500-400	0.71
330	13.34
220	3.97
35-110	0.31
35-110 (Interstate)	0.63
Total	22.90

Table 3. Number of substations of JSC NPC Ukrenergo

Number	Voltage class, kV
8	750
2	500
2	400
88	330
33	220
3	110
Total – 136 substations	

Installed capacity of transformer substations is
78884.381 MVA

In the monthly balance of the country's electricity, their share was 52.4%; HPPs and StPPs produced 3412.8 million kWh, which is 30.1% of the energy balance; HPPs and StPPs – 665.7 million kWh, or 5.9%; RES – 1111.2 million kWh, or 9.8%; Power plants of other types (block stations and other sources) – 215 million kWh, or 1.9% [5, 6].

DEVELOPMENT OF SMART GRID TECHNOLOGY IN THE WORLD

One of the main reasons for the introduction of smart grid technology Smart Grid is the great development of modern technologies in the information field. The development of “smart grids” is a symbiosis of energy with various other industries. One of such industries is the automotive industry, namely the introduction of an innovative direction – electric transport. To equalize the difference in the grid, it is need to increase electricity consumption at night. That is why one of the most necessary elements in the Smart Grid is an energy storage device that can receive energy at night and emit it during the day, thus equalizing the load drops in the power grid [8, 9].

Almost all post-industrial countries consider the development of energy-efficient Smart Grid technologies to be one of the most important areas, and countries invest a lot of money in this every year. For example, in the United States to modernize the grid was spent about \$ 5 billion. But all this is only because American experts plan to save about 1.5 trillion dollars in 2020 due to the implementation of the Smart Grid system by increasing the reliability of networks and reducing the amount of energy consumed.

Many countries are conducting active research in this area, implementing various pilot projects that make it possible to calculate efficiency and build demonstration models of networks.

In Japan, began testing Smart Grid M-tech Labo (part of a large project working to create energy and social systems of the new generation in the eco-city of Kihanna), as generators of the system used electric cars Mitsubishi i-MiEV five pieces and a number of old batteries that have been removed from electric mobiles. Such system makes it possible to equalize the peaks of energy loads by using night electricity to charge the batteries of electric vehicles and then return this electricity back to the grid during the peak of its use [10].

The use of electric cars and old batteries, instead of using expensive generators reduces the cost of Smart Grid.

The analysis of the best world practices conducted by J'son & Partners Consulting shows that the active development of modern energy accounting technologies allows: to bring to a fundamentally

new level the quality of data collection and analysis of energy consumption; increases the efficiency of operational management of energy assets; promotes the active involvement of energy consumers in the processes of regulating their own energy consumption, and is also an important tool for improving the overall energy efficiency of the economy [11].

The market for Smart Grid technologies in the world is in its infancy. At the same time, the continuous development and modernization of energy infrastructure in each region has its own characteristics and approaches. In recent years, the implementation of programs and projects in the direction of Smart Grid, covering a wide range of problems and tasks, embarked on the vast majority of industrialized countries, as well as many developing countries. The largest programs and projects in this area have been developed and implemented in the United States, Canada and the European Union, as well as China, South Korea and Japan. It was decided to implement similar programs and projects in a number of other major powers (India, Brazil, Mexico). In particular, by 2020 China expects to reach the level of modern energy accounting systems in 90-95%, the United States – 50-60%. In the period after 2020, 100% of smart meters are planned in the United States, China, Brazil, Japan, and most EU countries [12].

For example, one of the main tasks of the energy policy of the EU countries, defined in the “Electricity Directive”, is to equip by 2020 at least 80% of consumers with “smart” metering systems. The commitments of the participating countries to define a plan for the introduction of “smart” meters create the necessary impetus for the deployment of programs for the development of smart systems in the European Union. In particular:

- France: issuance of a directive on smart meters in September 2010, which mandates the installation of 95% of smart meters by 2016;
- Germany: a law from January 2010, which makes it a condition to install Smart meters in new buildings under renovation, or at the request of the consumer;
- United Kingdom: the government has commissioned the implementation of smart meters between 2012 and 2020;
- Spain: Royal Decree 1110/2007 and Ministerial Order 2860/2007 oblige to replace all electromagnetic electricity meters with intelligent ones by 31 December 2018 [13, 14].

SMART GRID IMPLEMENTATION SCENARIOS IN UKRAINE

Smart Grid is an automated network for generating, transmitting and consuming electricity and is an

S.M.A.R.T. system, i.e. able to self-monitor and provide reports on any member of the network (its condition, needs, etc.) and complete information on the generated and transmitted electricity in any context: efficiency, loss or economic benefit. Smart Grid also increases network reliability by providing a seamless switch to another source when the main one fails. As the reliability of individual power supply networks already reaches 99.97%, the use of Smart Grid is able to guarantee uninterrupted power supply 24/7.

Smart Grid increases the “performance” of the network as a whole by reducing losses in wires and optimal load distribution, establishing for large consumers effective (shorter) connection routes (Fig. 1) [15].

The ideology and conceptual basis of Smart Grid should be provided by the acceptability of the development of electricity and the definition of the level that has organizational, economic, technological and resource (in a broad sense) potential and real in achievement.

There are several possible scenarios for the development of the Smart grid concept in Ukraine:

- 1) scenario of monitoring and point implementation of certain Smart Grid technologies;
- 2) scenario of development of existing and creation of new competencies in the field of Smart Grid;
- 3) scenario of development and implementation of a comprehensive national program of innovative development of electric power on the basis of the Smart Grid concept.

The first scenario of monitoring and point implementation: monitoring of various aspects of Smart Grid implementation in Ukraine and abroad. According to the results of monitoring – “following the leader”: the implementation of foreign decisions and developments (do not exclude their domestic development) [16, 17].

Benefits

- having an understanding of the Smart Grid development process border and the possibility of applying individual results in domestic practice;
- reduction of costs for financing the development of innovative and breakthrough technologies.

Disadvantages

- further loss of key positions in the field of innovative development energy development;
- Ukraine remains on the side of technical progress in the field, extremely important for ensuring energy security of countries;
- consolidation of technological gap and import dependence.

Currently, the first steps have been taken in Ukraine to implement this scenario - it is possible to state the beginning of the monitoring process. However, the currently monitored implementation of the concept abroad is carried out by individual companies and research organizations and is not systemic in nature. There is no industry-level center that would analyze the results of monitoring and define its main goals and objectives [18, 19].

Figure 1. Comparison of conventional and smart grids [15]

The second scenario is the development of existing and creation of new competencies in the field of Smart Grid – involves the inclusion of Ukraine in the global process of technology development in those areas where it may have potential competitive advantages, use and development of existing potential in those areas its competencies remain unique and have no analogues.

Benefits

- promotion of own developments and technologies on a world level;
- reducing the level of import substitution in the industry;
- development of domestic scientific, technical and innovative potential.

Disadvantages

- in 10-15 years Ukraine, developing separate directions in science and technology, not united by the system concept similar to Smart Grid, can have a certain set of modern technologies which will successfully solve separate local problems, but will not allow to provide you. -solving systemic problems of energy complex development at the world level;
- Ukraine remains technologically dependent on the development of foreign spheres that are outside the scope of our key competencies [20].

The third scenario is the development and implementation of a comprehensive national program of innovative development of electricity based on the concept of Smart Grid.

Ukraine is developing its concept related to all state priorities of the country's innovative development, key areas and critical technologies, as well as adopted national programs and projects [21].

The main driving forces for the implementation of this strategy may be:

- energy efficiency;
- reliability and safety;
- advanced technologies – FACTS, superconductivity, drives, nano-materials, etc.;
- theory and methods of managing large energy systems;
- information systems and technologies;
- supercomputers and parallel computing systems and algorithms.

Benefits:

Technological:

- a) Ukraine develops its own directions in science and technology on the platform of the Smart Grid concept;
- b) ensuring the unity of standards and compatibility (interchangeability) of technologies;
- c) a balanced approach to the development of the power grid complex – extensive (where

necessary) and intensive (through the introduction of new management technologies);

- d) construction of new networks is carried out taking into account modern standards and requirements of Smart Grid and experience of implementation of pilot projects in the directions (domestic and foreign).

Political:

- a) Ukraine – one of the leaders in energy security;
- b) increasing the prestige of Ukraine as a leader of scientific and technological progress;
- c) ensuring the innovative development of the country's energy sector.

Social:

- a) investment in the development of its own industry and science;
- b) creation of new jobs in this area;
- c) new markets for the sale and export of technologies and goods;
- d) the release of resources for the development of other sectors of the economy (in the future) [22–24].

The latter scenario is the most comprehensive and best, integrating the forefront and includes their main advantages, as well as developing them at the expense of a systematic and integrated approach. As part of the development of a comprehensive national program of innovative development of electricity based on Smart Grid, the following issues should be addressed in the first place:

- the strategic vision of the future innovative development of energy in Ukraine is formed;
- the main requirements and functional properties of the domestic energy system based on the concept of Smart Grid and the principles of their implementation are determined;
- the main directions of development of all elements of the energy system are determined: generation, transmission and distribution, sales, consumption and dispatching;
- the main components, technologies, information and management decisions in all the above areas are identified [25, 26].

CONCLUSION

The introduction of Smart Grid technology raises the issue of solving the problem of forecasting in the power industry depending on many factors, including weather conditions and the impact of alternative power sources.

The theoretical solution of the tasks is proposed to be solved based on modern computational algorithms of machine learning using Microsoft Azure Machine Learning Studio.

Smart Grid technology will not only provide a mathematical model with a large base of statistical materials, but also allow accurate adjustments state of the power system depending on the operation of the power consumption control center.

In energy, Data Science can help solve many problems, such as forecasting electricity consumption, forecasting electricity prices, calculating optimal tariffs, diagnosing energy facilities, optimizing consumption patterns and more.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author(s).

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Аналіз можливості впровадження мережі Smart Grid в умовах поточного стану об'єднаних енергосистем України

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Анотація. В роботі проаналізовано поточний стан енергетичної системи України та ефективності генерації і передачі електричної енергії. Аналіз передових світових практик показує, що активний розвиток сучасних технологій обліку енергоресурсів дозволяє: вивести на принципово новий рівень якість збору і аналізу даних про енергоспоживання споживачів; підвищує ефективність оперативного управління енергетичними активами; сприяє активному залученню споживачів енергії в процеси регулювання власного енергоспоживання. Енергосистема України експлуатується доволі довго і їй складно витримувати навантаження нового часу. Високий рівень зносу основного і допоміжного обладнання енергосистеми і нерівномірний розподіл навантаження в мережі часто призводять до аварійних ситуацій і відключень електропостачання споживачів. Безумовно, підвищення ефективності видобутку і постачання електроенергії є важливою і актуальною задачею для енергетики України. Однією із сучасних і інноваційних концепцій, які можуть суттєво вплинути на показники якості передачі електроенергії є технологія Smart Grid. Така технологія і її можливості не є новими. Але проблеми, які супроводжують широке впровадження Smart Grid в умовах енергетичного ринку України, не мають однозначного і ефективного вирішення. У зв'язку з цим в цій роботі пропонується для розгляду і обговорення декілька сценаріїв реалізації Smart Grid в Україні, із оглядом їх переваг і недоліків. Зокрема, це сценарій моніторингу та точкового впровадження окремих технологій Smart Grid; сценарій розвитку існуючих та створення нових компетенцій у сфері Smart Grid; сценарій розробки та реалізації комплексної національної програми інноваційного розвитку електроенергетики на базі концепції Smart Grid. Окремо визначаються шляхи математичної постановки задачі оптимізації Smart Grid з використанням підходу Data Science на базі системи машинного навчання і нейронних мереж. Сюди входять методи обробки великих даних (Big Data), інтелектуального аналізу даних (Data Mining), статистичні методи, методи штучного інтелекту, а також машинне навчання (Machine Learning). Data Science включає методи проектування і розробки баз даних і прикладного програмного забезпечення. Основна практична мета роботи вченого за даними – це витяг корисних для бізнесу відомостей з великих масивів інформації, виявлення закономірностей, розробка і перевірка гіпотез шляхом моделювання і розробки нового програмного забезпечення, а отже є необхідними і достатніми умовами для теоретичного обґрунтування практичного впровадження Smart Grid в Україні.

Ключові слова: енергетична система, ефективність, Smart Grid, статистика, машинне навчання, Data Science, прогнозування, електроенергетика.

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