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OVERVIEW OF MODERN CONCEPTS IN ELECTRIC POWER INDUSTRY

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Abstract- This article discusses the use of Cyber Physical Systems in power supply systems. In addition, Cyber Physical Systems make it possible to create an intelligent power supply system. There are also discussed elements of Smart Grid. There are also considered modern Information Technologies to implement the above. There is a new architecture for an electricity supply system based on a cyber-physical system at the end of this study.

Keywords: Industry 4.0, Electricity, Cyber-Physical Systems, SCADA, Micro-Grid, Smart Grid, Internet of Energy, Internet of Things.

1. INTRODUCTION

We are now living on the eve of the 4th industrial revolution. There can be distinguished three industrial revolutions in the human history:

1. The Great Industrial Revolution. It is characterized by the transition of mankind from an agrarian society to an industrial society;
2. The Technological Revolution began with the introduction of an inexpensive the Bessemer process to produce steel. The main achievements of this revolution are the distribution of chemicals, electricity, railways, wood paper production, etc. [1].
3. The Digital Revolution began with the advent of the first computers. A feature of this revolution is the transition from analog technology to digital technology. The main driving force is the widespread spread of computing devices [2].

The 4th Industrial Revolution (Industry 4.0) is the coming revolution where there is expected the massive introduction of Cyber-Physical Systems (CPs) in all spheres of human activity. The main technologies that contribute to this are modern information technologies: AI (Artificial Intelligence), IoT (Internet of Things), Big Data, Cloud Computing, Distributed Systems, Parallel Computing, etc. [3].

1.1. Modern Information Technology

The CPs are based on these technologies. The CPs are systems that it allows to join physical processes it is continuously managed in real time with digital systems [4]. When implementing CPs, they have to the following requirements:

- *Support for data heterogeneity*. They can negatively affect the effectiveness of the system. The system must support a large number of data formats to prevent this;
- *Reliability* will be one of the main requirements for these systems given that CPs actually directly affects the environment. And it must adapt to the environment in unforeseen circumstances given that the environment is unpredictable;
- *Data management*. CPs must store and analyze large amounts of data in a short period of time in real time;
- *Confidentiality*. CPs must contain tools to preserve confidentiality in order to prevent the leakage of personal data of users;
- *Security*. One of the requirements for CPs is to ensure the security of communications. Security mechanisms become more complex as CPs constantly expand. This requires the use of advanced security tools;
- *Real-time mode*. CPs must have powerful tools that support distributed and parallel computing to operate large data in real time, as physical processes proceed regardless of processing time and calculation results. [5]

The principle of operation of CPs can be formulated in this way: the "brain" of the system is advanced information technologies, which receive data from sensors that are leading observations of physical processes. [5]

The above sensors are also referred to as smart sensors, which form a IoT. The IoT combines devices into a computer network and allows them to collect, analyze, process and transfer data to other objects through software, applications or technical devices. According to Gartner's forecasts, 2021 billion devices will be connected to the Internet by 25. Cybercriminals will continue to attack them because the IoT system is a reliable and fast way to spread malware. Ordinary users, companies and entire cities will increasingly use intelligent technologies to save time and money. For example, refrigerators will be able to warn of ambulance damage to products, traffic lights with built-in video sensors will regulate traffic depending on traffic. Now, however, the key problem of implementing IoT is the lack of uniform standards. Therefore, existing solutions are difficult to integrate with each other, and new ones appear more slowly than they could. Another nuance - "things" on the Internet of things should be autonomous, that is, be able to receive energy from the environment, without human participation.

The digital part of CPs is AI, big data, cloud computing, distributed systems, parallel computing. AI is a feature of intellectual systems to run creative functions. CPs are also developing along with the development of the field of AI since the efficiency of work of these systems is largely determined by the performance of processing of data present in the system. One of the problems that AI solves in CPs is security, that is, the providing of system’s protection against CP attacks. The better method of protecting CPs is to find anomalies in communication channels between the PLC (programmable logic controller), process control on equipment and the SCADA. There is used a recurring neural network to find for anomalies in control channels.

Big Data are data collection of different structure and also methods of their processing which allow is distributed to analyze information. Such data is efficiently performed using scalable tools that became an alternative to traditional databases and Business Intelligence solutions. Big data analysis performs in order to extraction new, previously unknown information. Such discoveries are called insider, which means insight, guess, sudden understanding.

Cloud Computing is a dynamically scalable method to accessible computing resources provided through the Internet, without the user needing any special knowledge about the cloud infrastructure or management skills of this cloud technology. In other words, Cloud Computing is hardware-software complex that is accessible to the user through the Internet or local network that allows you to use a comfortable interface for remote access to allocated resources.

Currently, almost all large software systems are distributed. A distributed system is a system in which information processing is not concentrated on one computer, but is distributed among several computers. When designing distributed systems, which has much in common with software design in general, some specific features should still be taken into account. There are six main characteristics of distributed systems.

1. *Share resources*. Distributed systems allow the sharing of both hardware (hard drives, printers) and software (files, compilers) resources.
2. *Openness*. This is an opportunity to extend the system by adding new resources.
3. *Parallelism*. On distributed systems, multiple processes can run simultaneously on different computers on the network. These processes can interact during their execution.
4. *Scalability*. Scalability refers to the ability to add new properties and methods.
5. *Fault tolerance*. The presence of several computers allows duplication of information and resistance to some hardware and software errors. Distributed systems can support partial functionality in the event of an error. Complete system failure occurs only in case of network errors.
6. *Transparency*. Users give full access to resources in the system, while information is hidden about the allocation of resources by system from them.

Parallel computing (parallel processing) is the use of several or many computing devices to simultaneously execute different parts of a single program. In other words, parallel computing is computing that can be performed on multiprocessor systems using the ability to simultaneously perform many actions created by the process of solving one or many tasks. The main aim of parallel computing is to reduce time to solve a problem. Many of tasks required for needs of practice need to be solved in real time or a very large amount of computation is required to solve them.

After the Industry 4.0, cardinal changes will occur not only in economics and science, but also in society. The future new society is called Society 5.0. The concept of "Society 5.0" is aimed at closing the gap between information technologies and industry to solve social problems. Many important areas (health, underground transport, industry, film industry, etc.) depend on electricity. In other words, many social problems require a safe, reliable, and uninterrupted supply of electricity.

Today there need to be addressed the following global challenges in the electricity sector:

1. As the well-being of the people of developing countries is getting find and there is growing the world 's population, it will increase the demand for electricity;
2. Changes in the quality characteristics of energy consumption. Industrialization will take place on a new technological base (digital systems, additive and precision production) within Industry 4.0 that is sensitive to supply reliability and electricity quality;
3. Environmental concerns. According to the IEA (International Energy Agency), the electricity industry is a source of 42% of greenhouse gas and pollutant emissions. Renewable Energy Sources is solution of this problem;
4. Investment costs. The power grid of several countries requires heavy costs of update, upgrade and maintenance. Traditional energy supply system chains were built through powerful public investments that are not now available. In this case, it is necessary to find investors;
5. Urbanization. There is a need for a new generation of urban energy due to the growth of the urban population: with a high concentration of capacity, a significant margin of strength and opportunities of growth. [6]

The purpose of this article is to explore the utility of CPs in the electric power industry. To do this, modern trends in the electric power industry will be considered, which contribute to the development of two large-scale concepts "Industry 4.0" and "Society 5.0".

2. STRUCTURE OF POWER SUPPLY SYSTEM AFTER INDUSTRY 4.0

Industry 4.0 enables informatization and digitalization of the power supply system. There necessary to introduce advanced information technology developments in the electric power sector to achieve this. Due to the fact, that the driving force of the implementation of "Industry 4.0" is cyber-physical systems, it is necessary to consider their implementation in the electric power industry. This give srise to Smart Grid, SCADA, Energy Management System, Micro-grid, Energy Router, and Internet of Energy.

2.1. Smart Grid

At present, many countries of the world have a centralized electricity supply system where there are present the above-mentioned problems. Smart grid is the solution that can solve these problems. Smart Grid is a power supply system based on CPs [7].

It must perform the following functions to address these challenges:

- Allow for the integration of RES for a solution global climate change and to relieve the burden on the central electricity grid;
- To ensure active customer participation engagement for better energy efficiency and to implement the concept IoE;
- To provide for cyber-secure communications systems to ensure system safety;
- Make better use of existing assets to ensure long-term stability;
- The ability to optimize energy stream to reduce power losses and reduce the price of electricity. [1]

The main elements of a smart grid are smart meters and sensors. They are capable of collecting information on electricity production and consumption that it increases efficiency, reliability, and economic benefits.

The advantages of an intelligent network include [17].

1. Improving reliability;
2. Increased physical, operational and cyber security and resilience to attacks or natural disasters.
3. Self-repair or ease of repair, especially remote repair;
4. Increasing the amount of information available to consumers on their energy consumption.
5. Improving energy efficiency along with the environmental benefits derived from such efficiency;
6. Integration of a greater proportion of renewable energy sources, which by their nature may be unpredictable;
7. Integration of plug-in electric vehicles; and,
8. Reduce peak demand.

As part of pilot projects, Smart Grid is being implemented in many countries of the world: in the Republic of Korea, in China, in the USA, in India, in Japan, in Canada, and in the European Union.

2.2. Management System of Electric Energy Grid

The electricity industry, like other areas of industry, needs automation. Given that many electric energy grids are now becoming smart grid, the question arises of their control. Two main categories of control systems are used to implement control of electric power systems: Distributed Control systems (DCs) and Supervisory Control and Data Acquisition (SCADA).

• *Distributed Control Systems*

The DCs is a CPs that manages the continuous industrial process. The DCs is mainly used in chemistry and petrochemicals, oil processing and oil production, gas processing and gas production, metallurgy, food industry, energy supply and etc. where the industrial process is of permanent. The DCs structure consists of two levels. There are non-centralized elements of the system that they monitor production processes at the lower level. There are system components that monitor these elements on the upper level. The system components are connected to a single Local Control Network. [2]

The DCs has the following main elements:

- Human-machine interface (HMI). HMI provides the necessary conditions to the operator for easy manual manage of industrial processes;
- Controllers are system components of control that contain an algorithm for management corresponding devices;
- Local Control Unit (LCU) is device that interacts directly with field devices. The LCU accepts signals from controllers and sends them information collected from field devices;
- Communication protocols are a set of rules that define how system elements interact with each other. [3]

There are the following main features among all the capabilities of the distributed management system:

- Processing complex processes. Since production has a complex structure and a large number of I/O operations, programmable logic controllers are unable to service it. In such situations, the DCS should be used;
- Reservation of a system. In case of emergency situations, the DCS allows the system to resume operation thanks to the redundancy function at each level of the system. This results in data redundancy, but also improves system reliability;
- Predefined functional blocks. The DCS provides a variety of algorithms to facilitate the writing of an application to manage complex systems;
- A complex Human Machine Interface provides the operator with the necessary information to monitor and control the system;
- Scalability. As production processes increase, DCS can scale by adding additional clients and servers to the communications system and adding additional I/O modules to distributed controllers;
- Security of system is provided at all levels of DCS access for better factory automation control [3, 4].

• *SCADA*

The DCs is mainly applied to management one generating power plant or on a small geographical zone, but SCADA is applied to management long-distance electric energy transfer on any geographical zone. To build a smart grid is typically used SCADA. SCADA is a tool for creating and monitoring systems for collecting, processing, displaying and archiving information about an observed object in real time. In essence, SCADA is a cyber-physical system, which is the first step to implement the concept of "Internet energy" [8].

The main functions of the SCADA system are:

- Data collection on process parameters;
- Processing and storage of received data from devices and sensors;
- Graphical representation of the current processes of the system;
- Notification of process state changes, especially pre-emergency and emergency situations;
- Generation of reports on current processes;
- Automatic management of processes of system based on defined algorithms [9].

Among the features of SCADA are the following:

- SCADA systems must have a person (operator, dispatcher);
- Any improper impact can lead to a failure of the control object or even catastrophic consequences;
- The manager is generally responsible for managing a system that, under normal conditions, only occasionally requires tuning parameters to achieve optimal performance;
- Most of the time, the manager passively watches the displayed information. The manager's active participation in the management process is infrequent, usually in the event of critical events - failures, emergency and emergency situations, etc.;
- Operator actions in critical situations can be severely limited in time (a few minutes or even seconds).

The SCADA system consists of the following components:

- Remote control hardware of substations;
- The local processor collects data from field devices;
- Digital devices are field devices that allow to determine such parameters of the power grid as current, voltage, temperature, radiation, etc.;
- Communication devices provide data transfer between system components. Two types of communication identify short-range and long-range. Short-range communication use to exchange data between the local processor and its associated digital devices. Long-range communication is used to exchange information between local processors and the host server;
- The host server is the main element of the system that provides engineers and operators with the necessary information collected from local processors to monitor and management the electric energy grid. [5]

- *Energy Management System*

Management systems in the electricity industry are usually considered Energy Management Systems (EMS). [5] The EMs is a system of management of electric energy system that allows monitor and management of power plants, electric energy transmission network, and network subscribers. The EMs is able to consist of DCs and SCADA. Here, it is advisable to use DCS in large power plants (if any), which have a complex structure, and SCADA is better used for monitoring and control by electrical power transmission network and network subscribers, as power transmission networks are sometimes big length and subscribers are geographically distributed.

2.3. Micro-Gird

EMs provides an opportunity to identify places of lack of electricity, where necessary to build power plants and places of excess electricity, where necessary to redistribute it. This makes it possible to create a distributed electrical grid where the main element is the micro-grid. Micro-grid is a power supply system that manages distributed energy sources and brings together power producers, storage systems and consumers [10].

The microgrid architecture can be presented in 3 levels. At the lower level are consumers of electricity, i.e. subscribers. The middle level consists of electrical power transmission lines, transformers, i.e. means by which electricity is delivered to consumers. The upper level is a generating power station and power storage systems that are responsible for providing electricity in common grid.

The use of micro-grid enables the introduction of renewable energy sources that allow make decarburization. This will reduce fuel costs (oil, gas, coal) for traditional power plants; reduce emissions of harmful substances into the environment. It is also not possible to rely on only one source of green energy, since the electricity generated in power plants at RES depends on climatic conditions. It is useful to use multiple RES in a single micro-grid.

2.4. Energy Router

In order to connect micro-grid into a single grid and its elements to each other inside the common system there are used energy routers. These devices provide stable operation of generating, storing and consuming devices. Energy routers perform functions control of power flow and information exchange [11].

Since low voltage current (0.4 kV) flows in the micro-grids, there should be used low voltage Energy Routers to combine them into a single smart grid. An energy Router is a device for exchanging information and electric energy between two facilities of an electric power supply system. The power supply network object can be members of a micro-grid, as well as micro-grid and Energy Routers. The main advantage of this device is the possibility of bi-directional current flow, which allows grid subscribers not only to receive electricity from the common grid, but also to sell surplus electricity that received from RES to the common grid.

The functions of the Energy Router include:

- Electric power distribution. In case of excess electric power, ER are able to redirect it from one micro-grid to another.
- Data collection. It is necessary to have information about the status of the current demand, generation and consumption of electricity of the micro-grid in order to optimize the operation of the power supply network. This information helps to further distribute electric power across the all-smart grid.

The energy router consists of three main elements: power electronics, communication module, distribution grid intelligent module [6].

- **The distribution grid intelligent module** processes preliminary data received from field devices to perform control over the micro-grid.
- **The communication module** is necessary to maintain data exchange between the energy router and the grid components. This module provides data integrity, data protection against unauthorized access and data falsification. The communication module is responsible for the waiting time, if this time is exceeded, retransmission is necessary.

- Energy electronics is a component of an energy router that works directly with electricity. It provides the micro-grid with electricity, that is, in case of shortage of electricity, additional sources of electric energy are connected to the grid, and in case of excess it is distributed to other grids.

2.5. Internet of Energy

The above-mentioned provisions allow the electricity industry to implement the concept of "Internet of Energy". Internet of Energy is a decentralized energy system with intelligent distributed control, which is carried out through transactions between its participants. The features of Internet of Energy are:

- Distributed nature of the power system;
- The possibility of bidirectional power flows and dynamic role change by the system participant;
- Availability of both electrical and information connections between electric power devices;
- Implementations of distributed intelligent management;
- Decentralized availability of market;
- Perform all processes and manage them through direct transactions between users [13].

Following from the above, the Internet of Energy is a peer-to-peer power system where all processes between power producers and consumers take place thanks to direct transactions between them.

The implementation of IE, in addition to the components listed above, requires several more important components: energy storage, plug-and-play interface and digital substation [7].

• *The Energy Storage*

The energy storage in the smart grid operates as follows: when there is an excess of electricity in the smart grid or in the micro grid, the electricity starts to be stored in these stores, and when there is a situation where power plants are unable to provide electricity to the grid, the electricity starts to come from the energy storage.

Obviously, the philosophy and economy of the energy storage reflects the problems of the entire energy industry as a whole. Given the uneven production of energy from renewable sources, especially during periods of over expenditure and shortage during periods of peak consumption, it is the trajectory of the development of renewable energy market capacities (including innovative interest in electric vehicles) that forms the success of its development.

In the field of renewable energy storage, we can note the promotion of the use of both traditional, gradually cheaper energy storage technologies and innovative breakthrough technologies, the development and improvement of which will accelerate the use of renewable energy products and, accordingly, will lead to the gradual replacement of traditional types of energy, freeing up their use for deeper processing and the creation of final gas and petrochemical products with higher added value.

• *The Plug-and-Play Interface*

The plug-and-play interface enables the introduction of new power generation and storage elements into the power grid without any difficulties. This interface is a computer equivalent, where the plug-and-play interface recognizes the new connected device without spending much effort.

• *Digital Substation*

In order to increase the reliability of operation, observability of electric power objects, accuracy of measurement of the state of processes of the micro-grid there is required a digital substation. A digital substation is a new generation substation where the processes of information exchange between elements of the software and hardware complex flow in digital form. These substations also allow you to learn about the failure before the accident occurs. Digital substations are implemented according to IEC 61850 standards, so power equipment is subject to the following conditions:

- Use of digital transformers of current and voltage according to IEC protocol 61850-9-2;
- Use of systems of diagnostics and monitoring for substation components according to IEC protocol 61850-8-1;
- Use of controls of reactive power compensation with controllers according to IEC 61850-8-1;
- Use of communication means with voltage 6-750 kV according to IEC 61850-8-1;
- Use of signalization and control devices in DC boards according to IEC 61850-8-1 [12].

According to the above components, digital substations must exchange, collect, store and protect information in digital form. This, in turn, means that all devices associated with these functions must be performed on the MP base, and communication between them must be performed by means of digital signals.

In addition, scientists and experts describe three levels of control and information exchange: the level of primary equipment (power transformers, switches, disconnectors, etc.), the level of connection (terminals) and the stationary level (SCADA). All these levels involve the use of digital signals only, and each of them describes its own protocol (SV, MMS, GOOSE).

This means that the IEC 61850 protocol not only lists the components of the digital substation, but also describes the architecture of their interaction, which allows for a more accurate understanding of the system in question. Such standardization should significantly reduce the costs of designing, commissioning, operating and maintaining power facilities in the future. At the same time, it is worth noting that IEC 61850 does not regulate the power units themselves (primary circuits), which indicates that there is no relationship between the replacement of power equipment at the substation and the digital substation, with the exception of the use of optical transformers instead of traditional ones.

3. CONCLUSIONS

With the coming fourth industrial revolution, many sectors of the economy are being digitized. This process cannot be bypassed by the energy sector. It makes is possible to create a distributed supply system using CPS (Figure 1).

Firstly, it is necessary to build new power plants based on renewable energy sources and electricity grids based on the SCADA-system of the fourth generation in order to be able to create a micro-grid, and for connections of the micro-grid are needed energy routers. With the help of energy routers, it is possible to build a distributed power supply system and install sensors to monitor the energy routers and the distributed power grid. To use achievement in CPS to collect and analyze data in digital substations.

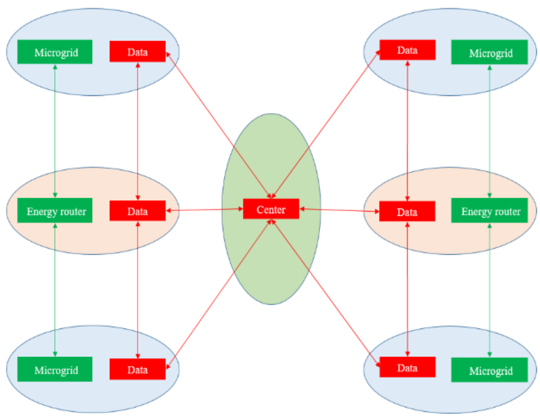

Figure 1. The diagram of digital distributed electrical power supply system

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