ANALYSIS OF THE SMART GRID CONCEPT FOR DC POWER SUPPLY SYSTEMS

АНАЛИЗ КОНЦЕПЦИИ «SMART GRID» ДЛЯ СИСТЕМ ТЯГОВОГО ЭЛЕКТРОСНАБЖЕНИЯ ПОСТОЯННОГО ТОКА

PhD (Technical), Associate Professor, Nerubatskyi V.[1], PhD (Technical), Associate Professor, Plakhtii O.[2],
Dr.Sc. (Technical), Associate Professor, Ananieva O.[3], PhD (Technical), Associate Professor, Zinchenko O.[4]
Faculty of Mechanics and Energy [1, 2, 4], Faculty of Information-control systems and technologies [3] – Ukrainian State University of Railway Transport, Ukraine
NVP9@i.ua, a.plakhtiy1989@gmail.com

Abstract: *The Smart Grid network system is a concept of a fully integrated, self-regulating and renewable power system with a network topology and includes all generating sources, main and distribution networks and all types of electrical energy consumers controlled by a single network of information and control devices and systems in real of time. The article proposes the introduction of the Smart Grid concept into the traction power supply systems, an analysis of the necessary steps to upgrade the traction substations, and the boundaries of the energy-saving effect from its implementation.*

***KEYWORDS**: SMART GRID, INNOVATIVE DEVELOPMENT, POWER SUPPLY SYSTEM, TRACTION SUBSTATION, ELECTRIC POWER INDUSTRY.*

1. Introduction

The fourth industrial revolution (Industrie 4.0) is the transition to fully automated digital production, driven by intelligent systems in real time in constant interaction with the external environment, which goes beyond the boundaries of one enterprise, with the prospect of joining into the global industrial network Internet of Things.

Industry 4.0 describes the current trend of automation and data exchange development, which includes cyber-physics systems, the Internet of Things, and cloud computing. It is a new level of organization of production and management of the chain of value creation throughout the life cycle of products.

Despite the active introduction of various types of information technology, electronics and industrial robotics in production processes, the automation of industry, which began at the end of the XX century, was predominantly local in nature, when each enterprise or subdivision within a single enterprise used its own (proprietary) control system (or a combination of them) that were incompatible with other systems [1, 2].

The development of the Internet, information technology, stable communication channels, cloud technologies and digital platforms, as well as information "explosion" broke out from various data channels, provided the emergence of open information systems and global industrial networks that go beyond the boundaries of an individual enterprise and interacting with each other [3, 4]. Such systems and networks have the effect of transforming the impact on all sectors of the modern economy and business beyond the information technology sector itself, and translate industrial automation into a new fourth stage of industrialization.

2. Components of the Smart Grid network

The term «Smart Grid» has become known since 2003, when it appeared in the article «Reliability demands drive automation investments» by Michael T. Burr [5]. In this paper, several functional and technological definitions of the smart network are listed, as well as some advantages. A common element for most definitions is the application of digital data processing and communication to the electrical network, which makes data flow and information management the key technologies of smart networks. Various opportunities for the wide integration of digital technologies, as well as the integration of a new network of information flows to control processes and systems, are key technologies in the development of smart networks. Currently, the power industry is being transformed into three classes: infrastructure improvement («strong network in China»); adding a digital layer that is the essence of the smart grid and transforming business processes that make smart grids profitable. Most of the work is focused on upgrading electrical grids, especially concerns the distribution and automation of substations, which will now be included in the overall concept of smart networks, but other additional capabilities are also developing.

Smart grid system is a concept of a fully integrated, self-regulating and renewable energy grid, which has a network topology and includes all generating sources, mains and distribution networks, and all types of electric power consumers, managed by a single network of information, control devices and systems in the mode real time.

At the current stage of sustainable energy development, technical means of intelligent systems, as well as advanced technical solutions of semiconductor power converters [6, 7, 8], play a decisive role in the implementation of the provisions of the Smart Grid concept [9]. Promising hardware can be divided into the following main groups:

- intelligent sensors of information, control and measuring instruments, accounting and control devices;
- systems for collecting and transmitting data containing distributed intelligence devices and analytical tools for maintaining communications at the level of objects of the grid;
- intelligent systems of forecasting, support and decision making (in particular, intelligent adaptive systems of protection and automation with automatic restoration function);
- improved topologies of semiconductor transducers and implementation of active power components of the electrical network;
- integrated information exchange systems.

The transition from the usual power system to Smart Grid, which meets the requirements of Industrie 4.0, includes 6 stages.

1. Computerization. Under computerization means the supply of means for the digital management of all major components of the system.

2. Network interaction (connectivity). At this stage, isolated technologies are combined into a common network that meets the requirements of the power system. Usually, for this purpose, use an Internet Protocol (IP) connection, thus creating the Internet of Things. Network interaction allows to combine CAD/CAM automated design and manufacturing procedures with Manufacturing Execution System (MES) process management tools, organize remote maintenance.

3. Visibility. Under the visibility understand the creation of a digital display or a virtual double system. The fall in prices for sensors and other digital equipment makes it possible. The more sensors, the more accurate the reflection. The presence of mappings associated with PLM, ERP, and MES systems allows operators to

see the state of the system in real time and make the necessary decisions.

4. Transparency. Transparency in this context means the connection of the digital mapping with analytical systems, more widely known as a system of work with large data. At this stage, the following tasks are solved:

- conversion of output "raw" data into a form suitable for analysis;
- actual data analysis;
- interpretation of data;
- application of the obtained results in practice.

5. Predictive capacity. Go to real-time planning tasks based on reliable information on the state of the energy system.

6. Adaptability. Provide automatic control system response to most industrial situations. That is, this solution, which is created individually for the particular equipment and individually tuned, thereby allowing the system to trigger automatic reactions to production events.

If the first two stages of the Digitalization group, ie the development of digital approaches, are purely technological, then the other stages, according to Industrie 4.0, are more cybernetic because they embody system principles [10, 11].

The schematic diagram of the power system that does not meet the requirements of Industrie 4.0 is shown in fig. 1.

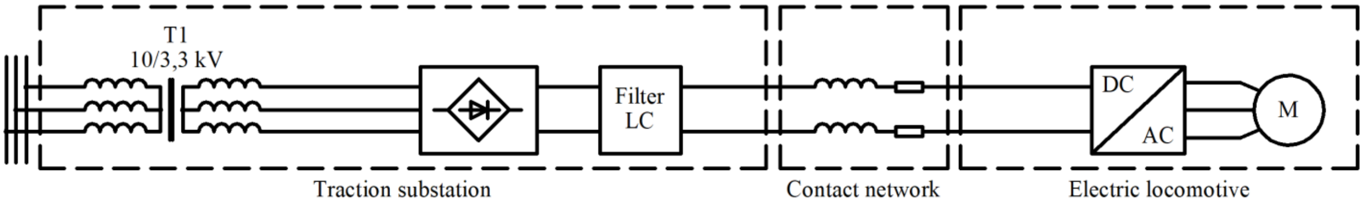

Fig. 1. *The schematic diagram of the power system that does not meet the requirements of Industrie 4.0*

The existing energy system has a number of shortcomings, including:

- low efficiency coefficient due to the presence of significant active resistance in the contact network and the presence of a passive voltage rectifier that has high static energy losses on the diodes;
- absence of the possibility of energy recuperation to the contact network;
- significant emission of higher harmonic components of current into the AC power supply network and higher voltage harmonics in the DC network;
- low power factor;
- high mass-size indexes.

Apply the concept of the Smart Grid to the existing system in order to improve the system characteristics is shown in fig. 2.

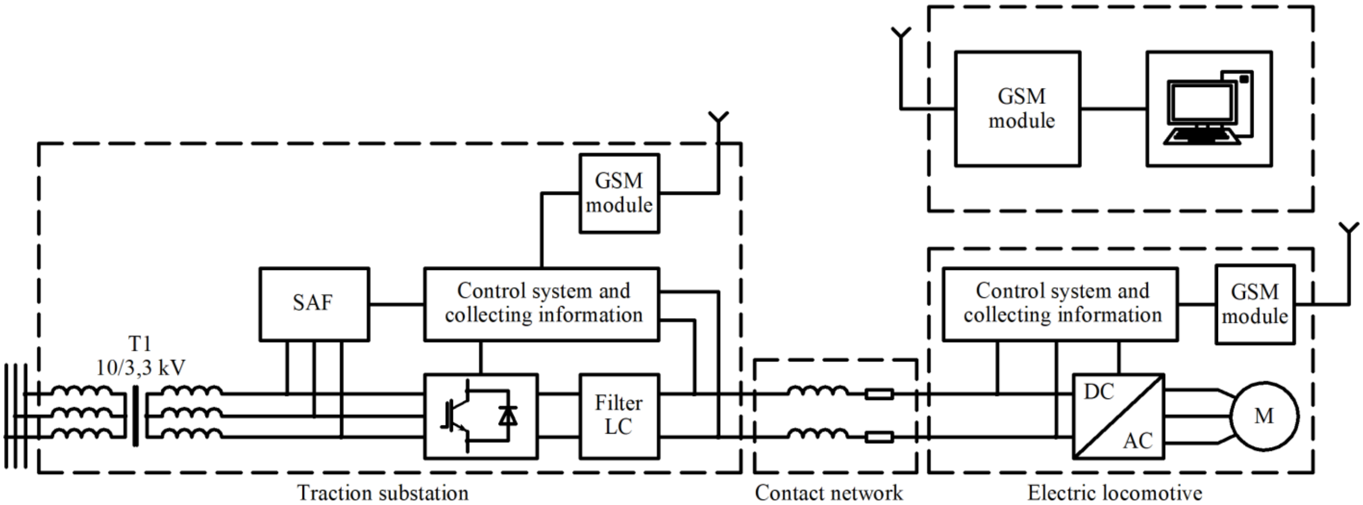

Fig. 2. *The schematic diagram energy system with the concept of Smart Grid*

Computerization should be carried out both on the side of the system that conducts the collection and analysis of data (operator), and on the side of the energy system, which is installed directly on the rolling stock.

The system of data collection and processing (operator) includes:

- personal computer;
- GSM module connected to the computer;
- database.

A personal computer (PC) connects to the GSM module. With GSM module the PC receives information from systems installed on the rolling stock.

With the availability of relevant software, the PC operator can conduct a current analysis of the data received.

Analysis results can be saved to the database.

The GSM module for connecting to a PC should have a communication interface (USB, Ethernet or RS-232). Main requirements for GSM modules:

- reception and transmission of SMS;
- reception and transmission using GPRS;
- work with serial interfaces RS-232 or RS-485;
- allows to manage the reception and transmission of data through serial interfaces RS-232 or RS-485 with AT commands according to GSM 07.05 and GSM 07.07.

Modern industry provides a wide range of similar modules [12, 13]. Among foreign samples:

- Siemens MC35i Terminal (GSM900/1800 + GPRS standard);
- 3G UMTS / HSPA + Wi-Fi Router UR5i v2 Libratum.

Among the domestic analogues:

- GSM/GPRS modem OWEN PM01;
- GSM modem iRZ MC52iT;
- SQUID-1H and SQUID-2H.

Particular attention should be paid to GSM routers SQUID-1H and SQUID-2H, developed by the company «Microl» (Ivano-Frankivsk city). They provide a permanent online connection between remote objects and dispatching points, and allow not only to receive information from objects, but also manage them.

Main features of SQUID GSM routers:

- reception and data transmission using GPRS;
- receiving and sending SMS;
- archiving of data on SD card;
- archiving data to e-mail;
- the presence of built-in analog and discrete inputs/outputs.

At the control center, a computer is used as a server. The exchange of information between GSM routers and the computer takes place via the Internet. GSM routers form a "transparent" GSM channel, and in fact are "remote" serial COM ports. This allows you to connect a large number of routers to computer. At the same time data is transmitted simultaneously, without a significant loss of exchange rate. Delay of updating data from 125 objects is 2÷3 seconds, with 250 objects, respectively, 4÷6 seconds.

If the control room is not able to connect to the Internet, then SQUID1N server is used as a server or a standard 3G modem from any mobile operator. SQUID GSM routers use GPRS packet data, the cheapest method of data transmission. The amount of data that is transferred round the clock to the central dispatching station is included in any chosen tariff plan without additional payments.

Any SCADA system that supports the Modbus protocol can be installed on the control-desk computer. This allows the customer to use those SCADA systems to which he is accustomed and save money without buying specialized software. SQUID configurator and SquidService software for working with GSM routers SQUID-1N and SQUID-2N are free and available for download on the company's website.

In accordance with industry standards, the selected database should relate to the real-time database. That is, the database must provide real-time synchronization, replication and backup.

Real-time databases must provide real-time data storage, processing and output. Before moving on to real-time databases it is necessary to deal with the notion of real-time system.

The real-time system is a hardware-software complex that responds at a set time to an unpredictable flow of external events. This definition means that:

- the system must have time to react to an event occurring on the site during the time critical for this event (meet deadline). The value of the critical time for each event is determined by the object and between the event, and, of course, may be different, but the system response time must be predicted (calculated) when creating the system. Lack of response at set hours is considered a mistake for real-time systems;
- the system must be able to react to events occurring simultaneously. Even if two or more external events occur simultaneously, the system must have time to react to each of them at intervals critical to those events.

There are two types of real-time systems: hard real-time systems and soft real-time systems. Hard real-time systems do not allow any system reaction delays under any circumstances in the following cases:

- the results may be irrelevant in case of delay;
- an accident may occur in the event of a delay in the reaction.

Examples of hard real-time systems: on-board control systems, emergency protection systems, emergency event loggers. Soft real-time systems are characterized by the fact that the delay of the reaction is not critical, although it can lead to an increase in the cost of the results and a decrease in the productivity of the system as a whole.

Real-time databases are standard databases with additional capabilities that can provide reliable work. Used constant time, which is a certain range of time values for which data are still relevant. This range can be called topical time. The standard database can not work in such conditions as the discrepancies between real-world objects and data that are too serious to represent it. An efficient system should handle urgent queries, return only time-reliable data, and maintain priority queues. To enter data into the record, often a sensor or input device tracks the state of the physical system and updates the database with new information that reflects the physical system more accurately. When designing a database system in real-time, it should be considered how the facts will be related to the real-time system. Need to think about how to represent the values in the database so that transaction processing is correct and the consistency of the data has not had any violations.

The information collection and processing system (rolling stock) includes:

- software logic controller;
- a system of sensors and signaling devices;
- GSM module;
- PC.

According to the parameters, programming tools, features of the modules' association and appearance, controllers for automation systems can be divided into the following groups: programmable relays, modular programmable logic controller (PLC), person machine interface + programmable logic controller (PMI + PLC).

Programmable relays are the simplest and cheapest programmable devices that were created to automate simple systems that do not require a large number of inputs/outputs. They have a full range of technical resources necessary for use in industrial automation, engineering or manufacturing at the lower level of automation [14, 15, 16].

The Ukrainian market offers programmable relays of the following manufacturers:

- Siemens – series Logo;
- Eaton (Moeller) – series Easy;
- ABB – series CL;
- Mitsubishi – Alpha;
- Schneider Electric – Zelio Logic;
- OWEN PR100 and OWEN PR200.

Modular PLCs are characterized by expanded structure. The base unit can function individually, and usually contains at least 8 inputs/outputs, and if necessary, their number can be expanded by additional modules to 65536 discrete/4096 analog channels. This gives greater flexibility when creating process automation systems based on modular PLCs.

The following modular PLCs are represented in the Ukrainian market:

- Siemens – series SIMATIC-S7;
- Eaton (Moeller) – series XC100, XC200;
- ABB – series AC500;
- Mitsubishi – series System Q;
- Schneider Electric – series Modicon.

Modular PLCs support the function of programmable relays, but additionally have built-in network interfaces and the ability to expand the internal memory and inputs/outputs modules to a wide range. PMI + PLC systems are used to visualize the process and create simple SCADA systems. Depending on the model of the device, the PMI may not support the PLC functions, but it necessarily has a graphical display for displaying the technological process and a developed input device that the operator uses to influence the technological process. For communication with other elements of the automation system, such devices use network protocols CANopen, Profibus-DP, etc. PMI + PLC systems have the following functionality:

- visualization of the parameters of the technological process in text or graphic modes;
- management and processing of emergency messages, registration of time and date of occurrence of emergency messages;
- manual control using the function buttons or the touch screen;
- the ability to freely schedule schedules and configure the function keys;
- drawing diagrams and charts, outputting a report.

Display of information about the technological process is carried out using a character or graphic screen, the size of which depends on the requirements of the technological process, and for the input information used pushbutton or sensor controls.

The Ukrainian market is represented by means of PMI + PLC of the following major manufacturers:

- Siemens – series SIMATIC HMI IPC;
- Eaton (Moeller) – series XV1, XV2, XV3, XV4, MI4, MFD4;
- ABB – series CP400, CP400;
- Mitsubishi – series Vision 1000, E1000, IPC1000, GOT1000;
- Schneider Electric – Magelis series STO, STU, XBT GT, XBT GTW, XBT N, Compact iPC, Panel PC.

The system of sensors and meters include:

- sensors of electrical parameters of the network: currents, voltages, active and reactive power;
- temperature sensors;
- humidity sensors;
- pressure sensors.

The system includes a computer connected to the system using the wireless channel of GSM. It allows connecting several power systems to a single network with minimal communication costs [17, 18].

The network interaction of intelligent sensors is realized with the help of GSM modules, which connect to PLC modules using the interface RS-485. GSM modules operate at frequencies of the decimetre range (about 2 GHz), the data transfer rate is over 2 Mbps (3G standard). This allows you to arrange the connection between the power systems and the operator.

The availability for inspection is organized by installing the corresponding software on the operator's computer. The software builds a model that is a complete copy of the power system, based on the data obtained from real power systems. The operator has the possibility of flexible analysis of the operating modes of the system.

3. Results and discussion

The energy grid based on the Smart Grid concept should simplify the interconnection of distributed generation and power storage systems. The distribution of distributed generation will create new opportunities for the network due to its more mobile nature and less stable characteristics that can cause interruptions and sharp voltage drop across the network.

The Smart Grid system offers great opportunities for both consumers and manufacturers to enter the market by increasing the throughput capacity of trunk networks, implementing collective management initiatives, distributing distributed power sources in distribution networks, closer to consumers.

4. Conclusion

The energy system built in accordance with the Smart Grid concept has the following benefits:

- the power factor is close to one;
- the possibility of energy recovery from the contact network to the general network;
- higher efficiency (it is possible to increase by 5÷8 %);
- a lower coefficient of harmonic distortion;
- the possibility of monitoring the state of the power system in the online mode;
- ability to regulate and stabilize the voltage in the system's contact network in online mode;
- the possibility of connecting alternative power sources to the contact rail contact network.

One of the components of the successful implementation of the Smart Grid concept is the efficient use of the existing elemental power electronics base.

A review has been conducted of power electronics conversion devices, which can be used in Smart Grid.

5. References

1. Smolenski R. Conducted electromagnetic interference in Smart Grids. *Springer-Verlag London*. 2012. P. 160. doi: 10.1007/978-1-4471-2960-8.

2. Wilker S., Meisel M., Sauter T. Smart Grid architecture modelstandardization and the applicability of domain language specificmodeling tools. *2017 IEEE 26th International Symposium on Industrial Electronics*. Edinburgh, 2017. P. 152–157.

3. Neureiter C., Engel D., Uslar M. Domain specific and modelbased systems engineering in the Smart Grid as prerequesite for security by design. *MDPI Electronics*. 2016. Vol. 5, Issue 2. P. 24.

4. Piatkowska E., Bajraktari A., Chhajed D., Smith P. Tool supportfor data protection impact assessment in the Smart Grid. *Elektrotechnik und Informationstechnik*. 2017. Vol. 134, Issue 1. P. 2629.

5. Michael T. Burr. Reliability demands drive automation investments. *Public Utilities Fortnightly*. *Technology Corridor department*. Nov. 2003.

6. Plakhtii O., Nerubatskyi V., Ryshchenko I., Zinchenko O., Tykhonravov S., Hordiienko D. Determining additional power losses in the electricity supply systems due to current's higher harmonics. *Eastern-European Journal of Enterprise Technologies*. 2019. Vol. 1, No. 8 (97). P. 6–13. doi: https://doi.org/10.15587/1729-4061.2019.155672.

7. Plakhtii O., Nerubatskyi V. Analyses of energy efficiency of interleaving in active voltage-source rectifier. *2018 IEEE 3rd International Conference on Intelligent Energy and Power Systems (IEPS)*. P. 253–258. doi: https://doi.org/10.1109/IEPS.2018.8559514.

8. Scherback Ya. V., Plakhtiy O. A. Nerubatskiy V. P. Control characteristics of active four-quadrant converter in rectifier and recovery mode. *Tekhnichna elektrodynamika*. 2017. No. 6. P. 26–31. doi: https://doi.org/10.15407/techned2017.06.026.

9. Rylatt R. M. Exploring Smart Grid possibilities: a complex system modelling approach. *Smart Grid*. 2015. Vol. 1, No. 1. P. 1–15.

10. Vijayapriya T., Kothari D. Smart Grid: An Overview. *Smart Grid and Renewable Energy*. 2011. Vol. 2, No. 4. P. 305–311. doi: 10.4236/sgre.2011.24035.

11. Padmane P. V., Rane P. R. Improvement of power quality in multibus system by interphase power controller. *International Journal of Scientific Engineering and Research*. 2015. Vol. 3, Issue 10. P. 80–84.

12. Seyezhai R., Arthi K., Bhavani J., Archana A., Deepa M. Design and control of switched-inductor quasi-Z-source inverter for photovoltaic applications. *International Refereed Journal of Engineering and Science*. 2014. Vol. 3, Issue 10. P. 15–28.

13. Vijayakumar Y. N., Sivanagaraju D. Application of interline powerflow controller for powertransmission system. *IJIREEICE*. 2014. P. 2138–2142. doi: 10.17148/ijireeice.2014.21104.

14. Vijayakumar Y., Sivanagaraju D. Application of interline powerflow controller for powertransmission system. *International Journal of Innovative Research in Electrical, Instrumentation and Control Engineering*. 2014. Vol. 2, Issue 10. P. 2138–2142.

15. Caldeira E., Brandao G., Campos H. Characterizing and evaluating fraud in electronic transactions. *Proceedings of the 2012 Eighth Latin American Web Congress*. 2012. P. 115–122.

16. Ortiz G. High-Power DC-DC converter technologies for Smart Grid and traction applications. *Eidgenossische Technische Hochschule ETH Zurich*. 2014. 283 p.

17. Padmane P. V., Rane P. R. Improvement of power quality in multibus system by interphase power controller. *International Journal of Scientific Engineering and Research*. 2015. Vol. 3, Issue 10. P. 80–84.

18. Hsieh Y. P., Liang T. J., Yang L. S. Novel high step-up DC-DC converter for distributed generation system. *IEEE Transactions on Industrial Electronics*. 2013. Vol. 60, Issue 4. P. 1473–1482. doi: 10.1109/tie.2011.2107721.