SMART GRID СИСТЕМИ ТА ТЕХНОЛОГІЇ

SMART GRID SYSTEMS AND TECHNOLOGIES

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ANALYSIS OF THE SMART GRID CONCEPT IN THE RAILWAY TRACTION POWER SUPPLY SYSTEM

The Smart Grid network system is a concept of a fully integrated, self-regulating and renewable electric power system, which has a network topology and includes all generating sources, trunk and distribution networks and all types of electric energy consumers, managed by a single network of information and control devices and systems in real time mode. The article proposes the introduction of the Smart Grid concept into the traction power supply system of railways. The functional properties and technical solutions that will allow implementing the principles of Smart Grid intelligent power supply systems are considered. A comparative description of the functional properties of the existing energy system and the energy system based on the Smart Grid concept is presented. Possibilities of introducing Smart Grid into the traction power supply system of direct current due to increasing the carrying capacity of trunk networks, consumption management, location of distributed energy sources in distribution networks and closer to consumers have been determined. The limits of the energy-saving effect from the introduction of the Smart Grid concept into the traction power supply system have been determined.

Keywords: *SMART GRID, electric power industry, power supply, energy system, innovative development, network.*

Introduction

An electricity grid is a collection of multiple grids and power generation companies with multiple operators using different levels of communication and coordination, most of which are manually controlled [1, 2].

The Smart Grid concept is aimed at ensuring the reliability and energy efficiency of power supply, improving the quality of electrical energy, throughput of electrical networks and their control, equalization of variable load graphs, organization of monitoring of parameters and control of the state of the power system, integration of renewable energy sources, reduction of system system costs during network reconstruction [3, 4].

Due to the development of the Smart Grid concept, there is a need to introduce intellectual power supply systems on electric mobile composition and traction substations of railway transport. Improving the energy efficiency of traction power supply systems is possible by applying energy-efficient semiconductor converters that will allow to implement the principles of intellectual Smart Grid power supply systems, improve the efficiency of traction power supply systems and electrical thrust and reduce electrical energy.

Analysis of Recent Research and Publications

The development of communication systems with the transmission of data over the Internet offers the possibility of much greater monitoring and control throughout the energy system, and therefore more efficient, flexible and cheaper operation. This enables Smart Grid to use new information and communication technologies in the electricity system [5, 6]. However, due to the huge size of the power system and the scale of investments made in it over many years, any significant changes will be expensive and require careful justification.

The implementation of the basic requirements of the Smart Grid concept can be ensured by developing traditional and creating new functional properties of the power system and its elements. Within the framework of the Smart Grid concept to achieve the basic requirements, the development of certain functional properties should be envisaged [7, 8]. Improving the efficiency and reliability of smart grids is expected to save consumers money and help reduce CO_2 emissions.

In paper [9] it is stipulated that the Smart Grid energy system must simplify the relationship of distributed generation and electricity storage systems by creating a standardized relationship "Network – Generation", close concept of Plug and Play, which is used in modern computer systems.

Thus, in order to implement Smart Grid, it is necessary to optimize the solution of many aspects of technical, regulatory, environmental and cultural issues.

Purpose and Objectives of the Study

The purpose of the study is to analyze the energy efficiency of the traction power supply system with the integrated Smart Grid concept. To achieve this purpose, the following tasks are set:

– consider the functional properties and technical solutions that will allow implementing the principles of Smart Grid intelligent power supply systems;

– to present a comparative description of the functional properties of the existing energy system and the energy system based on the Smart Grid concept;

– determine the energy-saving effect of the implementation of the Smart Grid concept.

Main Material of the Study

At the current stage of energy development, technical means of intelligent systems, as well as advanced technical solutions of semiconductor power converters, play a decisive role in implementing the provisions of the Smart Grid concept [10, 11]. Prospective technical means can be divided into the following main groups:

– intelligent information sensors, control and measuring devices, accounting and control devices;

– data collection and transmission systems containing distributed intelligent devices and analytical tools to support communications at the level of power system objects;

– intelligent forecasting, support and decision-making systems (in particular, intelligent adaptive protection and automation systems with the function of automatic power restoration);

– improved topologies of semiconductor converters and implementation of active power components of the electrical network;

– integrated information exchange systems.

The transition from a conventional energy system to a Smart Grid system that meets the requirements of Industry 4.0 includes 6 stages [12].

1. Computerization. Computerization refers to the provision of means for digital control of all the main 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 energy system. Usually, Internet Protocol (IP) connections are used for this purpose, thus forming the Internet of Things. Network interaction allows to combine CAD/CAM automatic design and production procedures with Manufacturing Execution System (MES) technological process management tools, organize remote service, etc.

3. Availability for review (visibility). Visibility refers to the creation of a digital reflection or virtual double of the system. Falling prices for sensors and other digital equipment make this possible. The more sensors, the more accurate the display. The presence of a display related to PLM, ERP and MES systems allows operators to see the status of the system in real time and make the necessary decisions.

4. Transparency. Transparency in this context means the connection of digital display with analytical systems, more widely known as big data systems. At this stage, the following tasks are solved:

– transformation of the original "raw" data into a form suitable for analysis;

– actual data analysis;

– data interpretation;

– application of the obtained results in practice.

5. Prediction (predictive capacity). Transition to real-time planning tasks based on reliable information about the state of the energy system.

6. Adaptability. Ensuring automatic response of the control system to most production situations. That is, it is a solution that is created individually for specific equipment and is individually configured, thanks to which the system will be able to trigger automatic reactions to production events from production.

If the first two stages assigned to the Digitalization group, that is, the development of digital approaches, are purely technological, then the other stages, according to Industry 4.0, are to a greater extent cybernetic, as they embody system principles.

The scheme of the existing energy system of traction power supply, which does not meet the requirements of Industry 4.0, is shown in Fig. 1.

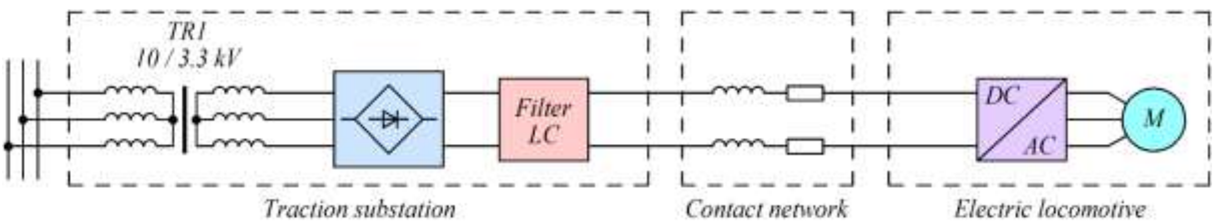

Figure 1 – *Scheme of the existing energy system of traction power supply*

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

– low efficiency due to the presence of significant active resistance in the contact network and the presence of a passive voltage rectifier, which has high static energy losses on the diodes;

– significant emission of higher harmonic current components into the alternating current power supply network and higher voltage harmonics into the direct current network;

– lack of possibility of energy recovery to the contact network;

– low power factor;

– high mass and size indicators.

When applying the Smart Grid concept, it is important to determine the technical parameters and characteristics of the traction power supply system.

Computerization must be carried out both on the side of the system performing data collection and analysis (operator) and on the side of the energy system installed directly on the rolling stock.

The information collection and processing system (operator) includes:

– a personal computer;

– GSM module connected to a computer;

– database.

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

If the appropriate software (software) is available, the PC operator can conduct current analysis of the received data.

Analysis results can be saved to the database.

The GSM module must have a communication interface (USB, Ethernet or RS-232) to connect to a PC. Basic requirements for GSM modules:

– receiving and sending SMS;

– reception and transmission using GPRS;

– work with RS-232 or RS-485 serial interfaces;

– allows to control the reception and transmission of data on serial RS-232 or RS-485 interfaces using AT commands in accordance with GSM 07.05 and GSM 07.07 standards.

Modern industry provides a wide selection of such modules:

– Siemens MC35i Terminal (GSM900/1800+GPRS standard);

– 3G UMTS/HSPA + Wi-Fi router UR5i v2 Libratum;

– GSM/GPRS modem OVEN PM01;

– GSM modem iRZ MC52iT;

– SQUID-1H and SQUID-2H.

Special attention should be paid to GSM routers SQUID-1H and SQUID-2H, which provide constant on-line communication between remote objects and the control center, and allow not only to receive information from objects, but also to manage them [13, 14]. The main characteristics of SQUID GSM routers:

– reception and transmission of data using GPRS;

– receiving and sending SMS;

– data archiving on an SD card;

– sending archival data to e-mail;

– presence of built-in analog and discrete inputs/outputs.

A computer is used as a server at the control room. Information exchange between GSM routers and a computer takes place via the Internet. GSM routers form a "transparent" GSM channel, and are actually "remote" serial COM ports. This allows to connect a large number of routers to computer. At the same time, data is transferred simultaneously, without a noticeable loss of exchange speed. The delay of updating data from 125 objects is 2...3 s, respectively from 250 objects – 4...6 s.

If there is no possibility to connect to the Internet in the control room, then SQUID-1H-server is used as a server or a standard 3G modem from any mobile operator. SQUID GSM routers use GPRS packet data transmission, which is the cheapest method of data transmission. The amount of data transmitted to the central dispatch center around the clock is included in any selected tariff plan without additional charges.

Any SCADA system that supports the Modbus protocol can be installed on the control room computer. The software "SQUID-configurator" and "SquidService" for working with SQUID-1H and SQUID-2H GSM routers is free and available for download on the company's website.

According to industry standards, the selected database must be a real-time database, meaning it must provide real-time data synchronization, replication, and backup [15, 16]. Databases must provide real-time data storage, processing and output. A real-time system is a hardware and software complex that reacts at set times to an unpredictable flow of external events. This means that:

– the system must have time to react to the event that occurred at the facility within the time critical for this event. The value of the critical time for each event is determined by the object and between the events, and naturally can be different, but the reaction time of the system must be predicted (calculated) when creating the system. Failure to respond within set hours is considered an error for real-time systems;

– the system must have time 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 within the time intervals critical for these 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 response delays under any circumstances in the following cases:

– the results may turn out to be irrelevant in case of delay;

– an accident may occur if the reaction is delayed.

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

Real-time databases are ordinary databases with additional capabilities that can provide reliable performance. Time constants are used, which make up a certain range of time values for which the data is still relevant. This range can be called the time of relevance. A standard database cannot work in such conditions, as the mismatch between real-world objects and the data that represents them is too severe. An efficient system must handle urgent requests, return only time-reliable data, and maintain priority queues. To enter data into a record, often a sensor or input device monitors the state of the physical system and updates the database with new information that more accurately represents the physical system. When designing a real-time database system, consider 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 the transaction processing takes place correctly and the consistency of the data does not have any violations.

The information collection and processing system includes:

– software logic controller;

– a system of sensors and alarms;

– GSM module;

– personal computer (PC).

According to parameters, programming tools, features of combining modules and appearance, controllers for automation systems can be divided into the following groups:

– programmable relays;

– modular programmable logic controllers (PLC);

– human-machine interface + programmable logic controller (HMI + 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 possess the full range of technical resources required for use in industrial automation, mechanical engineering or manufacturing at the lower level of automation [17, 18]. Programmable relays of the following manufacturers are represented in Ukraine:

– Siemens – Logo series;

– Eaton (Moeller) – Easy series;

– ABB – CL series;

– Mitsubishi – Alpha;

– Schneider Electric – Zelio Logic;

– OVEN PR100 and OVEN PR200.

Modular PLCs are characterized by an extended structure. The basic device can function individually and usually contains a minimum of 8 inputs/outputs, and if necessary, their number can be expanded with additional modules up to 65536 discrete / 4096 analog channels. This gives great flexibility when creating automation systems of technological processes based on modular PLCs.

The following modular PLCs are presented on the Ukrainian market:

– Siemens – SIMATIC-S7 series;

– Eaton (Moeller) – XC100, XC200 series;

– ABB – AC500 series;

– Mitsubishi – System Q series;

– Schneider Electric – Modicon series.

Modular PLCs support the functions of programmable relays, but additionally have built-in network interfaces and the ability to expand internal memory and input/output modules within wide limits [19, 20]. HMI + PLC systems are used to visualize the technological process and create simple SCADA systems. Depending on the model of the device, the HMI may not support PLC functions, but it must have a graphic display to display the technological process and an advanced input device that the operator uses to influence the technological process.

To communicate with other elements of the automation system, such devices use network protocols CANopen, Profibus-DP, etc. HMI + PLC systems have the following functionality:

– visualization of technological process parameters in text or graphic modes;

– construction of diagrams and graphs, output of the report;

– management and processing of emergency messages, registration of time and date of occurrence of emergency messages;

– manual control using functional buttons or touch screen;

– the possibility of free programming of graphs and setting of function keys.

Display of information about the technological process is carried out using a symbolic or graphic screen, the size of which depends on the requirements of the technological process, and button or touch controls are used to enter information. HMI + PLC devices of the following main manufacturers are represented on the market of Ukraine:

– Siemens – SIMATIC HMI IPC series;

– Eaton (Moeller) – series XV1, XV2, XV3, XV4, MI4, MFD4;

– ABB – series CP400, CP400;

– Mitsubishi – Vision 1000, E1000, IPC1000, GOT1000 series;

– Schneider Electric – Magelis series STO, STU, XBT GT, XBT GTW, XBT N, Compact iPC, Panel PC.

The system of sensors and meters includes:

– sensors of electrical network parameters: currents, voltages, active and reactive power;

– temperature sensors;

– humidity sensors;

– pressure sensors.

The system includes a computer that connects to the system using a GSM wireless channel. This makes it possible to connect several energy systems into a single network with minimal communication costs.

Network interaction of intelligent sensors is implemented using GSM modules, which are connected to PLC modules using the RS-485 interface. GSM modules work at frequencies of the decimeter range (about 2 GHz), the data transfer speed is more than 2 Mbit/s (3G standard). This makes it possible to organize communication between energy systems and the operator.

Availability for review is organized by installing appropriate software on the operator's computer. The software builds a model, which is a complete copy of the energy system, based on the data obtained from real energy systems. The operator has the opportunity to flexibly analyze the system's operating modes.

The scheme of the proposed energy system of traction power supply when applying the Smart Grid concept is shown in Fig. 2.

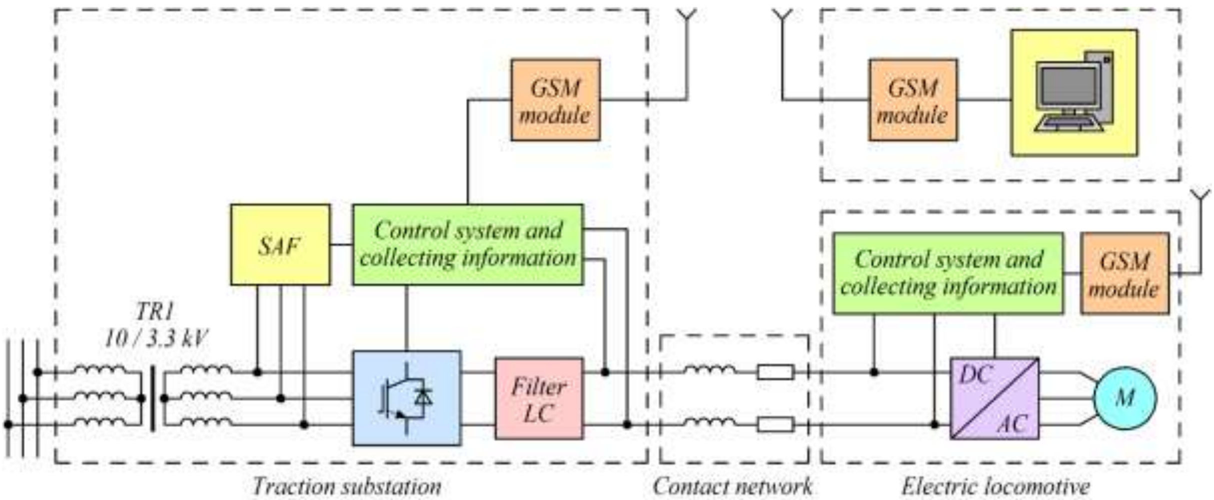

Figure 2 – *Scheme of the proposed energy system with the Smart Grid concept*

The comparative characteristics of the functional properties of the existing energy system and the energy system based on the Smart Grid concept are given in the Table 1.

An energy system built in accordance with the Smart Grid concept has the following advantages:

– the power factor is close to unity;

– the possibility of energy recovery from the contact network to the general industrial network;

– higher efficiency (a possible increase of 5…8 %);

– smaller coefficient of harmonic distortions;

– the possibility of monitoring the state of the energy system online;

– the ability to adjust and stabilize the voltage in the contact network of the system online;

– the possibility of connecting alternative power sources to the contact railway catenary network.

The energy system based on the Smart Grid concept should simplify the relationship between distributed generation and electricity storage systems. The spread of distributed generation will create new opportunities for the grid due to its more mobile nature and more stable characteristics, which are able to eliminate outages and dramatic voltage dips in the grid.

Smart Grid will reduce system losses, minimize reserve capacity, reduce capital and maintenance costs by optimizing the use of generating resources and adjusting the grid load schedule. Information about the state of the network will prevent most accidents and make repairs much faster when an accident does occur.

Table 1 – Comparative characteristics of functional properties of energy systems

Existing energy system	Energy system based on the Smart Grid concept
One-way communication between elements or its absence	Two-way communication
Centralized generation is a complex integrated distributed generation	Distributed generation
Reaction to the consequences of the accident	Response to accident prevention
Equipment operation until failure	Monitoring and self-diagnostics, which extend the "life" of the equipment
Manual recovery	Automatic recovery
Susceptibility to system crashes	Prevention of the development of system accidents
Inspection of equipment on site	Remote equipment monitoring
Limited power flow control	Power flow control
Unavailable or outdated information about the price for the consumer	Price in real time

Conclusions

On the basis of the conducted research, the following conclusions can be drawn:

– implementation of the main requirements of the Smart Grid concept can be ensured by developing traditional and creating new functional properties of the power system and its elements;

– in the energy system based on the Smart Grid concept, dynamic data obtained from equipment and sensors are used, due to which the bandwidth of networks is optimized and the probability of accidents is reduced;

– the proposed concept of Smart Grid allows to improve the coefficients of the efficiency of traction power supply and electric traction systems, as well as to reduce the consumption of electrical energy.

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АНАЛІЗ КОНЦЕПЦІЇ SMART GRID В СИСТЕМІ ТЯГОВОГО ЕЛЕКТРОПОСТАЧАННЯ ЗАЛІЗНИЦЬ

Система мережі Smart Grid – це концепція повністю інтегрованої, саморегульованої та відновлюваної електроенергетичної системи, що має мережеву топологію і включає в себе всі генеруючі джерела, магістральні та розподільні мережі та всі типи споживачів електричної енергії, що керуються єдиною мережею інформаційно-керуючих пристроїв і систем в режимі реального часу. У роботі запропоновано впровадження концепції Smart Grid в систему тягового електропостачання залізниць. Розглянуто функціональні властивості та технічні рішення, що дозволять реалізувати принципи інтелектуальних систем електропостачання Smart Grid. Представлено порівняльну характеристику функціональних властивостей існуючої енергетичної системи та енергетичної системи на базі концепції Smart Grid. Визначено можливості впровадження Smart Grid в систему тягового електропостачання постійного струму за рахунок збільшення пропускної спроможності магістральних мереж, керування споживанням, розташування розподілених джерел енергії в розподільних мережах та ближче до споживачів. Визначено межі енергозберігаючого ефекту від впровадження концепції Smart Grid в систему тягового електропостачання.

Ключові слова: *SMART GRID, електроенергетика, електропостачання, енергетична система, інноваційний розвиток, мережа.*

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