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ENERGY EFFICIENT WAYS OF USING ENERGY ACCUMULATORS IN THE SMART GRID CONCEPT

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The prospects for the application of the Smart Grid concept as one of the main directions of the development of the electric power industry are considered. The advantages of the implementation of the Smart Grid concept aimed at ensuring the reliability and energy efficiency of electricity supply, improving the quality of electrical energy, the throughput of electrical networks, the organization of parameter monitoring, control of the state of the energy system, and the integration of renewable energy sources have been identified. The topology of the Smart Grid network was studied with the possibility of connecting energy accumulators that create a bidirectional energy flow in the system, with the provision of regulation of its density depending on the demand for electricity at the current moment in time. The parameters of the intelligent network system with the use of energy accumulators are obtained on the example of the traction power supply of electric rolling stock, taking into account the electricity consumption by trains and the accumulator charge state. The given calculation results make it possible to state that the use of energy accumulators in the Smart Grid network increases the amount of energy returned to the electric power supply network, as a result of which the overall system costs are reduced. Ref.10, figure, table.

Keywords: Smart Grid concept, electric power industry, power supply system, energy accumulator, electric rolling stock.

Introduction. One of the main directions of the development of the electric power industry is the application of the methodology of intelligent networks (Smart Grid) [1, 2]. The implementation of the Smart Grid concept is aimed at ensuring the reliability and energy efficiency of electricity supply, improving the quality of electrical energy, equalizing variable load schedules, organizing monitoring of parameters and controlling the state of the energy system, integration of renewable energy sources [3, 4].

If consider the Smart Grid as an alternative to a single energy system, it is possible to distinguish several basic levels of its organization [5, 6]. The first level is related to the preservation of the existing structure of the network during the transmission of electrical energy on alternating current. The second level determines the connection between networks, whose parameters of electric energy may differ. The third level is formed by distributed generation objects at the stage of distribution and consumption of electricity – power plants based on alternative energy sources, "active" and "passive" consumers, as well as electricity accumulators connected to the network.

The components of the Smart Grid intelligent network include FACTS systems installed in the electrical network and designed to stabilize voltage, improve controllability, optimize flow distribution, reduce losses, damp low-frequency oscillations, increase static and dynamic stability, and as a result – increase network throughput and reduce losses [7, 8]. A significant role in the entire variety of FACTS devices is played by power electronics based on various modifications of voltage converters using controlled semiconductor switches.

An important role in the functioning of FACTS systems is played by electric energy accumulators that perform the following functions [9, 10]:

– equalization of load schedules y of the network (accumulation of electrical energy in periods of excess energy availability and supply to the network in periods of shortage;

– provision of uninterrupted power supply of particularly important objects, needs of power stations;

– ensuring, in combination with FACTS devices, an increase in stability limits;

– stabilization of the operation of decentralized sources of electrical energy;

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– damping of power fluctuations.

Thus, the issue of further introduction of electricity accumulators into the Smart Grid concept is an urgent task.

The purpose of the paper. The purpose of the study is to increase the energy efficiency of systems in the Smart Grid concept by using energy accumulators. To achieve this purpose, the following tasks are set:

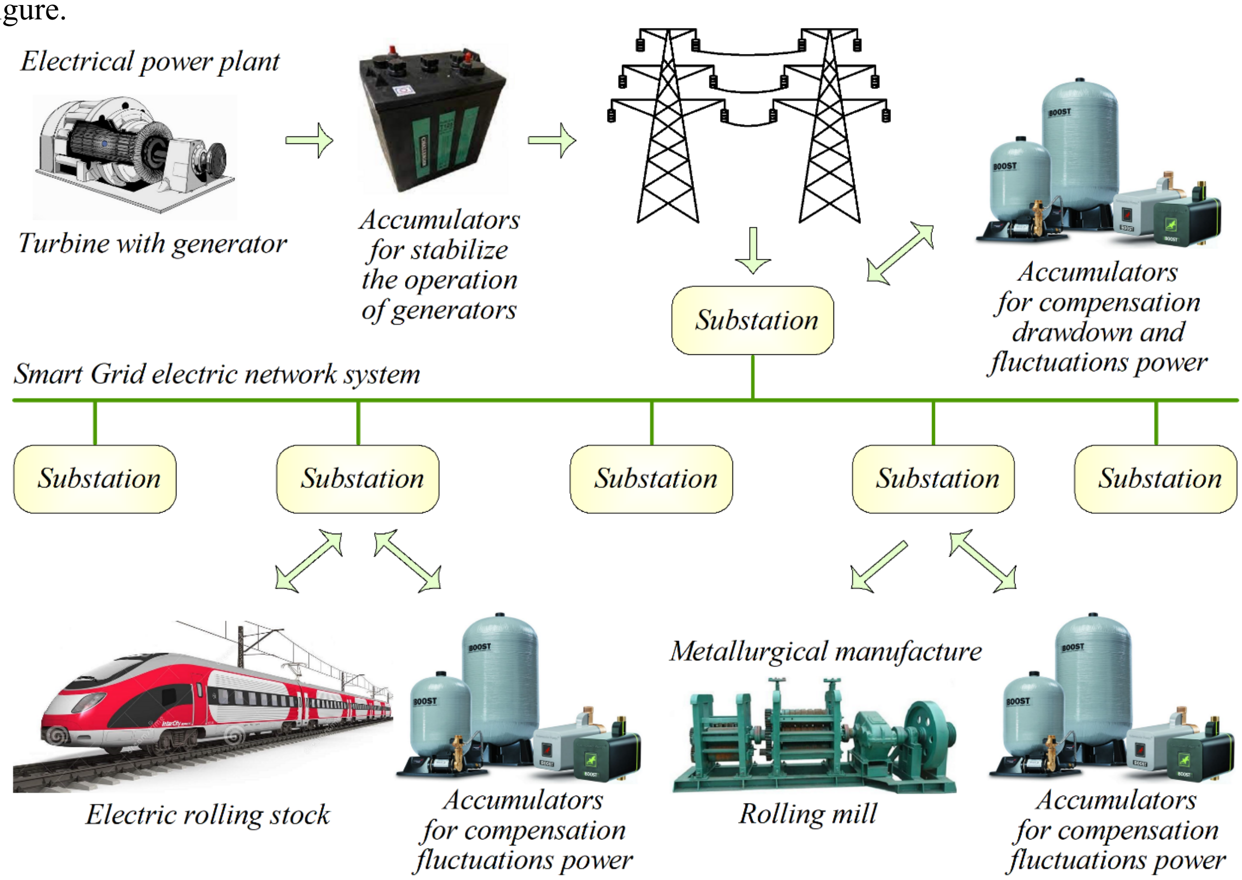
– determine the advantages of using energy accumulators in the Smart Grid concept;

– to consider the intelligent network system using energy accumulators on the example of traction power supply of electric rolling stock;

– to present the results of calculations of the system in the Smart Grid network with the use of energy accumulators.

The main material and study results. Energy accumulators are divided into electrostatic and electromechanical. Electrostatic energy accumulators includes high-capacity accumulators, energy accumulators based on molecular capacitors (supercapacitors), energy accumulators based on low-temperature (liquid gel cooling) superconductors. All types of electrostatic accumulators are connected to the network through power electronics devices – charging and converting devices.

The use of accumulators in the energy system based on the Smart Grid concept is shown in figure.



To electromechanical electricity accumulators there are two types of complexes: synchronous machines with frequency converters of the primary circuit with flywheels on the shaft; asynchronous machines with flywheels on the shaft.

The economic effect of using energy accumulators is achieved due to:

– differences in tariffs when buying electricity in hours of minimum load and selling it in hours of maximum;

– fuel savings at power plants due to the refusal to unload them during the hours of minimum loads with the accumulation of excess electricity and the refusal to load additional capacities during the periods of maximum loads with the release of accumulated electricity;

– refusal to buy expensive electricity from power stations that are in reserve on the wholesale market.

In addition, a quick reserve of power and electricity is provided in the event of emergency shutdowns of generators of power stations and elements of the electric network without the need to maintain an expensive reserve of power at power stations or the presence of a network reserve, and an additional economic effect is achieved due to:

– provision of system services for frequency regulation;

– maintenance of voltage levels at installation sites;

– creation of local intelligent electric energy systems;

– purchase of electricity during the day at the integrated tariff and its sale during peak hours at the maximum tariff;

– stabilization of power schedules of electricity generated by wind and solar power plants;

– postponement of deadlines or refusals of capital investments in the reconstruction of elements of the electrical network.

The railway transport system is one of the largest energy-intensive consumers in electric power systems. Therefore, there is a need to increase the energy efficiency of railway power systems by including Smart Grid components.

The system can consist of distributed generation (wind and solar energy generation) and a hybrid energy accumulators system (energy accumulators from accumulators and supercapacitors). Energy generated by trains during deceleration (regenerative braking mode) enters the network, and energy is consumed during acceleration of trains. At the same time, energy is exchanged between the Smart Grid intelligent network and the main power network.

The task of the proposed system is to minimize the total cost of operating the power system and intelligent network, taking into account the consumption of electricity by trains and the state of charge of accumulators, as well as taking into account various restrictions.

Increasing the energy efficiency of the traction power supply system of electric rolling stock with an integrated Smart Grid system is solved using a microgenetic algorithm, which is quite simple, reliable, flexible and capable of finding an optimal global solution. The microgenetic algorithm has an evolutionary concept based on random processes, selection of encoded solutions, reduction of the search space using special knowledge. At the same time, the processing time of the microgenetic algorithm is less compared to other algorithms.

The objective function of the proposed system is subject to equality and inequality constraints and is defined as:

$$F = \sum_{i=1}^{n} \left[C_{Grid}\left(P_{Grid}^{t}\right) + C_{c}\left(P_{c}^{t}\right) + C_{b}\left(P_{b}^{t}\right) \right], \qquad (1)$$

where P_{Grid} is the capacity of the Smart Grid; P_c is the power of the supercapacitor; P_b is the accumulator capacity; t is the planning period, $t = 1, 2, 3, \ldots, n$.

The power balance equation is defined as:

$$P_E^t + P_r^t = P_{Grid}^t + P_c^t + P_b^t, \qquad (2)$$

where P_E is the power of electric rolling stock; P_r is the excess power.

Parameter P_E has a positive effect on the energy consumption system during deceleration (recovery process) and negatively during acceleration of train movement.

The power limit from the public power system is defined as:

$$P_{Grid}^{\min} \le P_{Grid}^t \le P_{Grid}^{\max}. \qquad (3)$$

The excess power limit is defined as:

$$P_r^t \ge 0. \qquad (4)$$

The balance equation of the accumulator charge state is defined as:

$$C(t) = C(t-1) + I(t)\Delta t, \qquad (5)$$

where $I(t)$ is the charging (discharging) current of the accumulator.

Accumulator charge limitation is defined as:

$$C(t)_{\min} \le C(t) \le C(t)_{\max}, \qquad (6)$$

where $C(t)_{\min}$ is the minimum accumulator capacity; $C(t)_{\max}$ is the maximum accumulator capacity.

The limitation of the charge (discharge) current of the accumulator is defined as:

$$I(t)_{\min} \le I(t) \le I(t)_{\max}, \qquad (7)$$

where $I(t)_{\min}$ is the limitation of accumulator discharge current; $I(t)_{\max}$ is the limitation of accumulator charge current.

The limitation of the charge current of the supercapacitor is defined as:

$$P^{c}_{c\,\min}(t) \le P^{c}_{c}(t) \le P^{c}_{c\,\max}(t). \qquad (8)$$

The limitation of the discharge current of the supercapacitor is defined as:

$$P^{d}_{c\,\min}(t) \le P^{d}_{c}(t) \le P^{d}_{c\,\max}(t). \qquad (9)$$

The lower and upper limits of the accumulator charge are considered to be 10 kA·h and 15 kA·h, respectively. The maximum capacity of the accumulator is 1 MW. The maximum power of the supercapacitor is 2 MW. The maximum power from the Smart Grid intelligent power network is 20 MW. To compare the energy efficiency of power network systems, the calculations given in the table were made.

Parameter	Without Smart Grid system	With Smart Grid system
Energy consumed by electric rolling stock, MW·h	19.24	19.24
Energy returned to the electrical network, MW·h	2.32	4.49
Power of accumulator capacity, MW	–	0.76
Power of the supercapacitor, MW	–	1.16

In the first case, the calculations were performed without taking into account the components of the Smart Grid intelligent network. The energy consumed by electric rolling stock is 19.24 MW, and the energy returned to the electric network is 2.32 MW. In the second case, calculations were made taking into account energy accumulators. At the same time, the amount of energy returned to the electric network is 4.49 MW.

According to the results of the calculations, it can be seen that the amount of energy returned to the electrical network in the second case increases by 2.17 MW. Thus, the use of energy accumulators in a Smart Grid network increases the amount of energy returned to the electrical power network, resulting in a reduction in overall energy costs.

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

– an important advantage of the use of energy accumulators in the Smart Grid concept is the provision of a quick reserve of power and electricity in the event of emergency shutdowns of power station generators and elements of the electrical network;

– the intelligent network system with the use of energy accumulators on the example of the traction power supply of electric rolling stock ensures the minimization of the total cost of power system operation, taking into account the electricity consumption by trains and the state of charge of accumulators;

– from the results of the calculations shown, it is clear that the use of energy accumulators in the Smart Grid network increases the amount of energy returned to the electric power supply network, as a result of which the total costs of electricity are reduced.

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ЕНЕРГОЕФЕКТИВНІ ШЛЯХИ ЗАСТОСУВАННЯ НАКОПИЧУВАЧІВ ЕНЕРГІЇ В КОНЦЕПЦІЇ SMART GRID

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Розглянуто перспективи застосування концепції Smart Grid як одного з основних напрямків розвитку електроенергетики. Визначено переваги реалізації концепції Smart Grid, що спрямовані на забезпечення надійності та енергоефективності електропостачання, підвищення якості електричної енергії, пропускної здатності електричних мереж, організації моніторингу параметрів, контролю стану енергосистеми, інтеграцію відновлюваних джерел енергії. Досліджено топологію мережі Smart Grid із можливістю підключення накопичувачів енергії, що створюють у системі двонаправлений енергетичний потік, із забезпеченням регулювання його щільності залежно від попиту на електроенергію в поточний момент часу. Отримано параметри системи інтелектуальної мережі із застосуванням накопичувачів енергії на прикладі тягового електропостачання електричного рухомого складу з урахуванням споживання електроенергії поїздами і стану заряду акумуляторних батарей. Наведені результати розрахунків дають змогу стверджувати, що застосування накопичувачів енергії в мережі Smart Grid збільшує кількість енергії, що повертається в електричну мережу живлення, в результаті чого зменшуються загальносистемні витрати. Бібл. 10, рисунок, таблиця.

Ключові слова: концепція Smart Grid, електроенергетика, система електропостачання, накопичувач енергії, електричний рухомий склад.

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