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Grid Connection Management of Distributed Generators on the Basis of Renewable Energy Sources

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Abstract—The concept of distributed energy of renewable energy sources is becoming increasingly popular. It is not simply supplementary but a real alternative to the conventional power supply from centralized power grids. Distributed electricity generators integrated into the Unified Energy System are a complex system in which the relationship between the observed parameters and the system state is ambivalent and ambiguous. Therefore, the approach to management in automatic control systems based on control of the output parameters is inappropriate in nature. In this case, the elaboration of a control action should be carried out on the basis of data on the current state of the object of control. Issues of the grid connection of distributed generators and control of their process parameters are considered.

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INTRODUCTION

The power system of the future should combine large power plants, without which it is problematic to provide large consumers with power supply and to ensure the growth of electricity consumption and distributed generation. Large power plants make it possible to step up low generated voltage to the voltage of a bulk power system, through which electricity is transported to large consumption centers. Distributed generation facilities, including renewable energy sources (RESs), operate through distribution networks. The next stage of the future energy system will be mini- and micro power plants (mini- and micro-HPPs, wind power generators, solar power plants, fuel cells, etc.) that are connected to low-voltage networks of small consumers, for example, individual houses or small enterprises, including agricultural ones. In short, there is a tendency to move from a merely centralized power supply to a combined one with an increasing number of local power sources [1, 2].

The wide use of alternative energy sources corresponds to the highest priorities and tasks of the security of energy supply of any country and is the most rapidly developing area of the energy industry. In view of this, Uzbekistan is carrying out certain activities aimed at development of the renewable energy sector, including the use of hydropower potential [3–5].

In particular, AO Uzbekenergo has started the implementation of revitalization and reconstruction projects for the existing HPPs. In the medium term, it is planned to modernize and reconstruct the Farkhad HPP, HPP-14 of the Nizhne-Bozsu power chain, HPP UFK-1 of the Shahrikhan power chain, HPP-10 of the Chirchik power chain, and HPP-2B of the Samarkand power chain and to build the Kamolot HPP with 8 MW of power [5].

In the framework of the implementation of the Decree and Resolution of the President of the Republic of Uzbekistan of March 1, 2013, No. UP-4512, "On Measures for the Further Development of Alternative Energy Sources," and PP-1929 "On the Establishment of the International Solar Energy Institute," an International Solar Energy Institute was cofounded by AO Uzbekenergo on the basis of the Physics-Sun SPA.

In addition, AO Uzbekenergo works on the involvement of RESs in the fuel and energy balance. The use of RESs on a commercial scale will ensure significant natural gas savings in the country for the production of electrical and thermal energy and, accordingly, will reduce emissions of harmful substances into the environment. In the medium term, construction of solar photovoltaic stations with a capacity of 100 MW each is planned [5].

Assessment of the gross capacity and technical potential of various types of RESs across the country makes it possible to draw the following conclusions: environmental safety, energy resource adequacy, and the accessibility of many types of RES almost throughout the entire territory of the country necessitate a radical review of the national energy resource

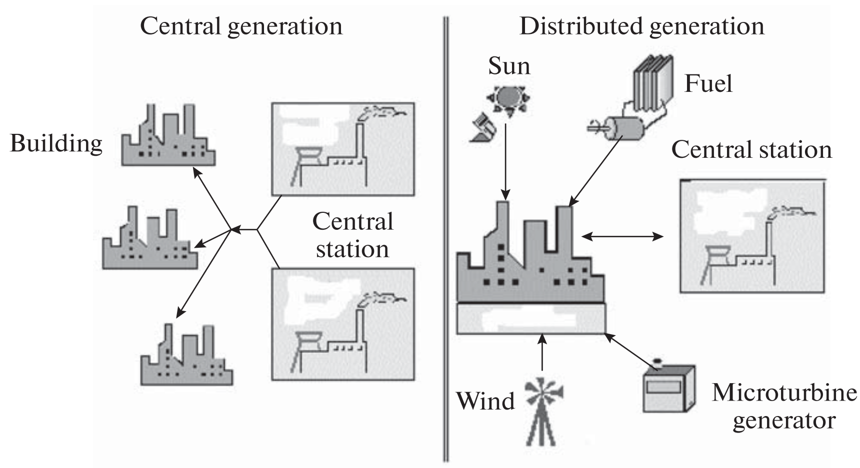

Fig. 1. Structural diagram of centralized and distributed energy generation.

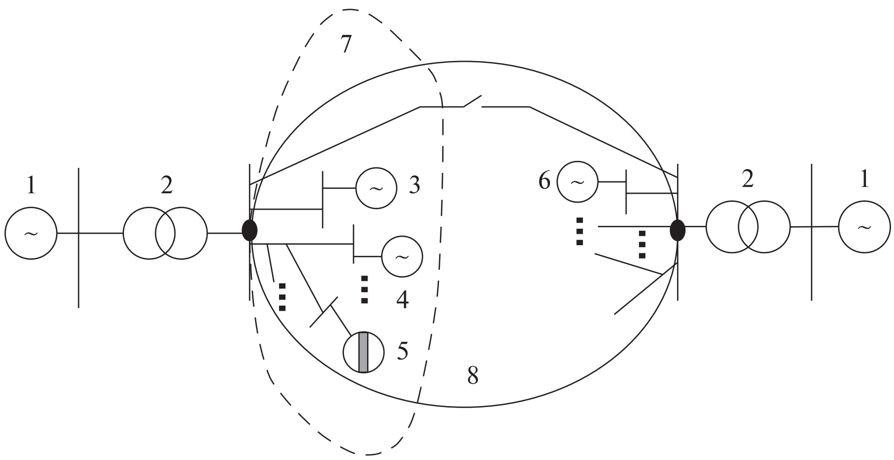

Fig. 2. Equivalent circuit of the power grid with a mixed power supply. (1) EES; (2) 110/10 kV transformer; (3) SHPP; (4) SPP; (5) capacitor batteries; (6) WPP; (7) LEN; (8) single-area power network.

strategy, both for the foreseeable future and the long-term perspective.

The large-scale use of various RES types by means of a transition to decentralized energy supply in feasible technical and economic limits will solve a number of problems related to improvement of the energy supply of facilities in rural areas, especially in remote, hard-to-reach areas.

For these reasons, at present, the distributed energy concept based on RESs in Uzbekistan has gained increasing popularity and become not only a supplement but a real alternative to the traditional power centralized power supply.

DISTRIBUTED GENERATION SYSTEMS

Distributed generation systems are hybrid power supply systems consisting of various energy sources and are built in close proximity to the consumer, taking into account to the maximum extent individual features of the consumer in terms of power and activity type (Fig. 1). They have such advantages as controllability, reliability, economy (including elimination of transport losses), scalability, and flexibility [6].

Thus, the power distribution network (PDN) is gradually turning into a network with characteristics typical for a local electrical network (LEN), which receives power both from its own distributed energy sources (DESs) and from a centralized source—the electric energy system (EES). An equivalent circuit of the electric system with mixed power supply is shown in Fig. 2.

Electric energy is generated in these systems by solar photovoltaic panels, wind power generators, or other conversion systems. Thermal generation for heating systems, hot water supply, and technological processes is carried out by solar collectors (flat-plate and evacuated-tube), geothermal systems, and other thermal energy converters. The combination of various renewable energy sources is not only the presence of such components as solar collectors, photovoltaic panels, wind turbines, and heat pumps but also the use of a unified control system to ensure the efficient operation of these components; this forms the core of a more stable hybrid power supply system.

Today, distributed generation systems are generally represented in the form of autonomous energy centers, since the connection of distributed generators to centralized grids is so far limited by the lack or imperfection of the legal environment and effective means of technological control.

For efficient operation of a hybrid energy supply system with renewable energy sources (RESs), it is necessary to coordinate the intensity of energy supply with its consumption by consumers. Such coordination can be carried out on the basis of energy input and energy consumption monitoring and management by a unified system built on the basis of modern information and communication technologies [6].

Distributed Generator Management

The distributed generators are managed as "virtual" power plant microgrid integrated into the macroscaled Unified Energy System (UES), and thus into the electricity and capacity market, which will contribute to an increasing role of the consumer in the energy system management [7].

In the process of creating "virtual" power plants, it is necessary to solve a number of organizational and technological issues, one of which is the problem of connecting distributed generators to a unified system and managing their operation. Distributed electricity generators integrated in the UES are a complex system in which the relationship between the observed parameters and the system state is complicated and ambiguous. Therefore, the approach to management in automatic control systems based on output control is inappropriate in nature. In this case, the development of a control effect should be carried out on the basis of the current state of the object of control [6, 7].

Specific questions on the use of renewable energy sources as a distributed generator, as well as the approach to the synthesis of the operating level of the active adaptive automatic control system of the combined installation within the framework of the UES, were considered in [6].

The effectiveness of managing distributed power generation systems containing RESs, energy storage units, and intelligent control systems is achieved via the possibility of an integral action on the process parameters of the generator regimes.

For example, voltage regulation, apart from the use of conventional means, can be realized via changes to active or reactive power generation by affecting the energy storage means or controlling the load.

This set of measures, together with hardware and software, represents a management system for distributed power generation.

The main purpose of such a management system is to integrate distributed generators into a unified power grid and to ensure optimal process control to meet the needs of consumers in power supply.

The management of distributed generators requires the creation of a telecommunication network and a dispatch center. There should be monitoring of market prices, the state of the networks and load conditions, and processing of data on neighboring producers and sellers in the center (and perhaps at the generation sites themselves) in order to make decisions on the use of capacities. Deployment locations of generators should be equipped with special smart equipment capable of being controlled by signals from the remote dispatch center, the generators' operation regimes, and the energy consumption of the rooms in which they are installed [7–9].

To connect the generating equipment to the grid, a potential power supplier requires special equipment that meets the remote control requirements. Special meters transmitting measuring results in real time should also be a standard component of the distributed generation architecture. Anticipating the growing complexity, network companies often offer a very complicated and expensive certification procedure for each particular connection, which really hinders the development of the market [9].

The management of such power systems, which are characterized by considerable spatial distribution and inhomogeneity, is very relevant at present. System inhomogeneity can be associated with the use of such alternative sources of electricity as wind and solar power. Optimization of network operation should be performed by several local smart devices.

The most promising at present for use as a power supply system for remote small and medium power consumers are autonomous combined wind-solar power plants (WSPPs). The idea of an autonomous power plant in a loose sense is the following (Fig. 3). In order to ensure high energy efficiency of the autonomous power supply system, the energy generated by the primary energy source should be directly delivered to the consumer (Path A). In periods of excessive energy generation, the energy should be stored by the accumulation system (Path B). If there is a shortage in the energy generated by a primary source, the accumulated energy from secondary sources should be delivered to the consumer, covering the existing gap (Path C).

The use of WSPPs is especially relevant is in areas remote from power grids, as well as in mobile application. However, these energy sources also have their drawbacks, including the main issues of low power, variability in time throughout the day and year, and unpredictability. At the same time, according to mete-

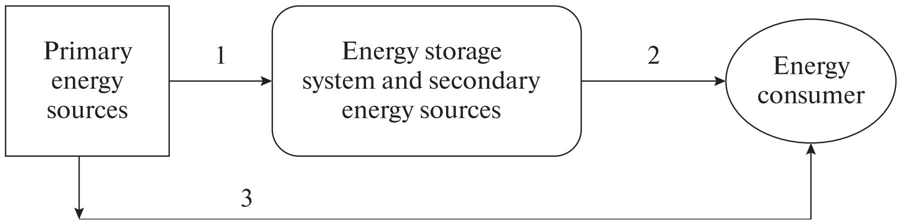

Fig. 3. Main autonomous power-supply system components.

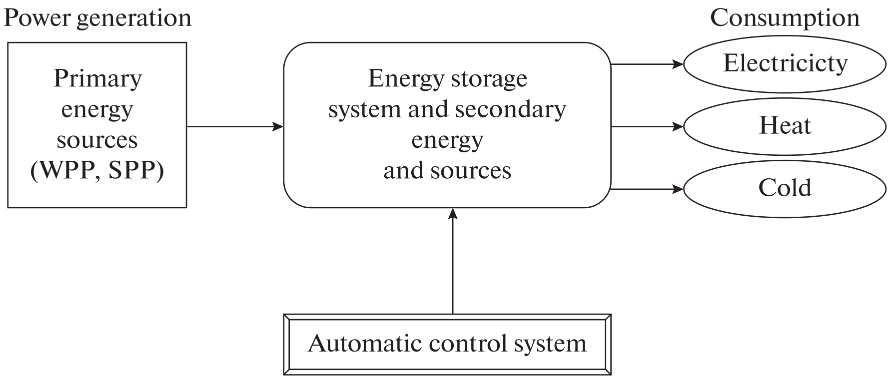

Fig. 4. Main autonomous RES-based power plant components.

orological data, the advantages and disadvantages of such renewable energy sources as solar radiation and wind flow successfully complement each other.

(A) The lack of sufficient radiation during a long sequence of cloudy days is usually balanced out by the presence of wind.

(B) The absence of solar radiation in the nighttime hours is also balanced out by the presence of wind.

(C) Wind is statistically usually stronger in winter, while solar radiation is stronger in summer.

A simplified design of an autonomous RES-based power plant is shown in Fig. 4. The structure of the considered power plant includes primary energy sources, photoelectric converters and a wind power turbine, the power generation of which, as a rule, substantially does not coincide with the consumers' energy consumption schedule; they generally need electricity, thermal energy, and sometimes cooling. In this situation, key components of the autonomous power plant are accumulation, transformation, and secondary generation systems. To ensure the most effective primary energy conversion and to meet consumer needs, the power plant should be equipped with a smart automatic control system.

RES-based energy systems, in general, have the following three control methods based on surplus energy dumping, energy accumulation, and load adjustment (Figure 5).

These methods can be implemented in various ways for the entire power system or its parts.

(A) Surplus energy relief system. Renewable energy flows exist constantly; if unused, they will be irretrievably lost. However, a control method based on the relief of a portion of this energy can be the simplest and cheapest. This control method is used, for example, at hydroelectric power plants, in solar heating systems with controllable dampers, and in variable-pitch wind turbines (Fig. 6).

(B) Systems with energy accumulators (storage batteries). The batteries can accumulate RES-based energy both in its original, unconverted form (for example, the accumulating substance is water in hot-water accumulators and the accumulating substance is air in cavities with coarse material) and in a converted downstream form (batteries).

(C) Systems with load adjustment. Such systems provide a balance between power supply and demand by switching on and off the required number of consumers. Such regulation can be used in any system, but it is most advantageous in the presence of a large number of dissimilar consumers (Fig. 7).

Modern autonomous power supply systems, as a rule, already contain special microcontrol units, which are designed to solve only field-specific tasks related to the controlled process (for example, a wind generator).

As an example, let us consider an autonomous combined WSPP, which is also a typical complex technical system [10]. The WSPP includes the following subsystems (installations), as shown in Fig. 8.

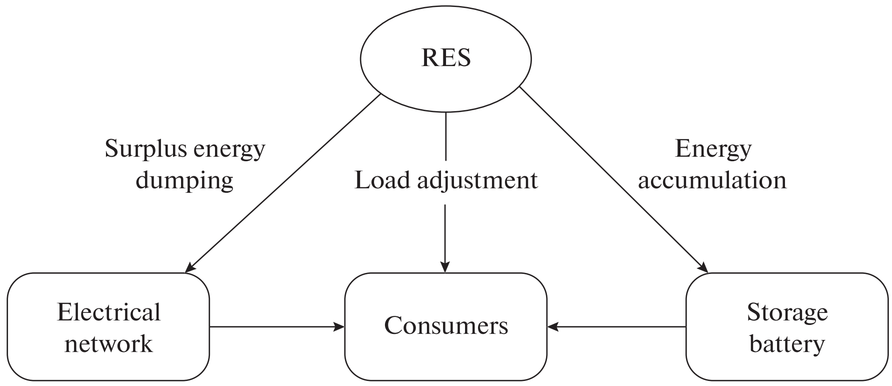

Fig. 5. Scheme of methods for the control of energy flows from RES to consumers.

The power system under consideration is characterized by the following processes:

(A) mechanical (wind-flow energy conversion into the WPP wind wheel mechanical energy of rotation);

(B) rotation of SPP modules;

(C) energy (electricity generation, conversion, and transmission);

(D) information (data acquisition, processing, and transmission).

Such a combination of processes makes it possible to use a two-level automatic control system (ACS), which usually takes place in a real WSPP [10]:

(A) level of system components;

(B) operational level.

At the level of system components, the ACS performs the optimal control according to the technical efficiency criteria. The existence of the operational level means that the effective operation of autonomous WSPP is possible only in the presence of ACS, i.e., it depends not only on the effective operation of the WSPP components considered separately but also on their interaction.

The operational level at which optimal control is carried out according to economic or other efficiency criteria is of the greatest interest.

When the object under control is a complex system, an approach to control in the ACS based on the parameters control is inappropriate. In this case, the development of a control action should be carried out on the basis of a current state of the object under control. In general, an object's state identification problem on the basis of its parameters is a typical pattern-classification problem.

ACS synthesis is carried out with allowance for the analysis of WSPP at two levels:

(A) at the level of system components, which solves the problem of optimal control of individual WSPP devices;

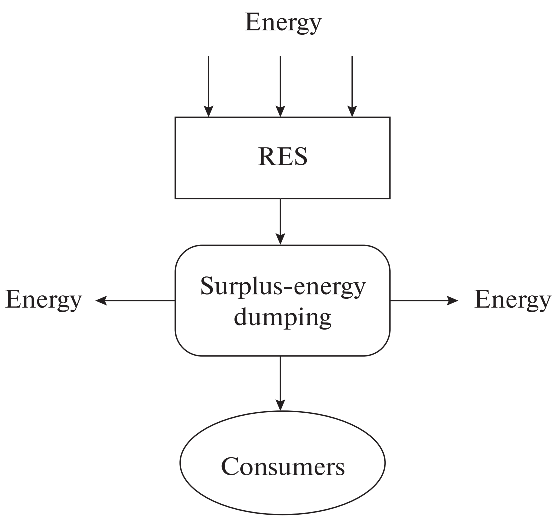

Fig. 6. Surplus energy–dump control system.

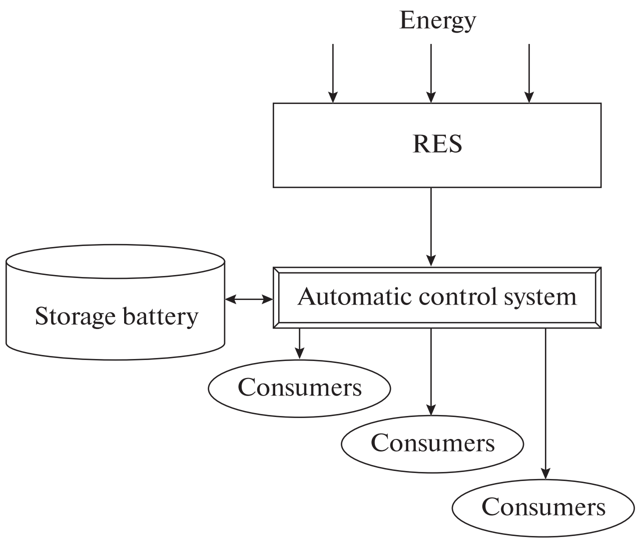

Fig. 7. Load adjustment system.

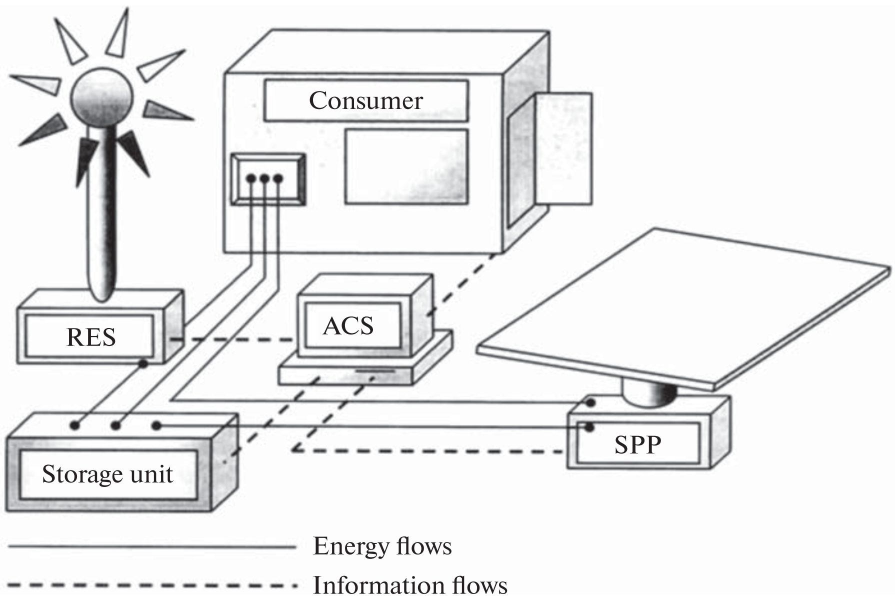

Fig. 8. Schematic diagram of WSPP.

(B) at the operational level, which solves the problem of optimal power distribution between consumers and the storage.

The purpose of the ACS is to automatically ensure the process requirements for operability of the power system components and to reduce the likelihood of emergency situations related to the customer curtailment. This purpose is achieved by automatic maintenance of the power generator operation in the maximum power regime, automatic protection of devices from emergency situations, and the coordination of individual units to bring the electricity generation to a specified, normal mode.

In the general case, optimization of the mode conventional electric power systems can be seen as ensuring the demand for electricity with the greatest economic effect for the economy as a whole. In this case, as a rule, the minimum input criterion for electricity production and transmission is accepted as an optimality criterion.

The use of nonconventional renewable energy sources eliminates the costs associated with the extraction, the transportation and processing of organic fuels, and the problem of emissions into the atmosphere. In addition, the energy transportation cost is reduced due to the maximal approximation of generators to consumers. However, there are other factors associated with a power supply that is irregular in time (the cyclical nature of energy input from RES over a year, season, and day), which impose certain limitations and require a rational balance of different energy sources in the electric power supply to a consumer.

Therefore, a key problem in the development and creation of a fully autonomous RES-based power plant is the optimal configuration and optimal equipment to ensure a reliable power supply of a given consumer at minimal cost. The solution to this problem should be based on an accounting of actual climate data on the intended operation site, features of the load schedule, and mode parameters of the plant components. At the same time, it is of fundamental importance to develop an automatic control system that provides rational logic for plant operation, since the combination of primary and secondary energy sources and various storage batteries require control algorithmic optimization, ensuring the maximum integral efficiency of energy conversion and the maximum service life of the main units. On the other hand, the relatively low energy-output ratio of distributed (local) EESs with WSPPs significantly affects the variation in power consumption on their operating modes. In addition, WSPPs are characterized by the instability of output power associated with uncertain wind and solar characteristics as power sources. Against this background, to ensure a reliable power supply to consumers, it is necessary to provide operational control of EES modes by means of flexible redistribution of active and reactive power with respect to the specific unfolding situation associated with load adjustment or wind and sun parameter changes corresponding to the WSPP output power changes.

Autonomous WSPPs are characterized by a high cost of generated power and irregular supply. These features make it practically unacceptable to dump surplus energy. The majority of both industrial and household power consumers do not have proper energy storage facilities. Therefore, the most effective system and operational control method is a system that uses surplus energy storage devices. When designing autonomous WSPPs without back-up power sources, designers assign an availability factor of the power system (the ratio of time when the load is served to consumers to the full operation time) as 0.8–0.9 due to the significant increase in plant cost when availability approaches 1; therefore, under unfavorable climatic conditions from the energy point of view and (or) during peak energy consumption, there is a shortage of generated power. Therefore, it becomes necessary to disconnect some consumers, which should be done with an allowance for their priority.

Due to the features described above of autonomous WSPPs, it is advisable to adopt a method combining surplus energy accumulation and load distribution as the operational control method. At the same time, under conditions of the existing or predicted energy shortage, the load should be distributed with allowance for priority, and, in the case of its surplus, it should be accumulated.

CONCLUSIONS

For the moment, there is no obvious optimal energy distribution algorithm for autonomous WSPPs under the conditions of an energy shortage. In addition, due to the large variability in the supply of renewable energy, this optimal control algorithm may not coincide for different climatic conditions.

At the operational ACS level, the operational control of energy flows distribution between power system components is carried out via the coordination of the operation of first-level individual control devices.

The objective of the considered ACS level is the most comprehensive and uninterrupted power distribution to consumers in the context of its irregular supply and under normal operating conditions of all power system components. Thus, the objective of the ACS at the operational level is dual: the most complete satisfaction of both current and future needs of power consumers [5].

Consequently, the management system at this level should be optimal. The level of power supply reliability can be adopted as an optimal criterion: the minimum of time-averaged mathematical expectation with respect to the undersupply of energy to different groups of consumers with allowance for the weight coefficients of these groups [6].

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