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Research

CONCERNING THE CONCEPT OF CONSTRUCTING COMBINED UPS SYSTEMS

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ABSTRACT

In Russia, more than 50% of the regions are experiencing power shortages due to the import of electricity and thermal energy. At the same time, 2/3 of the country is the area of decentralized power supply with high prices and tariffs on fuel and energy. Besides, in more recent times, the number of the first category consumers for whom any breaks in energy supply can lead to significant economic damages has significantly increased. Thus, today the level of scientific and technological progress requires the establishment of efficient energy systems. The development of energy-efficient and energy-saving combined systems of uninterrupted power supply implemented with the use of traditional and renewable energy sources is a promising trend. The reliability of combined systems in their construction using modular design will significantly improve. The article deals with the basic problem of the synthesis of combined uninterruptible power supply systems, implemented with the use of new components.

INTRODUCTION

As currently, 2/3 of the country is the area of decentralized power supply with high prices and tariffs on fuel and energy. However, more than 50% of the country regions are energy-deficient due to the import of electricity and thermal energy, the importation of fuel, and the gas service is installed in no more than 80% of the populated areas (60%- in rural areas). Besides, the connection of high-tech equipment, which is sensitive to the deterioration of electric power quality, including uninterruptedness of electricity and energy supply (of industrial complexes, automated process control systems, telecommunications equipment, medical equipment, etc.), to electric networks may be associated with large economic losses due to loss of electric power supply and failure of the normal operating modes of the consumers of electrical and thermal energy (Dolgov, *et al*., 2012; Strebkov, *et al*., 2009).

Thus, the level of technological progress today requires the creation of energy-efficient and reliable uninterruptible power supply systems (UPSs). Since the basic shortcomings of conventional energy sources are associated with their limitations and environmental pollution, and the main advantages of renewable energy sources (RESs) with their unlimitedness and sustainability, it is now appropriate to create a combined UPS, built on the basis of traditional and renewable energy sources. In this case, in the creation of the combined RESs the important role belongs to the optimization of the structural and circuit system solutions by main criteria, which are the economic indicators, reliability indicators, efficiency and power quality indicators (Sibikin and Sibikin, 2010; Strebkov and Kharchenko, 2011).

METHODS

Common approaches to solving the problem

It is known that the UPS structure includes two or

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more power sources, including the emergency one-rechargeable battery (ACC), which usually are the source of electricity to consumers during the power transition from the main power supply to the backup one. Static converters engaged in the coordination of the source electric power parameters with the load are an important functional element of the UPS (Sharov, *et al*., 2011).

Modern UPSs should meet the following basic requirements:

1) Enabling or disabling the power to consumers from different power sources must be performed in an automatic mode;
2) Having the possibility to optimize the structure, both in normal and emergency modes, by adaptively changing the supply chain structure and blackouts of consumers taking into account the loads priority;
3) Having the possibility to increase capacity by parallel connection of different types of energy sources to the tire uninterruptible power supply buses;
4) Carry out maintenance and repair works without the electric power interruption to the responsible consumers.

Rationale for structural and circuit UPS design for the complex of responsible consumers can be carried out according to different schemes. Moreover, the main power source is an external network, and the diesel and natural gas-fired power plants, and renewable energy sources can be the back-up autonomous energy sources (AESs). It is known that, depending on the pattern of the consumer connection to electricity sources, the UPSs can be built using three main structures-central, autonomous (local) or combined one (Amerkhanov, *et al*., 2010).

The design should take into account that the UPS centralized structures are used with a large number of responsible consumers located at a short distance from each other (Fig. 1a). The cost of the transmission line significantly increases, and the quality of electricity is reduced in case of large distances.

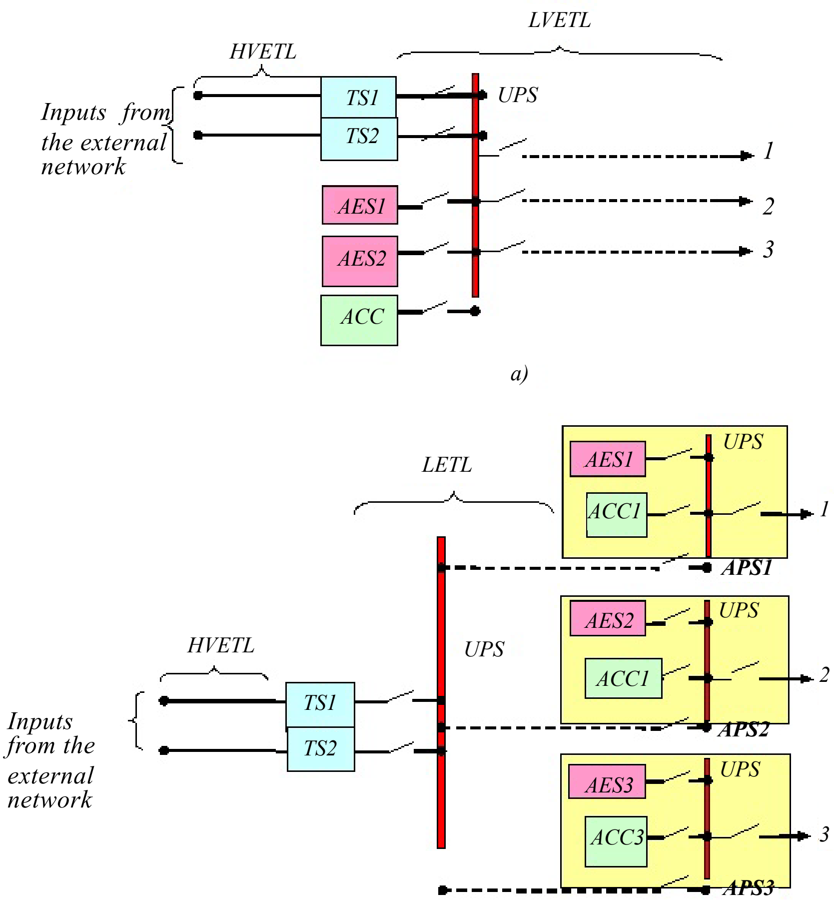

Fig. 1 Centralized (a) and combined (b) structure of the UPS: transformer substations-TS1-TS2; autonomous energy supply sources – AES1-AES3; accumulator batteries-ACC1-ACC3; autonomous power supply systems-APS1-APS3; High-voltage and low-voltage electrical transmission line-HVETL and LVETL; uninterruptible power supply buses-UPS bus, UPS bus 1-UPS bus 3; terminals for electricity consumers connections-1-3.

The main advantages of the UPS centralized structure are low sensitivity to local overloads, cost effectiveness and non-complexity in addressing the power capacity by connecting additional sources of electricity to the UPS bus (Fig. 1a).

The main disadvantage of the centralized UPS structure is a high probability of total failure due to the malfunction of the distribution network.

Autonomous UPSs are used when the consumers are at great distances from the external power grid when, from an economic point of view, it is impractical to lay overhead power lines. The main drawback of the autonomous UPSs is the increased sensitivity to overloads and unbalance in the network due to the power of single-phase consumers. Therefore, the autonomous sources have higher installed capacity, usually by 20% to 30%.

Currently, each of the considered individually structures by itself is used infrequently. To eliminate the discussed drawbacks of each of the systems, the combined UPS structure is applied in practice (Fig. 1b). The combined UPS structures involve the installation of autonomous power supply systems (APS) near each consumer; thus, the terminals from the external network can be provided in autonomous systems. Combined systems have high reliability. The main disadvantage of the considered connection structure is a high total cost of the UPS (Gordeyev, *et al.*, 2014).

New element base

To improve the operational and technical characteristics (efficiency, reliability, speed of control and protection systems) a new element shall be applied in the UPS structure. The contactless electrical machines, synchronous generators excited by permanent magnets and induction capacitive excitation generators shall be used as the electromechanical power generators. The development of power electronic devices used in the contactless generator control systems, as well as a significant reduction in the specific gravity of the excitation capacitors and the reactive power compensation, have significantly improved their performance in comparison with the contact electrical machines (the efficiency increased by 5% to 7%, while the margin of continuous operation increased 2-3 times) (Andreev, *et al.*, 2007; Butuzov, 2014; Vissarionov, 2004).

The use of a single-phase, three-phase transformers with a rotating magnetic field in the composition of autonomous inverters will reduce the number of power electronic devices in the conversion and voltage stabilization circuit, simplify the control system, reduce the level of electromagnetic interference generated by the semiconductor devices during switching, and in general improve the overall efficiency and reliability of DC/DC indicators. The weight and overall dimensions of autonomous inverters will significantly improve if the over frequency drop link will be used in their design (Uskov, 2011).

Good technical effect is achieved when the direct current inverters are used as part of a wind power plant as a voltage stabilizer and current frequency. This simplifies the mechanical design of the gearbox of the wind wheel shaft speed, eliminating the automatic system of rotation speed stabilization. The principle of operation of direct frequency converters allows for independent stabilization of voltage and current frequency of the wind turbine generator (Grigorash, *et al.*, 2014).

The use of combined power switching devices, whose design excludes the arc chambers, as part of UPSs, and implemented on power electronic devices, performing switching and the use of electromechanical contacts, running in the basic mode when the sources are connected to customers, significantly increases the service life, reliability and performance of such devices.

The trend to the development of multipurpose static electricity converters (MSCs), operating in the inverter mode, rectifiers, converters, and frequency converters capable of passing through a flow of energy in both directions is a promising one. An MSC is a complete device comprising units of power-driven electronic equipment, filters, control and protection system, switchgears, transformer unit. A feature of the MSC control system is that it is able to control its operation by several algorithms so that the converter can operate in all modes of all types of converters. The use of the MSC as part of the UPS will reduce the number of power converters and increase the efficiency of the system operation in emergency modes by adaptively changing the main circuit structure and the mode of change of the MSC operation modes.

Fig. 2 shows an embodiment of a structural-circuit UPS design, implemented with the use of the MSC. When the electricity consumers are powered by a wind turbine (WT) the universal static converter (MSC) works in a rectifier mode, while charging the ACC batteries (Fig. 2), the continuous line shows the electricity transmission direction from the MSC).

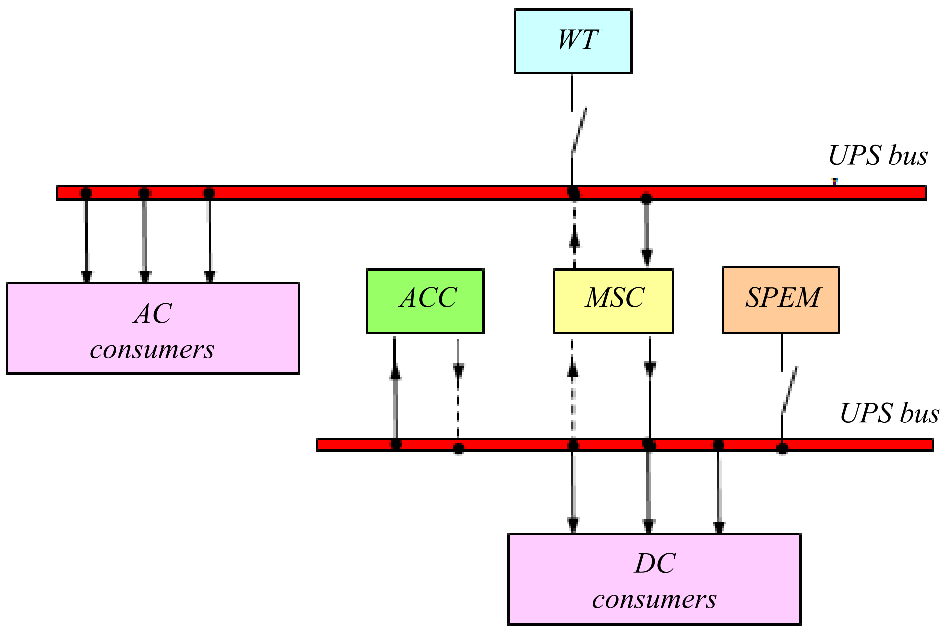

Fig. 2 UPS block diagram using the universal static inverter: wind turbine-WT; solar photoelectric mounting-SPEM; multipurpose static inverter-MSC; accumulator battery-ACC; uninterruptible power supply buses-UPS bus 1-UPS bus 2.

For example, in case of low level wind flow, the AC consumers receive power from the solar photoelectric mounting (SPEM). However, the universal static converter operates MSC in the inverter mode (Fig. 2), the dotted line shows the electricity transmission direction from the MSC).

Synthesis of UPS modular structures

The modular principle of UPS design will increase the reliability of the power supply system due to the redundancy of the main functional elements (blocks, units). It will allow increasing, if necessary, the power of autonomous sources, converters, stabilizers and power accumulators simply enough by switching the relevant modules for parallel operation. It is important that the UPS design using the modular principle reduces the time of their development, makes easier the problem of change of the UPS structure depending on the requirements of consumers. A significant economic effect is achieved in the operation of such systems by reducing the time for maintenance and troubleshooting in emergencies.

The technical and operational characteristics of modular UPSs are influenced mainly by two factors, depending on the requirements of electricity consumers: allowed break in the power supply; power quality indicators.

If a break in the power supply of consumers results in a significant economic damage, in this case, the number of backup sources and converters of electricity as part of the UPS increases. The higher are the requirements for power quality, the more complicated is the design of the converters of the power parameters.

In general, the issue of synthesis of the UPS modular structures includes:

1) The development of structural and circuit design of power supply system, taking into account the requirements for the quality of electrical and thermal power, as well as the allowable break in the power supply;
2) Determination of the backup degree (level) of the main functional elements (blocks, units) in view of ensuring the required reliability;
3) Providing the effective communication, including electromagnetic compatibility of the basic functional elements (sources, power converters), and their rational use in normal and emergency operation of the system;
4) Development of information and software compatibility of the central and local control systems.

Besides, the central UPS control system should perform the functions of control of electric power parameters, protection and switching, including when connecting or disconnecting the power sources and converters, changing the structure of the system, depending on the requirements of consumers and the operating mode (normal or emergency). The functions of stabilization and control of electrical and thermal power control should be implemented by local systems of control of autonomous sources, transformers, and power parameters stabilizers. Thus, the central control system with local control systems has the common links only by the control of parameters, and enabling or disabling their operation. Such cooperation will enhance the UPS performance and reliability.

Determination of the optimal UPS structure

An important issue in the development of new structural and circuit UPS solutions is to define the range of optimal values of the performance criteria (indicators of reliability, efficiency, quality of electric and thermal power, etc.) whose choice correctness depends on the operational and technical characteristics of the designed system in the complex.

The UPS optimization is an unsolvable problem simultaneously on all performance criteria with the determination of the range of their optimum values. However, today one of the simplest and most effective ways to optimize UPSs is the use of the accumulated experience of designing such systems and their building with the choice of basic functional units (sources, stabilizers, power converters, switching devices and protection devices) having high operational and technical characteristics, including energy ones.

The known one is a method of optimization based on the use of multi-parameter optimization using generalized criterion

$$F = A_x X + B_y Y + C_z Z + ...,$$

Where X, Y, Z – UPS performance criteria; A_x, B_y, C_{z}- weighting factors that determine the criteria level.

The minimization of F function is provided by all the performance criteria (X, Y, Z, …), and the priorities are set through the selection of the weighting values (A_x, B_y, C_z…), which, as a rule, are not strictly feasible, and relies on the use of expert assessments.

Another one not difficult approach is to optimize the system by or two criteria, considering the remaining as fixed ones.

However, a more comprehensive result in the UPS optimization, taking into account all the performance criteria, can be obtained using the method of successive deviations. At the first stage, all performance criteria are recorded (according to F function), except one that shall be optimized ($X \rightarrow X_{min}$). Then, the allowable deviation from X_{min} criterion shall be defined within the prescribed limits, and the following efficiency criterion Y_{min} shall be defined. Thereafter, the admissible deviation from Y_{min}, shall be set, using which the following efficiency criterion Z_{min} shall be found, etc. Best results are usually obtained using F function with the search of characteristic values of the weighting factors and the use of limited solutions in which all performance criteria cannot be simultaneously improved.

In any case, the use of some or other structural and circuit UPS design shall be justified by technical calculations, taking into account production losses due to the interruption in the power supply and reduction of power quality, as well as the cost of new element base, including power lines, alternative energy sources and renewable energy sources. In general, the task of optimizing the structure of the combined UPS in terms of power and cost of the equipment is to identify the most responsible consumers and minimize the number of consumer groups by developing a centralized adaptive control system able to change the system structure, depending on the operating mode.

RESULTS AND DISCUSSION

At the initial stage of design of combined UPSs, it is important to calculate and build an annual schedule of loads of electric and thermal power consumers (Fig. 3). This schedule, consumer requirements for power quality and their operating conditions are the basis for the choice of equipment for the UPS. The initial data considered allow optimizing the sources of electric and thermal power, and that it is important, eliminating double power conversion, for example, the conversion of wind power into electric one, and then the electric power into thermal one.

The issues of energy saving and improving the efficiency of energy supply system can be optimally resolved only through the integrated approach in the design and selection of sources of electrical and thermal power. For example, to reduce the payback period of the wind farm it is necessary to make it work

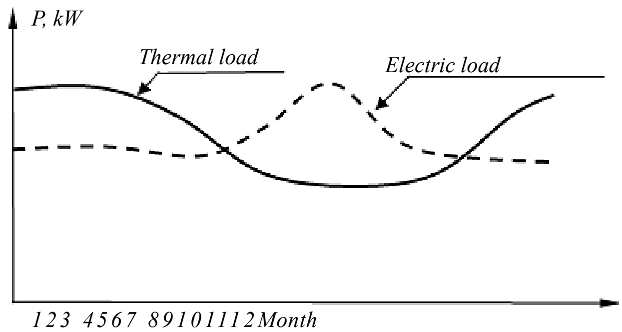

Fig. 3 Schedule of thermal and electric loads of consumers: 1 kW equals 3.6 MJ.

in master mode and the external network performed the backup source functions. It is possible to significantly reduce the capacity of the batteries in the APS (Fig. 1), which make a significant contribution to the overall cost of the system, if applied only during the transition of power from one source to another (wind power station, solar photoelectric mounting, gas powered stations). Solar collectors must be used to avoid double energy conversion and increase the efficiency of heat sources.

In general, the algorithm for estimating the UPS efficiency includes the following:

1) Assessment of consumers by requirements to electricity parameters (power, voltage, type of current and its frequency, power factor), quality of electricity, and uninterruptedness of electricity supply;

2) Selection (design) of functional units (alternative energy sources, including renewable energy sources, power converters and power parameters stabilizers, switchgears and protection devices), determination of the number of UPS buses, and the development of the UPS generalized block diagram;

3) Development of functional diagrams, circuit diagrams of the UPS power unit taking into account the redundancy of the functional unit's operations and the adaptive changes in the structure, operating modes of the system, and the loads priority;

4) Comparative assessment of possible options for the UPS construction using performance criteria: power quality, reliability, efficiency, cost and overall dimensions;

5) Study of the electromagnetic compatibility of functional units-mathematical modeling of physical processes in normal and emergency operating modes. Optimizing the structure of the system, taking into account customer requirements for the performance criteria priority;

6) Selection of optimal structure-circuit UPS design based on the studies and in view of operating costs. The development of practical recommendations on the technical design of management, protection and control systems.

7) The formation of the technical project on the UPS creation.

CONCLUSION

Those areas that provided fast enough direct economic effect were developed in the energy sector. At the same time, renewable energy has been viewed as an energy resource of the future, when the traditional energy sources will be exhausted, or when their production will become time consuming and expensive. Currently, the situation has dramatically changed the awareness of humanity of possible environmental disaster.

The first step in the introduction of renewable energy sources is to create combined systems of energy supply with the use of conventional energy. The theoretical research in the field of the development of energy-efficient and energy-saving combined UPSs led to the following conclusions:

1) The level of development of technical progress now requires the establishment of energy-saving, energy-efficient, and reliable UPSs;

2) The use of a new element base of contactless power generators, modern power electronic devices, single-phase and three-phase transformers with rotating magnetic field, multifunction static power converters, and combined switching devices will significantly improve the operational and technical characteristics of combined UPSs;

3) Modular building-block design of the main functional elements (units, blocks) of combined UPSs will increase the reliability and operational and technical characteristics of the system;

4) The simple ways of selecting the optimal UPS structure will improve the criteria by which the system effectiveness is evaluated;

5) The above algorithm for evaluating the effectiveness organizes a scientific approach to the development of energy-saving and energy-efficient combined UPSs.

An important step for further research to improve the operational and technical characteristics of combined UPSs is the mathematical modeling of physical processes in the system power circuits in normal and emergency operating modes.

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