Uninterruptible power supply for renewable energy sources

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Abstract. Scientific and technological advance results in a constantly increasing number of first category customers that in the event of input power failures can entail significant economic losses. A promising direction is the development of uninterruptible power systems that rely on renewable energy sources and, above all, photovoltaic arrays and wind power turbines. If energy customers are located near foothill and mountain rivers, it seems economically viable to apply mini or micro-hydro power plants. The paper examines different approaches to UPS topology based on renewable energy sources. Besides renewable energy sources, power supply encompasses some traditional autonomous sources including diesel, gas piston or gas power plants. In addition, the systems provide inputs for connecting an external power system. The paper shows that agrarian production finds it relevant to develop mobile uninterruptible power systems. The authors propose some modes of operation that improve the economic performance of uninterruptible power supply by using rechargeable batteries solely during power conversion from one power source to another. The paper contains proposals developed to improve operational and technical features of uninterruptible power systems through a new topology, modular character of main functional elements and optimization of system structure.

1. Introduction

Currently, automatic systems are widely used not only at the local control level (electric drive, sources, converters and stabilizers of electric power parameters, medical equipment, etc.), but also at the system level, including industrial and technological control, etc. Faulty operating performance of energy customers in such systems can lead to significant economic damage [1, 2].

According to static data on electrical equipment and energy systems, the main causes of emergency situations are power supply failures and mismatch between energy parameters generated by the sources, converting and stabilizing static devices (voltage stabilizers, inverters, rectifiers, frequency converters, etc.), which accounts for up to 45% of failures in normal performance. In addition, about 8% of failures in the performance of power supply systems are associated with errors that occur in the controls (protection and control systems that are software-driven). About 5% of energy blackouts result from power line breakdowns, power system short circuits and overload currents.

Thus, about 60% of emergencies in power supply systems are associated with equipment malfunctions, due to power failures and mismatch of energy parameters with nominal indicators, and the remaining 40% are natural disasters [1, 3, 4].

The use of UPS is relevant due to the fact that in Russia most of the regions belong to decentralized power-supply zones that also utilize highly efficient power equipment that requires continuous power supply with high power quality indicators [5, 6].

One of the promising areas is the use of renewable energy sources (RES) in the areas of...
decentralized power supply, primarily photovoltaic arrays and wind power turbines [7, 8].

2. Methods
One of the most widely used ways to increase the efficiency of energy systems is to employ several independent sources of energy that constitute such systems. One of the sources performs main functions, the rest are backup and emergency units. Such power systems are most commonly referred to as uninterruptible (continuous) power supply systems (UPS). The second way to increase the efficiency of power supply systems is to apply a new topology based on sources, converters, stabilizers, switching equipment, etc. It is also possible to improve UPS operational and technical features by optimizing approaches to UPS design based on the key performance criteria that embrace economic performance, efficiency, reliability, power quality and weight dimensions (for mobile systems) [2, 4].

3. Results
Despite the fact that the use of several types of electric power sources in UPS, including traditional and renewable, enables to improve power supply reliability, this generally results in deteriorating economic indicators. Therefore, to improve the economic performance of UPS, it is advisable to divide energy customers into two groups at the design stage [2]:

1) customers demanding high energy quality;
2) customers with underestimated energy quality requirements, including those that allow for power interruptions.

This separation of customers will significantly simplify the UPS of the second group, eliminating the additional redundancy of sources, converters and other functional elements of the system. As a rule, the second group includes autonomous energy consumers, remote from the external energy supply.

A significant share of the total cost of renewable stand-alone energy sources is reported to account for batteries whose life cycle is limited to 5-7 years. It is possible to significantly improve economic indicators of UPS by using batteries only during power conversion from one energy source to another.

Today, it is promising to develop mobile (transport) UPS that can be used to power agricultural consumers, including farms located far from external energy systems. Such systems should also include traditional sources – gas reciprocating or diesel power plants, and renewable ones – a wind power turbine with a vertical flywheel and a photovoltaic array with modular solar panels. The main advantages of mobile hybrid power plants include:

– fast deployment and power supply of consumers located in remote and inaccessible areas;
– long battery lifespan due to renewable sources, with an offline source to start up if it is necessary to increase the installed capacity of the system or in the absence of wind flows and solar radiation.

Mobile UPS can maintain a mini-hydro power plant that is deployed nearby mountain and foothill rivers and functions in parallel with other power sources [4].

To increase UPS efficiency, it is advisable to utilize RES as the main power source for consumers, when the level of solar radiation and wind speed correspond to the nominal parameters. Meanwhile, offline/standby sources (diesel or gas reciprocating power plants) and an external network, providing free connectivity, should be additional. In this case, the payback period of renewable energy sources will be significantly reduced.

In modern renewable UPS, including stationary and mobile, the following system functionality should be additionally provided:

– optimization of operating modes in emergency situations by adaptive automatic change in the structure of the system itself, providing consumers with electricity, subject to their priority;
– increase in capacity and its redistribution by connecting different types of power sources to consumers in accordance with the priority set;
– replacement of the main functional elements of the system, maintenance and repair without power interruptions (for vital, first category consumers).
It is possible to improve the energy characteristics of UPS by using new elements in its topology [4]:

1. It is necessary to use non-contact power generators as part of wind power turbines, small hydropower plants, gas piston and diesel power plants. Permanent magnet synchronous generators and capacitive excitation asynchronous generators are widely used nowadays. They were not used before due to some complexity related to voltage stabilization and the lack of small capacitors to provide compensation of the load reactive power.

2. Stand-alone inverters in solar photovoltaic installations and uninterruptible battery-powered systems should contain single-phase and three-phase rotating-field transformers. Their design and operational concept allow the development of inverters with fewer power semiconductors, which further simplifies control and protection systems, thereby increasing efficiency and reliability of the static inverter. In addition, a decreased number of power semiconductors lead to reduced electromagnetic interferences that negatively affect automatic control systems of electrical devices and UPS.

3. Wind power plants should contain a direct frequency converter as a voltage stabilizer and current generator frequency generator. This will design an automatic mechanical system for shaft speed stabilization out of flywheel speed reducer and increase the efficiency of wind power reducer.

4. To coordinate energy parameters with the requirements of consumers, it is necessary to use universal static power inverters that can operate in inverter and rectifier modes, and in converter and frequency converter modes, if need be. One of the important advantages of universal static inverters is their ability to let energy flows pass through in both directions, while ensuring stabilization of voltage and current frequency. This will reduce the number of converters and power stabilizers, increase the reliability of the system and improve weight dimensions, which is important for mobile systems.

It is also possible to improve the operational and technical features of UPS due to:

– modular layout approach to the main functional elements, which will increase not only operational reliability, but also maintainability;

– centralized control of the system, where stabilization power functions should be assigned to local control systems in sources, converters and stabilizers, and the central control system should be responsible for monitoring, protection and adaptive changes in the structure of the UPS.

One of the UPS designs is shown in Figure 1. A direct current wind power installation 3 and a solar photovoltaic installation 4 are connected to a continuous DC power supply bus 1. Electric power sources 5-6 are connected to an AC bus 2: an AC wind power installation 5; a diesel or gas piston power plant 6. Bus 2 has an input 7 for connecting to an external power system. The figure also shows a charge controller for battery 8, an inverter 9, a battery 10, switchgear 11, central control system 12, and AC consumers 13.

Power is supplied to AC consumers from the continuous power supply buses 1 and 2. If there are DC consumers, they are connected to the continuous power supply bus 1. In order to increase the reliability of power supply to DC consumers, the inverter 9 can operate in a reversible mode – in a rectifier mode. In this case, DC power sources will be 5, 6 and 7.
The battery 10 is a power source to ensure uninterruptible power supply for vital consumers when power is converted from one source to another.

One of mobile UPS designs is shown in Figure 2. Offline power sources 1 (diesel or (and) gas-piston power plants) and WPP 2 (wind power and (or) mini-hydro power plants) are connected to a continuous power supply bus 4. Input 3 is for connecting an external power grid. Figure 2 also shows a solar photovoltaic installation 6, which is connected to the continuous power supply bus through an inverter 5, a rechargeable battery 7, a charger 8, a control and protection system 9, and AC power consumers 10.

An important issue at the development stage for new approaches to UPS topology using renewable energy sources is to determine the optimal operating modes of solar and wind power plants, i.e., modes when they generate maximum power. Hence, it is necessary to take into account that combined solar and wind energy generation is effective with year-round energy consumption. It should also be borne in mind that in winter the level of solar radiation drops significantly, and the strength of wind...
flows in winter, as a rule, increases. The service life of solar panels exceeds 25 years. They have significantly lower operating costs (maintenance and repair) in comparison with stand-alone offline and other types of renewable sources. Unlike photovoltaic arrays, the performance of wind power turbines is higher at the same power. However, they have much lower reliability indicators due to mechanical moving parts and relatively high operating costs compared to solar arrays [7, 8].

The final stage in the design of stationary and mobile UPSs is to optimize the system structure according to the main performance criteria: economic performance, efficiency, reliability, power quality and weight dimensions (for mobile systems). It is crucial here to determine the range of optimal values for evaluating the effectiveness, subject to which the operational and technical features of the designed system are selected [2].

It is almost insoluble to optimize approaches towards UPS topology concurrently upon all performance criteria with the determination of the range of their optimal values. Therefore, at present, four main methods are used to optimize UPS topology: based on the experience accumulated in the design and maintenance of such systems; optimization upon one or two criteria; multi-parameter optimization; series concession.

The first method is simple and effective. It involves the selection of the main functional elements of the system, including sources, converters, stabilizers, switching devices, protection devices that have the best operational and technical characteristics. The choice of functional elements should rely on consumer requirements for power quality and reliability of power supply. A viable UPS is evaluated against quantitative and qualitative characteristics of the main functional units used in its design.

The second optimization method is one of the simplest, since optimization is based on one or two criteria, considering the remaining as fixed.

The third optimization method is based on the use of multi-parameter UPS optimization by using a generalized criterion that looks like

\[ F = C_{EP}EP + C_{E}E + C_{RI}RI + C_{IGE}IGE + C_{WD}WD, \]

where EP, E, RI, IGE, WD are UPS criteria including economic performance, efficiency, reliability indicators, power quality and weight dimensions; CEP, CE, CRI, CIGE, CWD are weighting factors that determine the priority of system performance criteria.

The choice of weighting factors (CEP, CE, CRI, CIGE, CWD) is most commonly based on the use of expert estimates. Function F can be minimized by all performance criteria, but since their value is interdependent, the weighting coefficients are decisive.

An effective method is series concession (deviation). All performance criteria (1) are originally fixed, except for one that is optimized (EP → EPmin). Then a permissible deviation from EPmin n is defined within the specified limits and the following efficiency criterion Emin is defined. After that, the permissible deviation from Emin is defined, at which the next criterion for the effectiveness of Rmin is defined, etc.

The best results are usually provided through optimization with respect to the function F followed by enumeration of characteristic weight coefficients and the use of limited solutions that make it impossible to improve all performance criteria.

4. Conclusion
In general, the synthesis of UPS approaches based on renewable energy sources should include the following steps [2, 9, 10]:

1) analysis of seasonal and annual power-system load curves;
2) analysis of consumer requirements for the main power quality indicators (deviation and fluctuation of voltage and current frequency, unsinusoidality coefficient) and continuity of power supply;
3) analysis of climatic conditions and topography where renewable sources are supposed to be used;
4) selection of energy-efficient sources, converters and stabilizers of electricity parameters, as well
as switching devices;

5) development of a functional diagram based on possible operating modes, including outages, which provides consumers with electric energy through adaptive changes in the system;

6) calculation of the main criteria of system efficiency;

7) mathematical modeling of physical processes in power circuits in normal and emergency modes to study electromagnetic compatibility of sources, converters and consumers of electricity;

8) optimization of system design;

9) development of recommendations for the design of control and protection systems;

10) development of technical specifications for system design.

Today, scientific and technological advance requires the creation of energy-saving and energy-efficient systems, including those that provide reliable and high-quality power supply to energy consumers. The use of new elements and renewable energy sources in the UPSs will make it possible to address these challenges in the areas of decentralized energy supply.

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