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Operation of a Single-phase Autonomous Inverter as a Part of a Low-power Wind Complex

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The article discusses the experience of operating a wind power complex with a low-power wind power installation (5 kW), the use of which is promising for powering remote oil production facilities, exploration and other types of mining operations. The structure of the studied complex and its characteristics, technical problems that have arisen during operation for 6 years are given. The elements of the wind energy complex – the battery charge regulator and the inverter-converter are considered. The consequences of the mechanical regulator failure of battery charge are considered and recommendations for its replacement are presented. The issues of diagnostics and repair of one of the main elements of the complex – the inverter-converter, its component – DC link are highlighted in detail. Oscillograms of the output voltage of the inverter-converter are presented for different capacities of the DC link and the images of the repaired inverter-converter are given. Recommendations are given on choosing an inverter-converter and setting up the operating modes of the wind energy complex.

***Key words*:** autonomous voltage inverter; DC link; wind power installation; wind power; accumulator battery

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Introduction. According to the 2017 World Wind Energy Association, the installed capacity of wind power plants (wind turbines) is 539.3 GW. Mostly powerful wind turbines (more than 2 MW) are combined into wind farms and operate in parallel with the network [13, 14]. In the field of small wind energy, according to WWEA, in 2017 the number of small wind turbines (unit unit capacity of less than 100 kW) in the world exceeded 1 million. This sector is mainly used for power supply to individuals and organizations.

In the Russian Federation, the potential owner of small wind turbines is the population of sparsely populated territories located outside the reach of centralized energy supply, which makes up about 70 % of the country's territory [2, 4]. The conditions for the development of wind energy have been created: regulatory and legal framework and regulatory and technical documentation. In 2007, amendments to the Federal Law «Of the Electric Power Industry» were adopted, laying the framework for the development of the industry.

In 2013, the Government of the Russian Federation signed a package of measures to support the use of renewable energy sources [7, 8]. It should also be noted the promise of the use of low-power wind turbines for powering remote oil production facilities [9-11], exploration and other types of work related to mining.

Despite this, at present, operating experience with low-power wind turbines is not enough and problems with working with them are not covered. Information on resolving emerging issues is also missing.

Formulation of the problem. In 2012, the Mining University acquired a wind energy complex based on the small wind turbine «Breeze 5000» produced by CJSC «Vetroenergiticheskaya compania» (St. Petersburg). The complex is designed to carry out scientific work, autonomous power supply of outdoor lighting in the territory of the educational experimental base of the university with a

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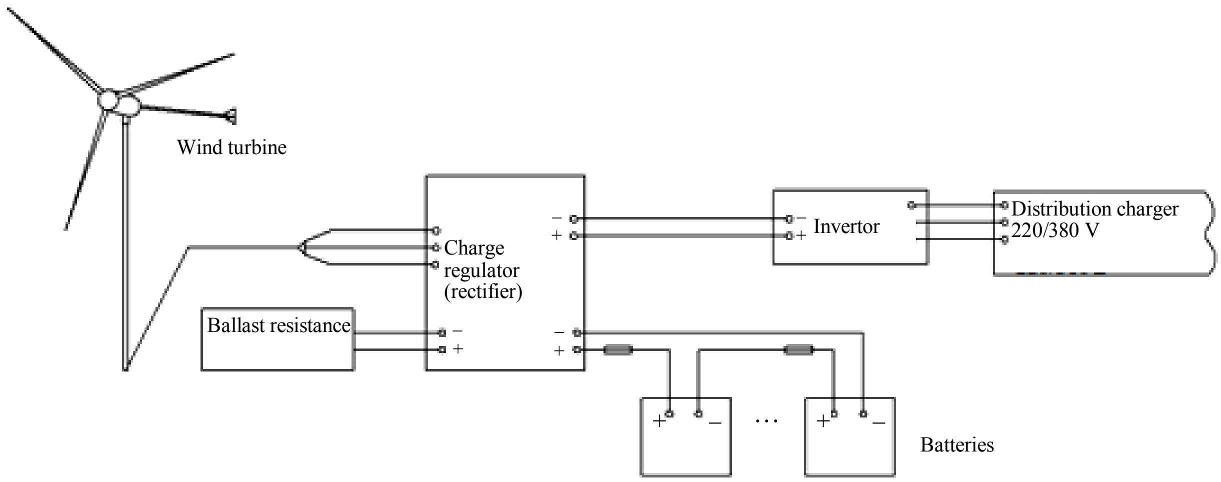

Fig.1. Scheme of the wind energy complex

subsequent assessment of the effectiveness of these systems. Over 6 years of using the complex with a small wind turbine, significant operational experience has been accumulated.

During the operation of the wind energy complex, numerous problems were identified with power and control equipment [3]. Deficiencies in the operation of the equipment led to the failure of the regulatory equipment, inverter and battery. The purpose of the work, the results of which are presented in the article, is to identify the causes of equipment failure, as well as a description of the features associated with this repair work.

Research methodology. The main elements of the wind energy complex are: «Breeze 5000» wind turbines, acid-helium batteries (batteries), autonomous inverter, charge regulator with rectifier (Fig.1). Technical characteristics of the wind energy complex:

Rated power………………………...	5 kW
Nominal (calculated) wind speed……	12 m/s
Rotor diameter (blade span)………...	5 m
Number of blades ………………….	3
Tower height………………………..	15 m
Type of electric generator………….	Three-phase synchronous with permanent magnet excitation
Nominal wind speed ……………….	400 rpm
Battery Overcharge Protection……...	Relay, with ballast switching
DC link voltage…………………….	48 V
Battery parameters, quantity……….	Acidic helium; maintenance free; 12 V, 200 A · h, 4 pcs., Service life 7 years
Inverter Parameters………………...	U_{in} = 40-60 VDC; U_{out} =230 VAC; power is 6 kW
Ballast resistance power……………	6 kW

When the blades of the wind turbine rotate, it generates an alternating voltage with a frequency of 10-100 Hz, which is fed to the battery through an uncontrolled rectifier. The charge regulator, in turn, controls the voltage on the battery and, if it exceeds 60 V, with the help of a thyristor switch switches the wind turbine to ballast resistance. When the voltage drops below 56 V, reverse switching occurs and the battery continues to charge.

In the presented scheme, special attention should be paid to the charge regulator. This device is intended for monitoring and indicating the magnitude of the charging current and voltage of rechargeable batteries, disconnecting the batteries from power sources when the voltage limit value is reached.

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Fig.2. Inverter-converter Tripp Lite APSX 6048 VR

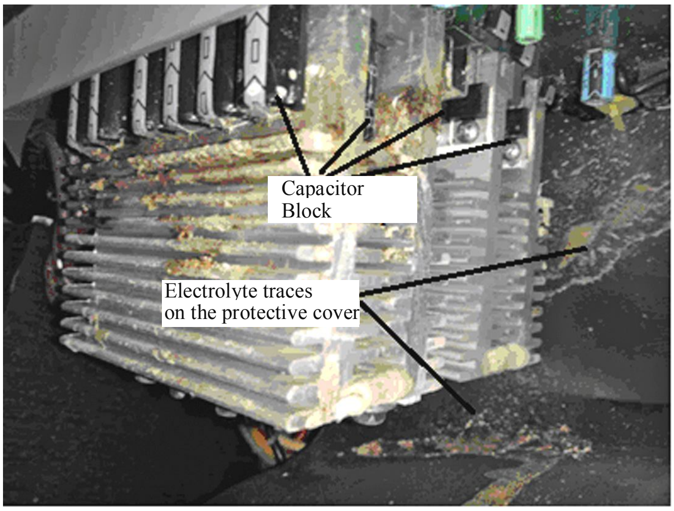

Fig.3. Inverter circuit board with DC link capacitors

Rated output power…………….	6000 VA
Short-term power outpu …………..	12000 W
Rated output voltage……………..	208/230 V
Output voltage accuracy………….	±5 %
Output frequency……………..…..	50 Hz ± 0,3 %
Rated input voltage ……………...	48 V
Maximum input current…….…….	30 A
Charging current………………….	23 or 90 A
Operating temperature range.……..	from 0 to +40 °C
Weight……………….……………	48 kg

In the presented scheme, special attention should be paid to the charge regulator. This device is intended for monitoring and indicating the magnitude of the charging current and voltage of rechargeable batteries, disconnecting the batteries from power sources when the voltage limit value is reached.

In the wind energy complex, the Tripp Lite APSX 6048 VR inverter-converter is used (Fig.2). As part of the complex, the inverter operates at the output load in DC/AC voltage invert mode. The inverter-converter has the ability to remotely monitor and control through the serial RS-232 interface. The main parameters are manually configured using DIP switches for specific operating conditions. Characteristics of the Tripp Lite APSX 6048 VR inverter:

One of the significant comments during the operation of the complex is the lack of redundancy and duplication of the electromechanical relay in the charge regulator, which is responsible for connecting the ballast resistance, thereby controlling the course of the battery charge. It would also be relevant to use a solid state relay instead of an electromechanical one, since this type of relay has a higher switching frequency limit.

During the year, there was wear and failure of the electromechanical relay. This led to the lack of switching to ballast when reaching a voltage limit of 60 V (58 V). As a result, the batteries recharged to a voltage exceeding the rated value. Overcharging the battery, in turn, caused the failure of the inverter link.

Diagnostics and repair. During the initial diagnostics of the inverter during measurements with an RLC meter, a short circuit was detected at the input terminals. Analysis and sequential diagnostics of the components of the inverter showed that the capacitor block at the inverter input failed (24 pcs., connected in parallel). Capacitor parameters: capacitance 470 μF, operating voltage 63 V. The printed circuit board on which they were located was attached to the upper part of the case (Fig.3).

Under the board there is a casing to protect the remaining elements of the device during the breakdown of capacitors and leakage of electrolyte, which can cause a short circuit in the circuit.

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The manufacturer does not provide for the possibility of replacing capacitors, but the elements themselves have a fairly compact arrangement under the radiator.

The capacitor block at the inverter input performs the following functions:

• reduction of high-frequency voltage ripples arising when the rectifier is connected to the inverter input, which improves the quality of the output voltage, since power switch control algorithms, as a rule, do not take into account the input voltage ripple;

• reduction of high-frequency overvoltages caused by switching power switches during inverter operation to an active-inductive and inductive load, which can lead to failure of power modules.

• reduction of high-frequency ripple current on the battery that occurs when the inverter works.

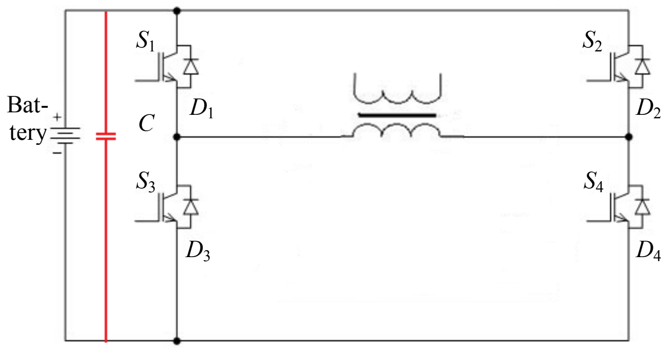

Fig.4. Simplified inverter power circuit

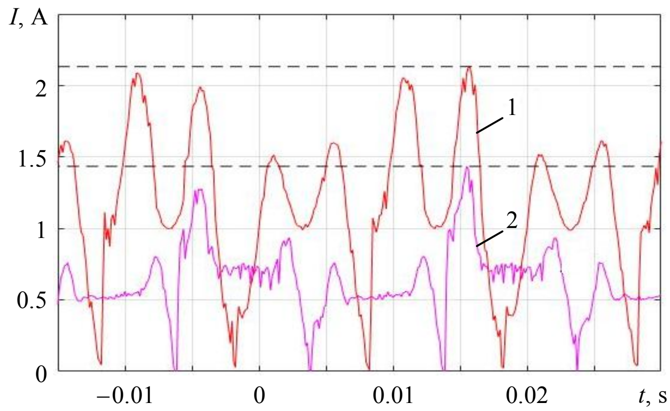

Fig.5. Oscillograms of battery current without block (1) and with block (2) of capacitors

The frequency of the high-frequency component of the voltage is determined by the switching frequency and the algorithm of the power keys of the inverter. The level of voltage ripple in the DC link is determined by the type of rectifier, the switching frequency and the algorithm of the inverter power switches, the nature of the load of the electric converter and the capacitance of the capacitor itself installed in the DC link.

Since a DC voltage with a battery is supplied to the inverter input in the wind power complex, the main function of the capacitor is to reduce overvoltages caused by switching power switches (Fig.4).

When analyzing the operation of the inverter keys for an active-inductive load, we can conclude that overvoltages in the DC link are caused by the process of charging the capacitor capacitance from the load side at those moments when the current flowing through the load flows through both inverse diodes of the inverter. The time during which the current flows through both reverse diodes depends on the algorithm of the inverter keys. Given this algorithm and knowing the magnitude of the output current and the nature of the inverter load, it is possible to determine the magnitude of the switching overvoltages as a function of the capacitance of the storage capacitor of the DC link according to the second commutation law, representing it by difference equations:

$$\Delta U_c = I_{load}\frac{\Delta t}{c},$$

or, expressing the value of the capacitance of the storage capacitor to ensure an acceptable voltage surge in the DC link

$$C = I_{load}\frac{\Delta t}{\Delta U_c},$$

where C – capacity of capacitor; I_{load} – load current flowing at the time of operation of two diodes; Δt – current flow time through reverse diodes; ΔU_c – capacitor ripple.

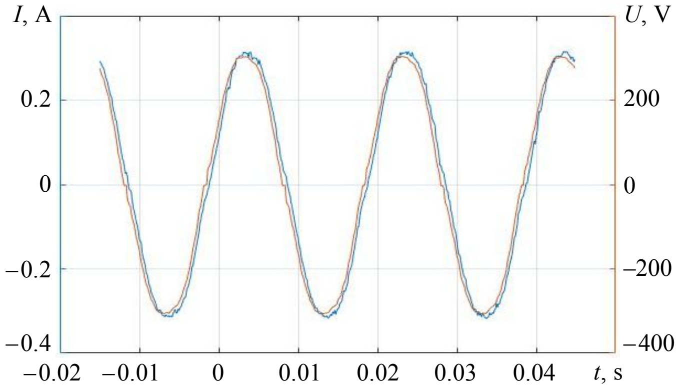

Fig.6. Oscillograms of output voltage and current

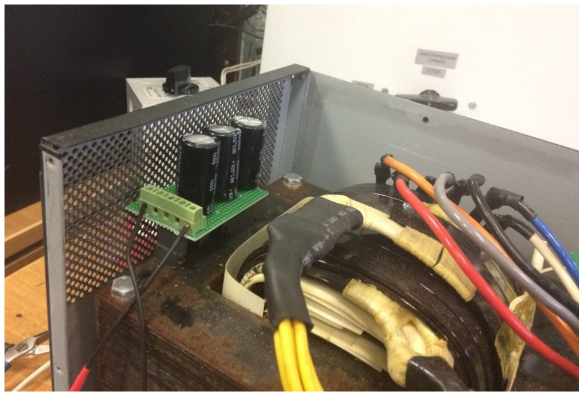

Fig.7. New capacitor bank on a separate board

When replacing the block of capacitors, the parameters on which the required capacitance of the capacitor depends do not change, therefore, the new capacitance must be chosen no less than that laid down during design (11,28 mF).

To check the operation of the inverter with a new block of capacitors, the inverter was connected to an active-inductive load of 50 watts. The waveforms of the current on the battery, output voltage and current were taken. The oscillograms considered (Fig.5) show that the battery current when operating with an inverter without capacitors reaches 2.13 A, and in the case of a capacitor bank, the current does not rise above 1.43 A. Figure 4 does not show high-frequency interference, which were present in the waveform of the battery current when working with the inverter without capacitors, since their display would interfere with the perception of the waveforms.

Thus, the new block of capacitors performs the functions noted earlier.

Figure 6 shows the oscillograms obtained from the inverter output. Output variables (voltage and current) are in-phase almost perfect sine waves. When the DC link capacitance changes, the shape and amplitude of the output current and voltage have not changed.

A new block of capacitors (3 pcs., Connected in parallel) with a total capacitance of 14.1 mF and an operating voltage of 63 V, is mounted on a separate board, which is located in another part of the case (Fig.7). As a result: maintainability of the inverter increased; there is no likelihood of components damage of the printed circuit boards due to the ingress of electrolyte on them when the capacitors are damaged.

Inverter choosing recommendations. In the case of using low-maintenance low-power wind turbines, special attention should be paid to the choice of an autonomous voltage inverter [1, 5, 6, 12, 15], the main characteristics of which are: rated output power, output and input voltage, rated input current, type of output signal (meander or sine).

In addition to the listed characteristics, it is necessary to pay attention to the following factors:

• Overcharge protection. Built-in overvoltage protection at the input terminals of the inverter allows avoiding its failure in case of failure of the charge regulator, which ensures switching of the wind turbine generation to ballast resistance when recharging the battery.

• Energy Efficiency. It characterizes the energy loss in the inverter when converting a constant voltage to alternating voltage and is determined by the ratio of the output power to the input power. This parameter must be included in the technical documentation of the inverter. Preference should be given to inverters of greater importance for energy efficiency over a wide voltage range.

• Configurable load on and off settings. With this function, it is possible to automatically switch the load depending on the voltage on the battery, which will protect the battery from deep discharge and extend its life.

Conclusion. The paper presents the structure, characteristics and features of the operation of small-capacity wind turbines. Particular attention is paid to the operation of the inverter, which is one of the main components of a wind turbine. According to the results of inverter diagnostics, mal-

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functions were detected in the DC link – short circuit of capacitors. Oscillograms of the current flowing through the batteries at various capacities of the DC link are also presented. Based on the presented dependencies, it is concluded that it is necessary to install capacitors to reduce the ripple of the current flowing through the batteries. Based on the operating experience, general recommendations are given for choosing an autonomous inverter.

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