Counter-rotating electric generator for wind power plants with liquid metal energy transfer

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Abstract. The problem of creating effective structures that ensure mutual rotation of the rotor and stator of an electric generator. The wide practical application of counter-rotor wind-electric generators, which provide a significant increase in specific power, is hindered by the disadvantages and low reliability of existing systems for removing electric energy from the windings of a rotating counter-rotor, due to the dry friction mode. It is possible to increase the reliability of the contact removal of electrical energy from the counter rotor (rotating stator) by replacing solid brushes with liquid metal contact groups, which will lead to a certain increase in the resistivity of the contact group, compensated by the contact area of the liquid metal with the contact ring. It is most advisable to use liquid metal contact groups based on gallium, which will raise the permissible temperature limit of operation by about 2 times compared to the achieved level to 275 °C and, thereby, additionally raise the specific power of the electric generator.

1. Introduction

The solution of the problem of increasing the specific power of wind power plants is associated with the solution of the problem of creating effective structures that ensure mutual rotation of the rotor and stator of an electric generator. To date, a significant number of designs of counter-rotating wind turbines have been created, as well as the influence of various factors on the efficiency of their operation has been theoretically and experimentally studied [1-8].

The basis of the designs are solutions based on the creation of wind turbine wheels spaced on different sides of the electric generator and connected to the generator by separate shafts or coaxially located on one side of the generator opposite rotating shafts for the counter drive of the rotor and counter-rotating (rotating stator).

In this case, the transmission of the generated electric energy from the counter-rotor is supposed to be carried out using a rotating brush mechanism of dry friction. This method of transmitting the generated electric energy has low reliability and significantly reduces the durability of the counter-rotor wind generator.

In order to increase the reliability of counter-rotor wind power plants, permanent magnet generators
are used [9-10]. However, they do not allow achieving the values of the specific power available for generators with an electromagnetic excitation system.

Thus, there is currently a contradiction on the one hand, the increase in the specific power of wind turbines is associated with the possibility of counter-rotation of the rotor and the counter-rotor in the supports of a fixed body. On the other hand, the available method of transmitting generated electrical energy is associated with low reliability and durability of the energy removal unit, implemented in the form of a dry friction brush mechanism.

This work contains one of the options for resolving the existing contradiction.

2. Materials and equipment

The power of a generator that converts the kinetic energy of a flow (liquid or gas) into other forms of energy is determined and confirmed by an experimental and empirical formula (Description of the patent for the invention of the Russian Federation №. 2420670):

\[ P = \frac{D^2 \cdot V^3}{7000}, \text{kWh}, \]  

(1)

where \( V \) - flow rate; \( D \) - diameter of the rotor of the liquid or gas flow converter.

The rotation frequency of the generator rotor is proportional to the flow speed. Thus, the most appropriate way to increase the power of the generator is to increase the speed of rotation of the generator rotor relative to the stationary stator.

The rotation frequency of the rotor of the electric generator for converting the energy of the flow is related to the speed of movement of this flow and its density. The increase in the flow speed is due to the influence of environmental factors and it is virtually impossible to influence it. Therefore, it is advisable to use the design of an electric generator in which the stator and the rotor rotate relative to each other and rotate together in different directions relative to some fixed body. Ensuring the counter rotation of the rotor and stator of the electric generator can theoretically lead to an increase in the speed \( V \) depending on (1) up to 2 times. Figure 1 shows a circuit of a counter-rotor electric generator with a liquid-metal supply of the excitation current and a liquid-metal transmission of electric energy [10].

Its difference from the known ones is the presence of liquid-metal nodes for supplying the excitation current to the rotor and liquid-metal nodes for transmission the generated energy from the counter-rotor windings. Mercury, gallium and other metals with a low melting point can be used as a liquid metal.

The rotor shaft 2 and the dielectric body 7 form a movable sealed fit. The counter-rotor shaft 11 and the dielectric body 15 form movable sealed landings. The dielectric bodys 7 and 15 are rigidly connected to the fixed housing 8.

The proposed counter-rotor electric generator works as follows: after the torques \( M_1 \) and \( M_2 \) are communicated, the rotor shaft 2 and the counter-rotor shaft 11 begin to rotate in opposite directions, while the body of the counter-rotor electric generator remains stationary, and electric current is supplied through the contact conductors 9, liquid metal 6 to the contact rings 5 of the rotor shaft 2 and further to the rotor windings (not shown in figure 1). An electromagnetic field is created around the rotor, which induces an electric current in the windings (not shown in figure 1) of the counter-rotor 10, which is fed to external electrical circuits through contact rings 13, liquid metal 14 and contact conductors 16.
Figure 1. Counter-rotor electric generator for wind power plants with a liquid-metal transmission of electric energy: 1 - rotor; 2 - rotor shaft; 3 - counter-rotor bearings; 4, 12 - body bearings; 5, 13 - contact rings; 6, 14 - liquid metal; 7, 15 - dielectric body; 8 - body of a counter-rotor electric generator; 9, 16 - contact conductors; 10 - counter-rotor; 11 - counter-rotor shaft.

The existing brush mechanisms have a permissible brush operation of about 140 °C. At the same time, the electrical insulation materials that cover the conductors of the windings of electric machines have a maximum operating temperature of 275 °C.

Liquid-metal brush mechanisms allow working at temperatures up to the boiling point of the metals used in them, are able to provide high current transmission and ensure operation at temperatures up to 275 °C, thereby contributing to an increase in the specific power of an electric generator by 1.5-2 times.

3. Results

Table 1 shows the characteristics of metals under normal conditions having a low melting point, the characteristics of the main conductor of electric machines - copper and the material of the main types of brushes of electric machines.

| Material or product                  | Melting point, °C | Resistivity, $\frac{\text{ohms-mm}^2}{\text{m}}$ |
|-------------------------------------|-------------------|--------------------------------------------------|
| Copper                              | 1084.5            | 0.0175                                           |
| Mercury                             | -38.9             | 0.94                                             |
| Gallium                             | 29.8              | 0.272                                            |
| Potassium                           | 63.6              | 0.066                                            |
| Sodium                              | 97.8              | 0.047                                            |
| Graphite Brushes                    | -                 | 15...40                                          |
| Carbon-graphite brushes             | -                 | 20...70                                          |
| Metal-graphite brushes              | -                 | 0.04...0.3                                       |
| Electric carbon electrodes          | -                 | 0.02...0.05                                      |

Analyzing the data in table 1, as well as taking into account the properties of metals in terms of activity and toxicity, the most appropriate material for use in the composition of liquid metal contact groups is gallium. In the case of replacing metal-graphite and electric-carbon electrodes with liquid-metal ones made on the basis of gallium, an increase in the contact surface area of liquid gallium and the contact ring from 1 to 6.8 and from 5.4 to 13.6 times, respectively, will be required to ensure identical performance indicators of brush-collector units.
An application for an invention of the Russian Federation has been submitted for the design of a counter-rotor electric generator for wind power plants with liquid metal energy extraction.

4. Conclusions

The wide practical application of counter-rotor wind-electric generators, which provide a significant increase in specific power, is hindered by the disadvantages and low reliability of existing systems for transfer electric energy from the windings of a rotating counter-rotor, due to the dry friction mode.

It is possible to increase the reliability of the contact transfer of electrical energy from the counter rotor (rotating stator) by replacing solid brushes with liquid metal contact groups, which will lead to a certain increase in the resistivity of the contact group, compensated by the contact area of the liquid metal with the contact ring.

It is most expedient to use liquid metal contact groups based on gallium, which will raise the permissible temperature limit of operation by about 2 times compared to the achieved level to 275 °C and, thereby, additionally raise the specific power of the electric generator.

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