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APPLICATION OF THERMAL PROTECTION METHOD TO DARRIEUS WIND TURBINE OF TROPOSKINO SYSTEM

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Abstract: *The method is applied in wind power engineering – it provides a stable operation of vertical-axis wind turbines in severe climate conditions. This becomes possible due to self-ventilation of warm air in the rotating turbine elements which results from centrifugal forces. During the greatest energy-demanding periods wind power stations can be damaged and even shut down since the sharp drop in air temperature and snow drifts may cause a formation of a massive ice layer on the turbine surface. One of possible ways to protect the external surface of the operating Darrieus wind turbine from the wet snow adhesion is heating with warm air flows through internal parts of the system. Different methods have been reported against sticking snowflakes to the turbine elements at subzero temperature of the environment. This paper describes the thermal method to protect turbine surface from the snow drift. This method is novel and it can be applied to any type of wind turbines.*

Key words: *wind power engineering, vertical-axis wind turbine, Darrieus wind turbine*

1. Introduction

Wind-driven power plants belong to the most perspective systems, so-called alternative energy. The offshore wind farms even today are an important source of renewable energy in many countries having an exit to the Baltic and Northern seas.

However in some regions, especially where the climate is characterized by severe winters, operators face very serious problem - formation of ice on blades of a wind wheel (see Fig. 1).

Deutsche Welle writes: "At some time this ice falls dawn from blade and spaced out to hundred-two hundred-three hundred meters apart, moreover this are huge pieces of ice of one, even two kilogram weight. Of course, such a tool can kill". And this is not the only problem. In winter during 5 months period the staff of the Swedish firm conducted twenty four hour monitoring of one of the Swedish wind turbines near the city of Hernesand, measuring the wind speed, ice thickness on blades and wind turbine performance. It turned out that little crust of ice significantly reducing the plant efficiency so far, as it sharply worsens aerodynamic characteristics of blades. As soon as thickness of ice exceeds one millimeter, losses are begun. As a result the wind turbine produced an electric energy 15 percent less. Even if "to scatter" these losses for all the year, more than 5 percent is still appeared - very essential figure 1-2.

Fig. 1. *Condition of the wind-driven power plant after a snow storm*

The problem of frosting is an actual practically for all wind turbines: their productivity considerably falls in winter. Besides that the freezing of super-cooled rain or water snow worsens aerodynamics of the blade, it's necessary to switch off wind turbines at all, if the thickness of an ice layer exceeds the critical value. The same situation is observed in Finland, in the north of Germany, in Switzerland and in Russia.

In recent years, extensive studies have been conducted to identify and design methods to prevent icing. There is a variety of techniques developed by experts in fields of alternative energy and flying machines to solve such a problem in the world. Most of these methods were derived from the aviation industry and can be divided into two categories: active and passive. Passive methods rely on the physical properties of the blade which prevent the ice accumulation, while active methods rely on the external system applicable to the blade. Two types of systems can be used to prevent icing: anti and de-icing. First removes the ice from the surface after its formation, while the other prevents the beginning of icing 3.

Methods of active protection require energy, they include thermal, chemical and pneumatic methods and act as systems for cleaning up ice or anti-ice 4.

Active systems for removing ice. Small aircrafts usually use mechanical systems to remove the ice - inflatable rubber wipers at the forefront of the wing, which expand and contract in the areas of aircraft icing. It is proved that these systems are not pragmatic to use in wind turbines for several reasons; it is obvious that they will lead to an increase in aerodynamic interference and noise which is caused by an inflatable wiper. Furthermore, additional mechanical complexity associated with such systems will significantly increase the burden for the service during a 20-year life of the turbine 5.

Active anti-icing systems. The most active methods developed at least before the prototype stage were based on thermal systems that remove ice by supplying heat to the blade. Heating surface of the blade can be achieved using several methods:

- Electric heating. Electric ice protection system consists of a heating membrane or element which is applied to the surface of the blade. Membrane or element are laminated into the structure of the blade. These thermal systems for icing prevention are simple and have been successfully used in aerospace industry for many years. Similar heating systems have been developed for use in wind power in the mid-1990s. 5 Currently, there are many commercially available types of electric heating blades. The Finnish system of blades heating - carbon fiber elements are attached near the blade surface - has a wide experience with the installation on 18 turbines in various places with a total of approximately 100 working winters 3. The system of direct resistive heating JE also showed the effective work, but has not yet entered into mass production6.

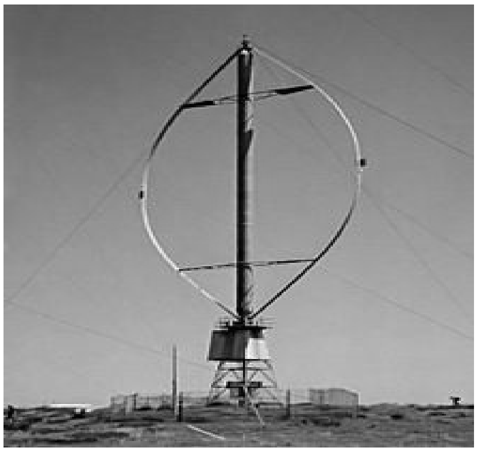

Fig. 2. Darrieus wind-power unit of troposkino system

- Indirect surface heating. This method heats the inner surface of the blade using warm air and radiator, and heat is conducted to the outer surface. This system was installed on the Enercon turbine in Switzerland7.
- Microwave heating. These systems are based on microwave energy, but unknown to us and have not been successfully implemented 3.
- A system in which the blade surface is protected by a layer of pure air. This system uses the air flow to the inner part of the blade, which is blown through a number of small holes in front and rear edges, to create a layer of pure and heated air surrounding surface of the blade if needed. This layer of air will reflect the large number of water droplets to the air and will sink some drops that were able to get to the surface 7.

Passive methods use advantages of physical properties of the blade surface to eliminate or prevent the formation of ice, and similar to active methods have an ability to act as ice cleaning systems or anti-icing 4.

Passive systems of anti-icing

- The system is designed for a sufficiently flexible blades that are able to crush loose formed ice, as flexible blades are already known for their properties of eliminating ice. As far as we know, there is little published information on this topic. A disadvantage of attempts to break loose ice is that thin layers of the ice may adhere quite strongly to the blade and can not be sufficiently brittle to break only from the blade vibration; it is likely to jeopardize the aerodynamic properties of the blade 7.

- Electric buoyancy system that depends on a very fast electromagnetic-inductive vibration has recently been certified for use on the Raytheon Premier I business-jet company. This system is promising for new small general aviation, but there is still no practical information for wind turbines 9.
- Other passive systems, such as active blade pitching, the start and the stop cycles of the blades in the direction towards the sun, are used for removing ice off the turbine blades. Although these techniques can work in an environment with light icing, very small amount of research has been published to verify the effectiveness, also such methods can damage the turbine and / or reduce the production of electricity 10.

In 1996, Yukon Energy " colored " their blades with black coating , which is called StaClean 8. StaClean was declared by the manufacturer as waterproof and better than Teflon, with a high level of abrasion resistance. These properties would be very useful to minimize the amount of ice formed. Subsequently, it was declared as the effective way to reduce the problem of icing 11. Although black has not significantly increased the temperature of the blade surface in the winter months 12. In fact in many cases blade areas coated with original gel actually reach much higher temperatures than the areas covered with black paint StaClean 4.

Therefore we offer the method of thermal protection of wind-power unit against adverse meteorological factors. The method belongs to infrastructure of wind power engineering – providing a steady operation of wind-driven power plant (WDP) of rotary type in severe climate conditions by using the self-ventilation of thermal air in the rotating WDP resulting from centrifugal forces.

One of the possible ways of protecting the external surfaces of Darrieus wind turbine details is heating the warm air flowing through internal channels.

2. The thermal protection method of Darrieus wind-power unit of troposkino system

The object of the invention is the organization of thermal protection of the unit by means of natural ventilation of heated air due to the action of the centrifugal forces resulting from rotation of the turbine.

Wind-driven power plant includes a vertical motionless rack, which lower end is closed up in strong base, the rotation shaft connected with the current generator, located coaxially with a rack and separated from it by aligning bearings, the elastic operating NASA-0021 blades bent in the form of onions, the lower end of which attached to a rotation shaft, and the top end - to its face part (see Fig. 2). WDP troposkino differs from rotary type WDP with that the rotation shaft connected with the current generator represents two adjacent ring channels of different height one of which is connected with the top end of the hollow blade of the turbine bended in the form of onion, and the second, short one, - is brought to the lower end of the curved blade so that at supply of warm air of pressure in rotation shaft junctions with blades were equal among themselves, and the way out for the fulfilled air in the atmosphere is found in a middle part of blades, providing natural ventilation of the all installation (see Fig. 2).

Constructive design of a troposkino wind-power unit is schematically shown in Fig. 3. Fundamental difference of schemes of troposkino wind-power unit from the wind generator of rotary type with natural ventilation of hollow elements of the device is that in the first case the equality of static pressure of P_1 on an entrance to the lower half bow-shaped blade (7) and P_1^I on its entrance to the top half is provided (see Fig. 3), i.e.

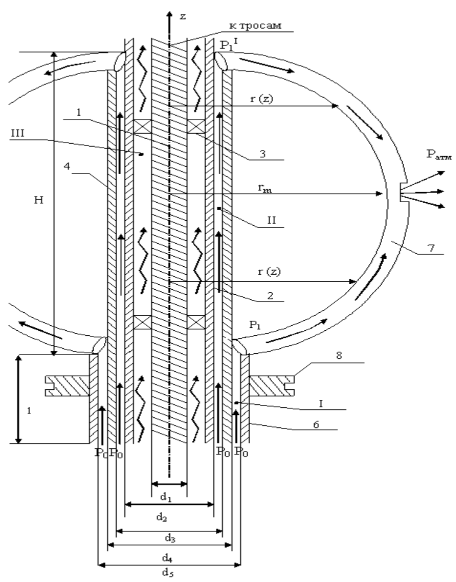

Fig. 3. *The schematic constructive schemes allowing to organize thermal protection of the rotating turbine with troposkino system*

$$P_1 = P_1^I \tag{1}$$

In this case the differences in pressure P1-P_{atm} and P_{1I} - P_{atm} will provide identical warm air rate on lower, as well as on the top halves of the blade (7). As a result we have three vertical ring channels (9), (10), (11) 13-18.

For performance of the condition (1) there is the task to find the sizes of the ring channel (9) (i.e. $d_5 – d_4$) depending on the relation of H/l if the sizes of the channel are known (are set) (10), i.e. $d_3 – d_2$ (see Fig. 3).

It is commonly known 19-20, the hydraulic resistance of channels (9) and (11) are determined by formulas:

$$\frac{P_0 - P_1^I}{H+l} = \frac{\lambda_2}{d_{э2}} \frac{\rho u_{cp2}^2}{2} \text{ and } \frac{P_0 - P_1^I}{l} = \frac{\lambda_1}{d_{э1}} \frac{\rho u_{cp1}^2}{2} \quad (2)$$

Warm air rate on the channel (9) Q1 and on the channel (11) Q2 will be identical when the condition (1) is performed, i.e.

$$Q_1=Q_2=Q_0/2, \quad (3)$$

where Q_0 – the general rate of warm air, necessary for thermal protection of a wind-power unit. In result we will:

$$\frac{(H+l)\lambda_2}{d_{э2}} \frac{\rho u_{cp2}^2}{2} = \frac{l\lambda_1}{d_{э1}} \frac{\rho u_{cp1}^2}{2} \quad (4)$$

where $d_{э1}$= $d_5 – d_4$, $\lambda_1 = 0{,}3164 \mathrm{Re}_1^{-0.25}$

$$\mathrm{Re}_1 = \frac{u_{cp1} d_{э1}}{\nu}, \; u_{cp1} = \frac{Q_1}{\pi(d_5^2 - d_4^2)},$$

$$d_{э2} = d_3 - d_2, \; \lambda_2 = 0{,}3164 \mathrm{Re}_2^{-0.25},$$

$$\mathrm{Re}_2 = \frac{u_{cp2} d_{э2}}{\nu}, \; u_{cp2} = \frac{Q_2}{\pi(d_4^2 - d_3^2)},$$

ν - kinematic viscosity of air.

If taking into account (3) the equality (4) to substitute expressions of all sizes included in it, eventually we will come to transcendental dependence of a type:

$$(d_5 - d_4)^3 (d_5 + d_4)^{1.75} = \frac{(d_3 - d_2)^3 (d_3 + d_2)^{1.75}}{l + H/l} \quad (5)$$

If d_2, d_3 and H/l are known by means of computer technologies it is easy to find the corresponding diameter of d_5, since d_4= d_3+h, where h – channel wall thickness.

3. Conclusions

The sharp increase in rated capacity of installation, resulted in growth of speed of snow blizzards, snowstorm, storm wind, can serve as a source of receiving warm air since wind power is proportional to a wind speed cube. Therefore the part of energy will be consumed to providing the consumer with the electric power, and other excessive part of energy goes to warm up the electric muffle furnace through which drawn outside an atmospheric air flows and heated up, and the charging of accumulator. It is possible to use for heating of drawn atmospheric air by burning of bottle-stored gas for receiving necessary heat, and all the additional power received due to the windstorm speed is accumulated. Application of electric coil for heating of external surfaces of the rotating wind turbines isn't desirable for the following reasons: at big currents the coil can be over burned and secondly the additional device for connection of coil to current generators at rotation of the wind turbine.

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