

A New Type of Wind Generator Blades Mechanical Automatic Control System

Alina Fazylova

*Dept. of Robotics and engineering tools of automation,
Satbayev University
Dept. of Electronics and Robotics
Almaty University of Power Engineering and
Telecommunications named after G.Daukeev
Almaty, Kazakhstan
a.fazylova@auess.kz*

Teodor Iliev

*Dept. of Telecommunications
University of Ruse
Ruse, Bulgaria
tiliev@uni-ruse.bg*

Abstract— Wind power in Kazakhstan, following the global trend, continues to develop and there is an increase in the number of RES power plants. The development of wind energy involves the creation of large-sized and high-power installations. The rotors of wind turbines experience heavy loads on their design. Thus, the actual task and problem for the wind energy park of Kazakhstan is to reduce the load on the structure by regulating it during wind gusts. The use of a control system for the rotation of the blades makes it possible to significantly reduce the load on the structure. However, due to the non-linearity of the process and the difficulty of accurately measuring the wind speed, the blade turning control system must be designed with great care. This paper presents the development of a lever mechanical system for controlling the blades of a wind turbine, which makes it possible to secure the operation of a wind generator. The purpose of the study is to develop a 3D model of a lever control system and create an automatic control system for it. A three-dimensional study of the rotor in various states of the rotor was carried out. This dynamic computer model is proof of the functionality of the communication system. The transfer function of the entire control system is also determined and, based on experimental data, a mathematical model of an experimental laboratory sample is developed. This installation will optimize the operation of a vertical axis wind generator by creating a wind flow control system for further converting the wind flow into electrical energy.

Keywords— automated control system, blades, lever, computer model, renewable energy, wind turbine.

I. INTRODUCTION

Currently, there is a deterioration of the environmental situation over the world, mainly due to the careless use of fossil fuels. Renewable energy sources can reduce their usage. Among the new energy sources, wind energy is of particular interest [1]. There are two types of rotors: horizontal axis turbines and vertical axis turbines. It is well known that vertical-axis wind generators are more efficient and versatile than horizontal-axis wind generators when they are used for individual consumption. It is due to the fact that vertical-axis wind generators do not need a rotor guidance system for air flow, since they work equally efficiently in any direction of the wind flow [2]. In addition, all the main components of the system, such as gearbox, control system, battery and generator systems can be located at ground level. Also, an important advantage of vertical-axis wind generators over horizontal-axis ones is ease of maintenance, which makes it possible to

use them on farms and remote areas where there is no opportunity to provide professional service [3].

To date, there are many design options for vertical-axis wind generators. But most of them have a safety operation problem in their work, namely, the control of the rotor blades is not provided. For example, a rotor is known, comprising a conical body with spiral blades around an axis of rotation. The main disadvantage of this rotor is the possibility of an emergency when the maximum permissible value of the speed of rotation of the blades can exceed the certain value, which can lead to the destruction of the blades [4]. This can take a place without a special automation blades control system. It includes a wind turbine with a vertical axis of rotation, which is placed on the rotor. Impellers are mounted on the turbine shaft using traverses.

At the end of the turbine shaft is a “Savonius” rotor [5]. This solution has several advantages: the ability to work in gusty winds, their speed coefficient is equal to 1. The disadvantage of this solution is the difficulty in mounting the structure, increased material consumption, as well as in the previous version, the lack of a control system when exceeding the maximum permissible value. Research in the field of vertical-axis wind generators is necessary to reduce the impact of negative external factors and improve their technical indicators.

In this paper presents design of a 3D model of the lever control system of the wind generator, as well as checking its operability, determining its mathematical model and, based on the obtained characteristic equation, determining the transfer function of the laboratory sample.

II. METHODS AND MATERIALS OF RESEARCH

In this article, the development and testing of a computer model of a wind turbine with a lever braking system of a wind generator, the study of this model, the development of a mathematical model of an open-loop control system for wind turbine blades are carried out. Regulation is based on wind speed data (anemometer) [6]. Further, based on the found transfer function of an open-loop system, research is carried out and the characteristics of the control system are obtained. In this model, the microcontroller controls the wind turbine blades by means of a motor driver and a stepper motor, based on wind speed data, controls the wind turbine blades. Using the SolidWorks software, a 3D model of a lever control system for wind turbine blades is built within SolidWorks software.

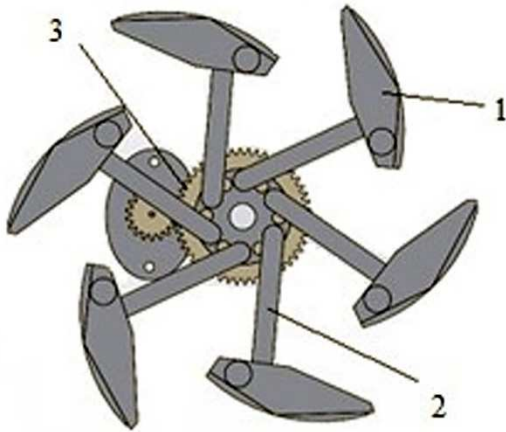


Fig. 1. Lever brake system: 1- blade, 2 - lever, 3 – gear wheels

Using the test complex Petom-51, experimental data on the change in the value of the output voltage over time in the laboratory model were obtained. Also, using the object identification algorithm based on acceleration characteristics, the transfer function is determined.

The safety problem of the operation of wind generators can be solved through the use of a brake lever system. Fig.1 shows a 3D model of a lever control system for wind turbine blades.

For automated control of the rotor blades, a stepper motor and a gear transmission are shown in Fig. 2. Thus, the lever brake system is able to control the position of all the blades using only one engine. The controller is located under the lower base, this creates additional protection for the control device from external influences.

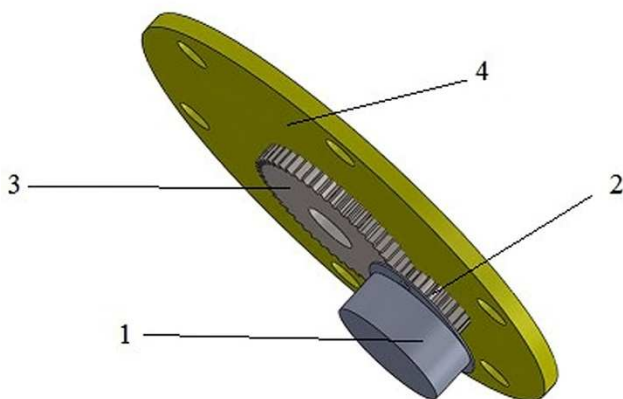


Fig. 2. Gearing: 1- stepper motor, 2 - small gear, 3 - large gear, 4 - rotor base

Thus, Fig. 3 shows the rotor operating modes based on the value of wind speed. At a critical value of wind speed, the blades of the wind generator are completely closed. In normal operation (shown on the left), the blades of the wind generator are fully open, and the wind generator converts the energy of the wind flow in its entirety.

In the center, the operating mode of the wind generator is shown when the critical value is exceeded, but there is the

possibility of its functioning after a slight closing of the blades. The emergency operation mode of the wind generator is shown on the right. When the wind speed exceeds the maximum permissible value, generator is shown on the right, shown in Fig. 3.

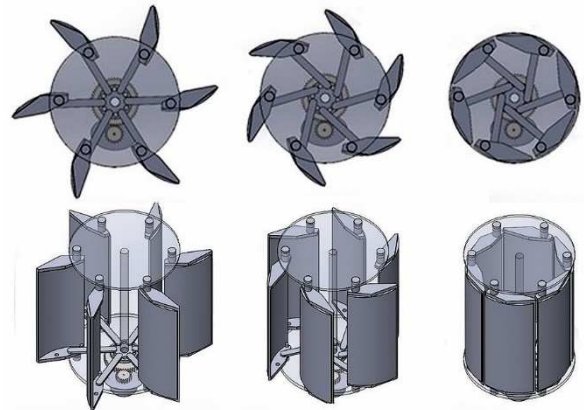


Fig. 3. Rotor control process

The circuit shown in Fig. 4 is an open-loop control system in which the wind turbine (1) rotates around its axis during normal operation, transferring mechanical energy to the generator system (2) [7] and, in addition, to the conversion circuit (3) and output connect load or indicator (4). When the maximum limit value of the wind speed is exceeded, which is recorded using an anemometer, the wind turbine blades are monitored. The anemometer is an impeller rotating (5) in the presence of wind, with a rotation sensor (6) fixed on its stationary part, and a magnet (7) on the moving part. In the form of pulses, the signal is sent to the microcontroller (8) when the anemometer impeller rotates. The microcontroller, according to a given algorithm, controls the stepper motor (9), which drives the wind turbine blades (10).

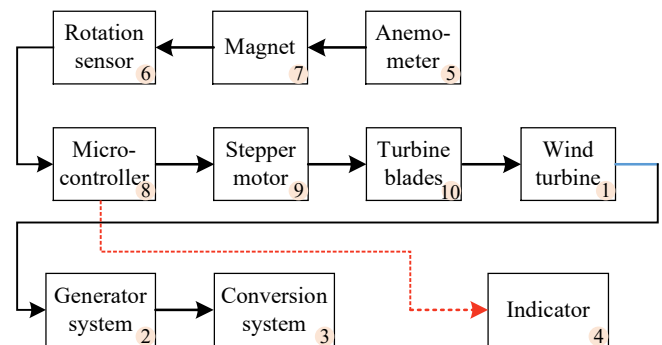


Fig. 4. General circuit of the rotor control system [8]

These pulses are processed by the microcontroller and converted as a value about the wind speed. Based on this value, the blades of the wind generator are controlled. The power for the electrical circuit is taken from the power supply of the electronic circuit.

Research of a computer model means the construction of its dynamic model for the further evaluation of the operation of the automated control system from the vision of the mechanical characteristics in the Solidworks software environment, the construction of this dynamic model has been performed [9]. For this, a wind flow of 15 m/s was specified in Fig. 5 result of 3D analysis in normal mode of operation of a wind generator was shown. The scale is equal to 1:10 000.

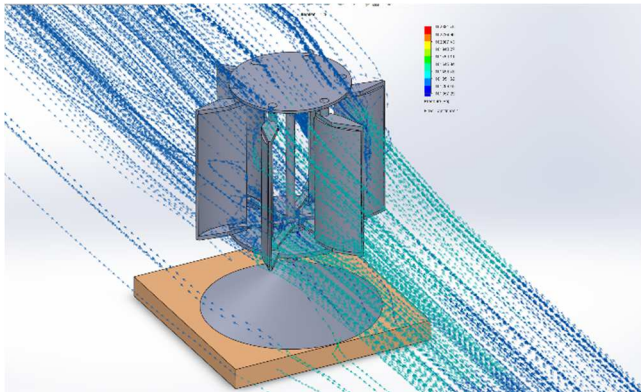


Fig. 5. Normal operating mode of a wind generator

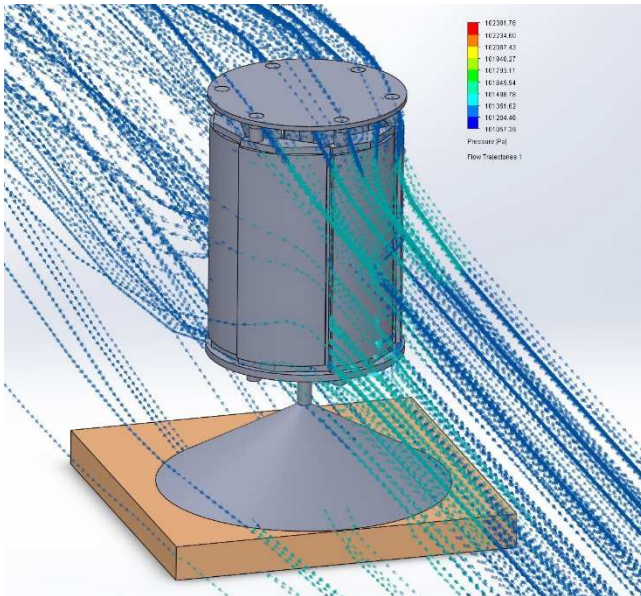


Fig. 6. Emergency operation of a wind generator

Fig.5 shows the normal operating mode of the wind turbine. At the same time, a sharp decline in the blades flow resistance (on the Fig. 5 is shown in green) is observed and the pressure setting remained by the winds of the wind-turbine. The force acting on the blade by the wind flow is shown in red in Fig. 5. In the normal mode of operation, the wind generator accepts kinetic energy of the wind flow for the next transformation of it. Further it is necessary to build a dynamic model of a wind generator in emergency mode (Fig. 6).

Also, as in the previous research [9] the same initial terms and scope were asked. The position of the blades in the emergency operation mode is established. As seared from the graphic (Fig. 6), after installing a wind turbine in this mode, the pressure provided by the wind flow is minimum. This says that the wind generator in this mode does not practically get energy, and the valves are not breaking, and the lever system fulfills its functionality.

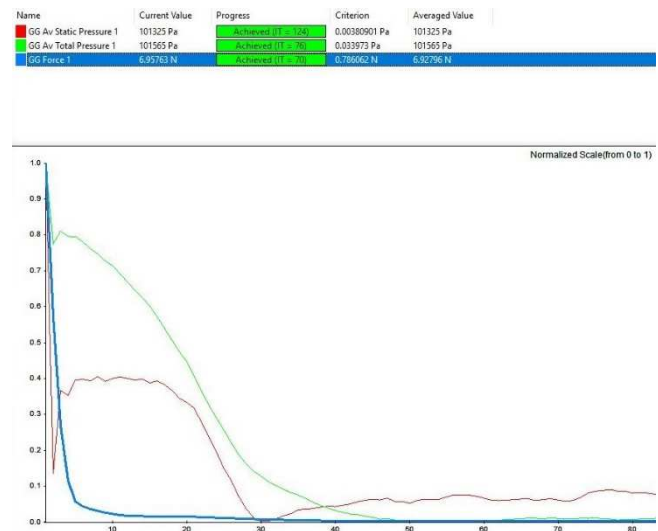
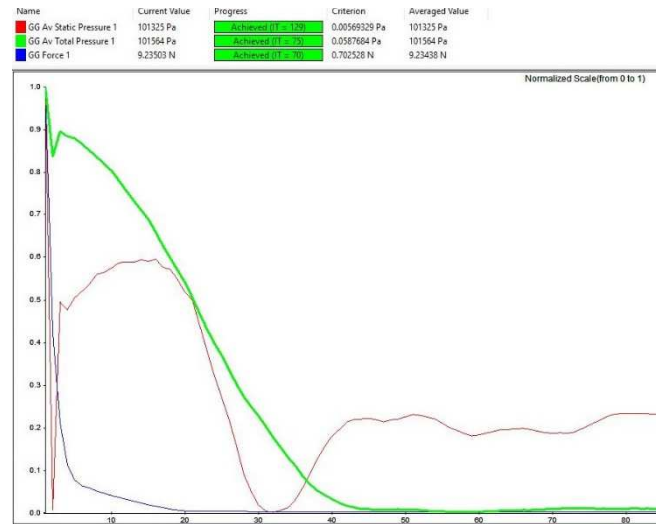


Fig. 7 shows the control circuit of the blades of a wind generator without feedback and describes the components of an automatic control system [9].

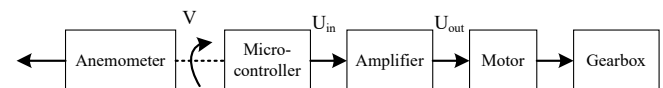


Fig. 7. The control circuit of the blades of a wind generator

The microcontroller processes the signal from the anemometer (wind speed sensor) to the value of the angle of the motor deviation. That is, with this deviation, voltage is applied to the amplifier and then to the motor, which forces the blades to rotate by a certain angle. To compose the transfer function of an open system, the following notation was introduced:

— α_1 is the deviation angle processed by the microcontroller from the anemometer;

– α_2 is the angle of rotation of the blades.

Thus, the transfer function of the open-loop control system of the wind generator is [9]:

$$W(p) = \frac{\alpha_1}{\alpha_2} \quad (1)$$

Next, the transfer functions of individual links are determined. First, the transfer function of the potentiometer was determined. Since the potentiometer is a timeless link, its transfer function is defined as follows:

$$W_1(p) = \frac{u_{in}}{\alpha_1} = K_1, \quad (2)$$

where K_1 is the slope of the potentiometer.

Next, you need to determine the value of the transfer function of the amplifier [10]. Given that the amplifier is an inertia less link, the transfer function of the amplifier has the form:

$$W_2(p) = \frac{u_{out}}{u_{in}} = K_2, \quad (3)$$

where K_2 is the voltage gain.

When determining the transfer function of motor with a gearbox, it is permissible to neglect transients that occur in the control winding:

$$W_3(p) = \frac{K_3}{p(1+T_d p)}, \quad (4)$$

where K_3 is the gear ratio of the engine (with gearbox) in speed; T_d - electromechanical constant in time.

Next, the transfer function of the object is determined. Given that the angular velocity of rotation of the blades is proportional to the angle of deviation of the processed value by the microcontroller from the anemometer, the angle of rotation of the blades is proportional to the integral taken from α_1 over time [10]. Thus, the transfer function of the object will take the form:

$$W_4(p) = \frac{K_4}{p(1+T_0 p)} \quad (5)$$

So, the transfer function of an open control system will take the form:

$$W(p) = W_1(p)W_2(p)W_3(p)W_4(p) \quad (6)$$

In accordance with (6), the transfer function has the form:

$$W(p) = \frac{K}{p^2(1+T_d p)(1+T_0 p)} \quad (7)$$

Thus, the transfer function was found, in accordance with which it is necessary to determine the characteristic equation of the system:

$$T_d T_0 p^4 + (T_d + T_0)p^3 + p^2 + K = 0 \quad (8)$$

III. RESULTS AND DISCUSSION

Using the Petom-51 test complex and the existing laboratory model of the wind turbine (Fig. 8), experimental data were obtained on the change in the value of the output voltage over time, the results are presented in Table 1.

TABLE I. INITIAL DATA

Time	0	0.001	0.002	0.003	0.004	0.005
Voltage	0	0.342	1.101	2.008	2.914	3.747



Fig. 8. Implemented laboratory 3D model of a wind turbine

Equation (9) shows the substituted values from Table 1 [11]:

$$\begin{cases} B_3 y_1 + B_2 y_2 + B_1 y_3 + y_4 = 0 \\ B_3 y_2 + B_2 y_3 + B_1 y_4 + y_5 = 0 \\ B_3 y_3 + B_2 y_4 + B_1 y_5 + y_6 = 0 \end{cases} \quad (9)$$

The result is shown in (10):

$$\begin{cases} 0B_3 + 0.342B_2 + 1.101B_1 + 2.008 = 0 \\ 0.342B_3 + 1.101B_2 + 2.008B_1 + 2.914 = 0 \\ 1.101B_3 + 2.008B_2 + 2.914B_1 + 3.746 = 0 \end{cases} \quad (10)$$

The coefficients are equal:

$$B_1 = -2.4218B_2 = 1.9255B_3 = -0.5037 \quad (11)$$

This gives the equation:

$$\lambda^3 - 2.421\lambda^2 + 1.9255\lambda - 0.5037 = 0 \quad (12)$$

The roots of the equation are obtained after solving (13):

$$\begin{aligned} \lambda_1 &= 0.67 = p \\ \lambda_2 &= 0.7518 = q \end{aligned} \quad (13)$$

It is necessary to determine the coefficients T_1 and T_2 :

$$\begin{aligned} T_1 &= \frac{-\Delta t}{\ln p} = 2.497 \\ T_2 &= \frac{-\Delta t}{\ln q} = 3.505 \end{aligned} \quad (14)$$

Substituting the values obtained characteristic equation [11]:

$$y_i = k_i \left(1 + \frac{T_1}{T_2 - T_1} e^{\frac{-t}{T_1}} + \frac{T_2}{T_1 - T_2} e^{\frac{-t}{T_2}} \right), \quad (15)$$

where $k = \sum \frac{k_i}{n} = 7.501$

Then the transfer function is written as:

$$W(p) = \frac{7.501}{(2.497p + 1)(3.505p + 1)} \quad (16)$$

Fig. 9 shows the overlocking characteristics of the obtained and reference transfer functions.

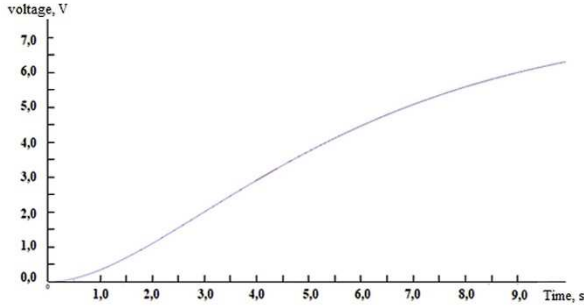


Fig. 9. The resulting and reference overlocking characteristics

Thus, the laboratory design of the wind generator was identified by static characteristics and by accelerating characteristics. The type of connection is established - inertial of the second order according to the type of characteristic obtained experimentally. As a result, the calculated curve coincided with the experimentally constructed model.

IV. CONCLUSION

Thus, a lever mechanical wind turbine blade control system was developed in the Solid Works software environment, which makes it possible to secure the operation of the wind generator. The dynamic computer model proved the robotic capability of this installation. The developed transfer function of the control system will allow adapting the control system to new conditions. The mathematical model obtained during the study can be used in the development of a lever control system for an industrial wind generator.

REFERENCES

- [1] M. Sajadi, J. D. M. De Kooning, L. Vandeveld and G. Crevecœur, "Harvesting wind gust energy with small and medium wind turbines using a bidirectional control strategy", *The Journal of Engineering*, vol. 2019, no. 17, 6, 2019, pp. 4261-4266
- [2] M. Zhou, M. Wang, J. Li and G. Li, "Multi-area generation-reserve joint dispatch approach considering wind power cross-regional accommodation", *CSEE Journal of Power and Energy Systems*, vol. 3, no. 1, March 2017, pp. 74-83.
- [3] A. Chowdhury, H. Akimoto and Y. Hara, "Comparative CFD analysis of vertical axis wind turbine in upright and tilted configuration". *Renewable Energy*, 85, 2016, pp.327-337
- [4] A. Al-Faruk, and A. Sharifian, "Flow Field and Performance Study of Vertical Axis Savonius Type SST Wind Turbine". *Energy Procedia*, 110, 235-242.
- [5] H. Belmili, R. Cheikh, T. Smail, N. Seddaoui, RW. Biara "Study, design and manufacturing of hybrid vertical axis Savonius wind turbine for urban architecture". *Energy Procedia* 136, 330-33.
- [6] K. Luo, W. Shi, Y. Chi, Q. Wu and W. Wang, "Stability and accuracy considerations in the design and implementation of wind turbine power hardware in the loop platform", *CSEE Journal of Power and Energy Systems*, vol. 3, no. 2, pp. 167-175, June 2017.
- [7] E.C. Douvi, D.C. Douvi Margaris, D.P., Drosis "Performance and Aerodynamic Attitude of KIONAS, a New Configuration of a Vertical Axis Wind Turbine". *Int. Rev. Mech. Eng.* 10 (3) 8873.
- [8] M. Petružela, V. Blazek and J. V. S. Mišák, "3D analysis of vertical axis wind turbine with enclosure," 2018 19th International Scientific Conference on Electric Power Engineering (EPE), 2018, pp. 1-5, doi: 10.1109/EPE.2018.8395945.
- [9] E. N. López-Ortiz and D. Campos-Gaona, and E. L. Moreno-Goytia, "Modelling of a wind turbine with permanent magnet synchronous generator", 2012 North American Power Symposium. IEEE, USA. ISBN 9781467323086.
- [10] A. Boute. "Off-grid renewable energy in remote Arctic areas: An analysis of the Russian Far East". *Renewable and Sustainable Energy Reviews*, 59, 2016, pp. 1029-1037.