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ASSIGNMENT
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ABSTRACT

Kerolos Nagy Abdou Megally Development of a model of wind power plant 141 - Electric power, electrical engineering and electromechanics; Ternopil Ivan Puluj National Technical University. Faculty of Applied Information Technologies and Electrical Engineering. Department of Electrical Engineering, IEE-42 group. - Ternopil: TNTU, 2022

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In this qualification work, a simulation model of a wind power plant was developed in the MATLAB \ Simulink field for reproduction of real physical processes with an acceptable degree of reliability.

The block diagram for modeling of the main units of wind turbines is developed; wind wheel. Reducer, asynchronous generator with short-circuited rotor. Simulation at constant and variable wind speeds was performed. The main energy parameters of the model are determined.

Keywords: asynchronous generator, wind power plant, mathematical model, wind wheel, wind turbine utilization factor, Matlab, Simulink.

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INTRODUCTION

Currently, the most efficient and most common in industrial wind energy are three-bladed horizontal-axial wind turbines. The efficiency of a wind power plant is determined by the ability to obtain the maximum possible part of wind energy and depends on both its design features and the control system.

Modeling of wind power plant (WPP) is an important scientific and practical step for the analysis and synthesis of the efficiency of industrial wind power plants (WPP). Modern wind turbines are a complex technical and physical system consisting of mechanical, electrical and hydraulic elements. The source of energy for wind turbines is wind, the parameters of which change for each moment of time. The transition from the actual design of the wind turbine to the appropriate mathematical model is necessary to optimize its operating parameters

Therefore, it is important to develop wind turbine models to reproduce real physical processes with an acceptable degree of reliability, which will provide a deeper understanding of the processes that take place, get an objective idea of quantitative and qualitative patterns for further forecasting in changing changing parameters. Modeling the operation of the wind turbine allows you to quantify the assumptions, which will greatly simplify the work when designing wind turbines.

The purpose and objectives of the study. The purpose research is the development of a mathematical model of wind turbines and the calculation of its energy characteristics.

1 ANALYTICAL SECTION

1.1 Analysis of wind energy potential in Egypt

In Egypt, the wind market increases quickly to make it one of the top countries in the Middle East. This study discusses the viability of wind resources and the economic assessment for four locations in Egypt: Ras El-Hekma, Farafra, Nuweiba, and Aswan through two stages. In the first stage, the optimal hub height for some wind turbines has been calculated by using Equilibrium Optimizer (EO) algorithm to achieve maximum wind energy with overall minimum cost. The second stage, the economic assessment has been evaluated by using such turbines to calculate the cost of energy (COE) compared to the global and Egyptian production costs of wind energy. Developed MATLAB programs are applied for statistical analysis of wind data. The results have shown that Ras El-Hekma's average wind speed is higher than other sites and its wind energy potential is the best. Moreover, the economic assessment for selected locations turns out that Ras El-Hekma by using EWT-DW61/22 turbine has the lowest COE.

Usually, the wind turbines are positioned perpendicular to the wind direction to take the maximum output of the wind energy. The wind rose diagram of 360° decides the direction of the wind at any location; such diagrams are used in to assess wind resources for ten selected sites in Kuwait. Also, the difference of the wind direction over five years at Shark El-Ouinat in Egypt has been studied using wind rose diagrams in . The results revealed that the wind frequency was very low at 90° and very high at 360° and 30°, which indicates that the northern winds are more effective.

Determining the optimal hub height for a wind turbne is considered one of the critical issues. In literature, different algorithms are applied to optimize the hub height of wind turbines. In , an algorithm is introduced to evaluate the optimized hub height by calculating the annual production of energy using the cost of the energy curve as a function of hub height. A new correlation is implemented in todetermine the optimal hub height for seven locations in Saudi Arabia by applying different ratings of wind turbines. It is deduced that the optimal hub height has reduced with increased wind shear exponent and the average wind speed. Optimizing the hub height to ensure the economic assessment is achieved by obtaining the net profit in by subtracting from the energy production cost. The optimization of blade length and the tower hub height at low wind speeds are also presented in.

To guarantee the suitability to set up a wind turbine in a particular location, turbine classes should be taken into consideration. For example, six turbines have been examined for energy production in three sites in Australia, where every two turbines are of the same rated power and various classes of turbines. The results displayed that class IEC III has more production of energy.

Typically, to assess the economic feasibility of power generation from wind energy, the cost of energy (COE) should be estimated. In Iran, by applying a 2.5 MW Dongfang DF100-2500 turbine, the lowest levelized COE is estimated by 0.0830 and 0.0786 $/kWh in Lotak and Shandol, respectively . In Algeria, the potential of wind energy and COE are examined in four different sites using collected meteorological wind data from 2005 to 2014, while the COE ranges from 0.032 $/kWh to 0.0422 $/kWh . For Shark El-Ouinat in Egypt, the wind speed data has been measured for five years at 100 m height, and then the Weibull distribution function is applied in [to determine the shape factor of 2.1 and the scale factor of 7.4 m/s. Such a study has displayed the expectable cost for wind energy is 1.3 cents/kWh for a 150 MW wind park.

In conclusion, the world is still looking for the possibility of utilizing new places for developing wind power projects, and hence the wind resource potential and the economic feasibility should be well assessed. Therefore, the contribution of this paper can be summarized as follows:

-The potential of wind energy is evaluated for four selected locations in Egypt with different wind classes, which are Ras El-Hekma, Farafra, Nuweiba, and Aswan. Such sites are not investigated in previous studies and there are no definite social, environmental, and political conflicts to study these sites.

Four different types of wind turbines are evaluated for the selected locations. They belong to several manufacturers and are of class IEC III compatible with the wind characteristics in tested locations.

-The optimal hub height has been obtained by using Equilibrium Optimizer (EO) algorithm. EO is a recent optimization technique introduced by in 2020; its idea depends on the balance of the volume mass. It is later implemented in literature to solve different engineering applications and ensured better results compared to some other optimization algorithms. Up to the authors' knowledge, the EO algorithm is not utilized before in literature for getting the optimal hub height of wind turbines

1.2 Wind energy in Egypt

Egypt ranks among the countries having great renewable energy in the Middle East. It has great coastal areas about 1150 km on the North Coast of the Mediterranean Sea, 1200 km on the East coast on the Red Sea, and 650 km on the Gulf of Suez and Aqaba, where the wind speed close to the coastal areas is higher than other areas. In addition, Egypt has great desert areas suitable to wind power plants.

According to the wind atlas, the following areas have been identified with sufficient wind energy resources:

▪ Gulf of Suez area (400–600 W/m2);

▪ Gulf of Aqaba area (400–600 W/m2);

▪ Western Egypt domain at the west bank of the Nile (300– 400 W/m2);

▪ Eastern Egypt domain at the east bank of the Nile (300 W/m2);

▪ Western desert – areas close to Kharga (300–400 W/m2).

Therefore, the Egyptian government has established New and Renewable Energy Authority in Cairo aiming to reach more advantage from country wind resources. Over the past two decades, many research studies have been considered to examine the wind energy potential in some Egyptian sites. In, 15 anemometers of meteorological centers are used to collect wind data at 25 m height during the period 1973–1994. The achieved result ensured that the highest wind energy density is at the Red sea coast. The convolution technique is used in to calculate the credit of capacity for wind generation considering the wind speed statistics during 1991–1995 collected for 10 min at height 25 m for four stations along the Gulf of Suez. The results displayed that the best layout for the substation is located at Zafarana. Accordingly, by 2019, the installed wind energy projects in Egypt were 580 MW at Gulf of El Zayt (using 2 MW wind turbines at 60 m height), while the Zafarana site produces 545 MW (using 700 turbines of 600 kW, 660 kW, and 850 kW rated power), and Gulf of Suez produces 250 MW. Other projects are still under construction, development, and planning in the Gulf of Suez, West Nile, and Ras Garab and thus the expectation of electricity production from wind energy production will be 14% at 2035.

Egypt started the experience of wind energy projects; however, according to wind atlas, the excellent wind resource areas are limited. The majority of areas in Egypt belong to “moderate” and “good” wind resource classes based on wind resource class classification demonstrated in Table 1.1 .

Table 1.1 Classification of wind power generation.

Various Heights		**At 10 *m***		**At 30 *m***		**At 50 *m***	
Class	**Resource class**	**Wind speed m/s**	**Wind power density W/m^2**	**Wind speed m/s**	**Wind power density W/m^2**	**Wind speed m/s**	**Wind power density W/m^2**
1	**Poor**	0–4.4	0–100	0–5.1	0–160	0–5.4	0–200
2	**Marginal**	4.4–5.1	100–150	5.1–5.9	160–240	5.4–6.2	200–300
3	**Moderate**	5.1–5.6	150–200	5.9–6.5	240–320	6.2–6.9	300–400
4	**Good**	5.6–6.0	200–250	6.5–7.0	320–400	6.9–7.4	400–500
5	**Excellent**	6.0–6.4	250–300	7.0–7.4	400–480	7.4–7.8	500–600
6	**Excellent**	6.4–7.0	300–400	7.4–8.2	480–640	7.8–8.6	600–800
7	**Excellent**	> 7.0	> 400	8.2–11	640–1600	> 8.6	> 800

1.3 Types of wind power plants

I. Ground-based wind farms. Currently the most common type of wind farm (WPP). The wind farm combines separate wind power plants into a single energy complex, which is able to provide electricity to small autonomous facilities or operates in conjunction with the power system

II. Offshore wind farms. In most European countries with access to the sea, legislation has been developed that allows the construction of offshore wind farms. Marine wind farms include: coastal wind farms, offshore wind farms, floating wind farms.

Coastal wind farms are built at a short distance from the sea or ocean. Manufacturers of wind turbines use standard ground turbines, upgrade their components and parts, as well as electrical control systems, using marine corrosion reduction methods, and install them on concrete bases (steel monolithic piles) for anchoring to the seabed. Electricity from wind farms is transmitted to earth from submarine cables .

Offshore wind farms are being built in the sea: 10-12 km from the shore. They are built in areas of the sea with a small depth - from 5 to 12 m. Wind turbine towers are installed on foundations from piles driven to a depth of 30 m. Electricity, as in the previous case, is transmitted by submarine cables .

Floating wind farms are installed at a depth of up to 200 m. The floating structure must provide sufficient buoyancy to maintain the weight of wind turbines and limit all types of oscillations caused by wind and waves. Therefore, deep-sea technology requires a broader program for the development of floating platforms .

1.3 Classification of wind turbines

Today, specialists in the field of wind energy mainly study the energy potential of two types of wind turbines (wind turbines): horizontal-axial wind turbines and vertical-axial wind turbines in terms of their effective use in modern technologies Fig.1.1.

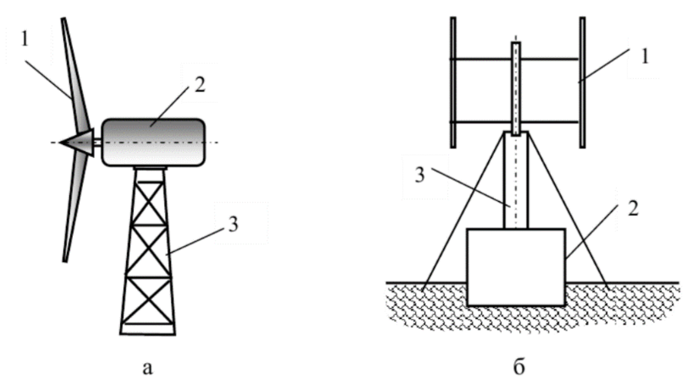


Figure 1.1 - Wind turbines: a - with a horizontal axial rotor, b - with a vertical axial rotor

The most popular are horizontal wind turbines, the axis of rotation of the turbine which is parallel to the ground. This type of wind turbine is called a "windmill", the blades of which rotate against the wind. The design of horizontal wind turbines provides for automatic rotation of the main part (in search of wind), as well as rotation of the blades, to use low-strength wind.

Vertical wind turbines are less efficient. The blades of this installation rotate parallel to the earth's surface in any direction and strength of the wind. Since in any direction of the wind, half of the blades of the windmill always rotate against it, the wind wheel loses half of its power, which significantly reduces the energy efficiency of the installation. However, wind turbines of this type are easier to install and maintain, because its reducer and generator are placed on the ground. The disadvantages of the vertical generator are: expensive installation, significant operating costs, as well as the fact that the installation of such a wind turbine requires a lot of space.

In today's world, wind turbines are used to power many facilities with different requirements: from stand-alone micro wind turbines with a capacity of 0.04 to 0.25 kW to charge mobile phones to large commercial network wind turbines with a capacity of 7.5 MW, which are part of industrial wind farms. operating in centralized power systems. The choice of type and configuration of wind turbine usually does not depend on its individual technical and economic characteristics or design solutions, which is determined by the combination of its properties that meet the requirements of the facility for its power supply in specified climatic conditions. In this case, the criteria for selecting a wind turbine for different objects may be directly opposite.

Wind power plants (WPPs) are classified according to the following characteristics:

-by the type of energy produced;

-by power;

-by field of application;

-by appointment;

- by methods of management;

- by the structure of the energy generation system .

Depending on the type of energy produced, they can be divided into: mechanical and electrical. Mechanical wind turbines are divided into wind turbines and wind turbines. Electric wind turbines, in turn, are divided into DC and AC wind turbines. Electric DC wind turbines are wind chargers, guaranteed and non-guaranteed power plants. Electric AC wind turbines are divided into autonomous, hybrid and network.

Depending on the capacity, wind turbines are divided into four groups:

a) high capacity - more than 1 MW;

b) medium power - from 100 kW to 1 MW;

c) low power - from 5 to 99 kW;

d) very low power - less than 5 kW.

1.4 Design of wind turbines with horizontal axis of rotation

The main difference between wind turbines with horizontal and vertical axis of rotation is the location of the axis of rotation to the rotor. The axis of rotation of the rotor of horizontal wind turbines is located horizontally and coincides with the direction of wind flow. The horizontal-axial rotor converts part of the energy of translational movement of wind flow into energy of rotation and transmits torque to the multiplier, which increases the speed of rotation of the rotor shaft to the speed of the electric generator, which generates electricity Fig.1.4.

VC control involves the process of orienting the rotor axis in the wind direction. There are several types of orientation system:

1. Weather vane (tail) - is very accurate, simple in design, but has a high speed of rotation of the head, increases its weight, complicates balance.

2. Windroses - small windmills located perpendicular to the plane of rotation of the main windmill. The principle of operation is that when the wind is directed at an

angle to the axis of the VC, the winds begin to rotate. As a result, they turn the VC perpendicular to the wind

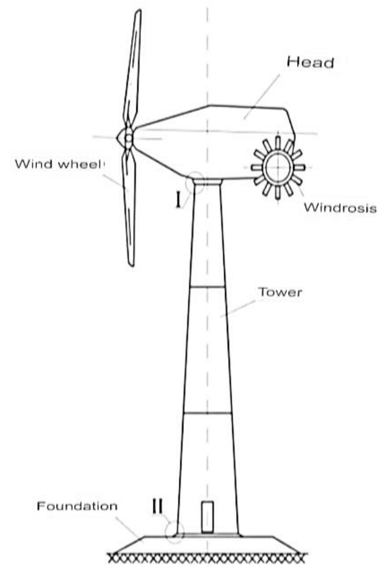


Figure 1.2 - Structure of a wind turbine with a horizontal axis of rotation

a)

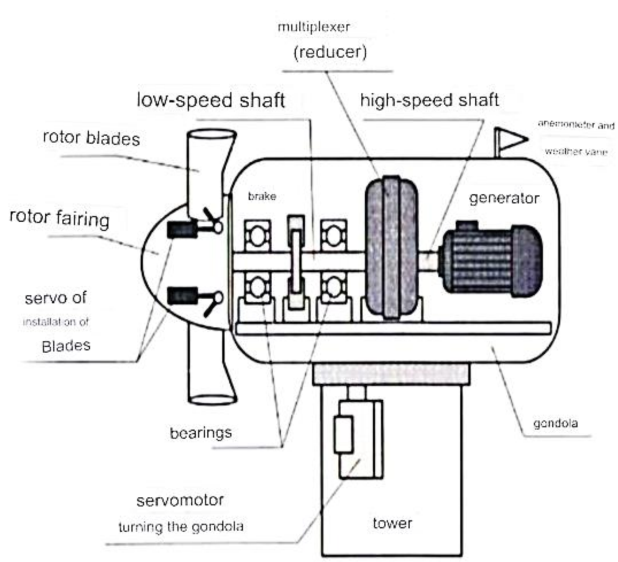


Figure 1.3 - The main elements of wind turbines

The rotor, multiplier, generator and part of other systems of horizontal-axial wind turbines form a common unit - the gondola (Fig. 1.3), which is located on the tower of the wind turbine. When the wind direction changes, the nacelle rotates, constantly ensuring the parallelism of the axis of rotation of the rotor and the speed of wind flow. This type of wind turbine currently dominates the global wind energy market.

For the most efficient operation of the wind turbine, its blades must interact as much as possible with the wind flow passing through the area of rotation of the VC. Wind turbines with a large number of blades are less efficient than a wind turbine with two or three blades, as the blades interfere with each other. The most widespread is the design of a wind wheel with three blades and a horizontal axis of rotation.

Blades are the busiest and most dangerous element of wind turbines. Cases of their separation and removal to a distance of several hundred meters have been recorded. This is due to sudden gusts of wind and premature wear. They experience wind loads, gravity, inertial loads. Different materials (fiberglass, steel, aluminum) are used for their production. The choice depends on many factors, such as weight, rigidity, price. Fiberglass is most often used.

Different materials are used to make gondolas. Previously, steel construction was used. In more modern wind turbines gondolas are made of fiberglass composite reinforced material. This choice of material is due to good sound insulation and protection against temperature changes. The cost of building the tower is about 20% of the cost of the entire wind turbine. As the length of the blades increases, the height of the tower increases and, accordingly, the output power of the wind turbine [20]. The higher the tower, the greater the load it is subjected to. The strength of the tower depends on the material of manufacture, for its production using steel or concrete.

1.5 Features of operation of wind turbines

Wind turbines are optimized so that they produce the most energy at the most probable wind speeds. And designing wind turbines for higher wind speeds would be economically inefficient, as high wind speeds are quite rare. But, nevertheless, there is a need to regulate all wind turbines in high winds. Otherwise, the rotor of the installation may be destroyed or the power transmission may be overloaded [19]. All this will lead to almost complete destruction of the wind turbine, as well as the danger of the surrounding objects and possible human injuries. Such emergency factors could be avoided by increasing the structural strength of the moving elements of the wind turbine, but then increase the mass and size characteristics,

In addition, during the operation of wind turbines in the generator there is a loss of energy, resulting in the release of heat. Although the efficiency of modern generators is very high, the absolute losses are quite large, which leads to a significant increase in the temperature of active steel, copper and insulation [20]. Increasing the temperature of structural elements, in turn, leads to their gradual destruction and reduced service life of the generator, in extreme cases - this can lead to fire of some elements of the generator [15]. In addition, the magnetic elements of the generator begin to lose their magnetic properties at high temperatures (over 150 ºC). Usually in industry and mechanical engineering to prevent this negative factor, various cooling systems are used [20]. But since the installation of a cooling system on wind turbines is economically and practically impractical,

The practice of operation of wind turbines has shown that at a certain speed can occur resonant oscillations of the mast and rotor. The resonant speed can be much lower than the speed limit. For example, for a vertical-axial installation with a power of 3 kW "VEU-3" resonant frequency occurs when rotating at 67 rpm and 120 rpm [14]. Although the maximum speed of rotation is 180 ... 200 rpm. The wind flow by its nature has a wavy characteristic, therefore, the wind power plant will accelerate or slow down (amplitude acceleration and deceleration jumps will be smoother than the wind flow, due to the inertia of the structure). As a result of constant acceleration and deceleration, the wind turbine will occasionally pass through a resonant speed. If the process of acceleration or deceleration of the rotor is relatively fast, the duration of stay in the resonant state will be short. However, if for some reason the change in rotor speed occurs at a low speed, the residence time of the installation in the resonance state increases.

Prolonged loads of resonant vibrations will lead to the destruction of the structure. It is known that the vibration effect reduces the durability of the unit, the destruction of bearings, cracking of the foundation, there is a radial beating - these negative effects lead to the destruction of wind turbines and create a danger during its operation [16].

Thus, for the safe and stable operation of wind turbines, it is necessary to equip them with control and emergency braking systems to prevent the occurrence of the negative factors listed above.

1.6 Conclusions to the section

This section analyzes the wind energy potential of Egypt. It is shown that Egypt has a high wind energy potential, and the use of wind is a promising area in the electricity sector. Based on the variety of types of wind turbines, it is important to develop a simulation model of a wind turbine, which would allow to study its energy characteristics.

2 CALCULATION AND RESEARCH SECTION

2.1 Justification of the choice of software for the development of a simulation model of a wind farm

Modeling the operation of a wind power plant is an important scientific and practical step for the analysis and synthesis of efficient operation of industrial wind power plants. Modern wind turbines are a complex technical and physical system consisting of mechanical, electrical and hydraulic elements. The source of energy for wind turbines is wind, the parameters of which change for each moment of time. The transition from the actual design of the wind turbine to the appropriate mathematical model is necessary to optimize its operating parameters. The main task of the model is to reproduce real physical processes of wind turbines with an acceptable degree of reliability. At the same time it is possible to better understand the essence of the processes taking place, to get an objective idea of quantitative and qualitative patterns for their further forecasting in terms of changing various parameters of wind turbines.

The MATLAB \ Simulink environment provides a variety of capabilities, from structural (mathematical) representation of the system to real-time system layout.

As a result of using Simulink elements to model the device, we obtain a simulation model. Under the simulation model is usually understood as a formal description of the logic of the system under study and the interaction of its elements over time, taking into account the most significant causal relationships and properties of the system. The resulting "virtual device" will allow you to conduct all stages of the study inherent in the experimental sample.

MATLAB is currently one of the most advanced programming systems for scientific and technical calculations, supplemented to date by dozens of more private applications related to computational mathematics, information processing, electronic instrument design, economics and a number of other sections of applied science.

The use of simulation methods at the design stage of complex systems can not only significantly reduce the cost of research, development and testing, but also significantly reduce the time of product development [21].

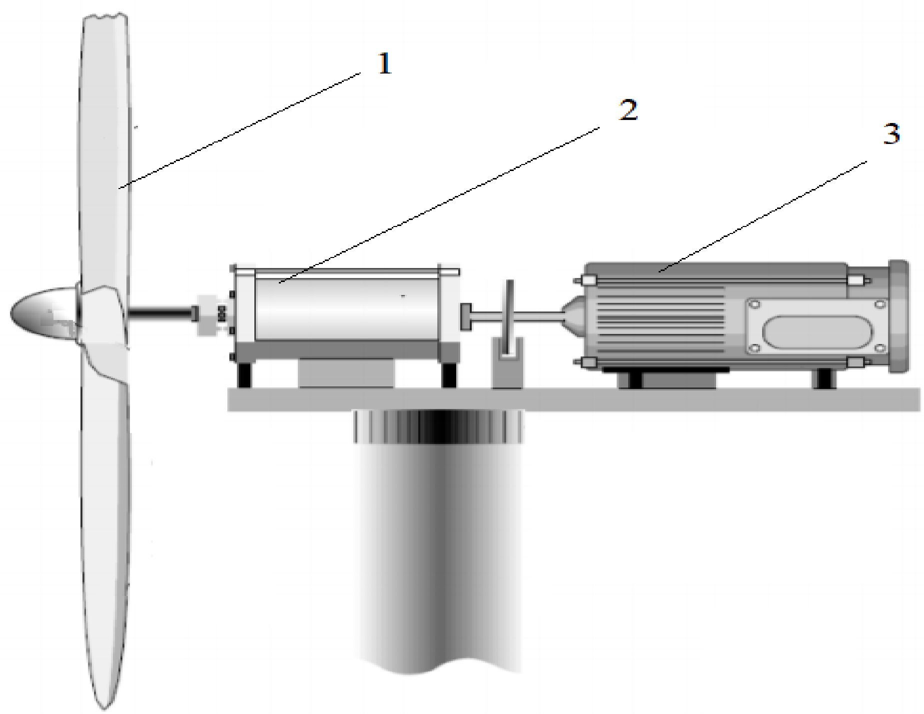


Figure 2.1 - The main elements of the wind turbine model

The model of wind power plant (Fig. 2.1) consists of the following components: wind wheel -1, reducer - 2, electric power generator –

3.The wind wheel is a converter of wind energy into mechanical energy of rotation. It includes a wind turbine design element consisting of blades, wings or other parts that perceive the flow of air and convert the energy of this flow into rotational motion, which is transmitted to the gearbox for further conversion of mechanical energy.

Reducer - a device for transmitting mechanical torque from the wind wheel to the generator of electric energy.

Electric generator - an electric machine that converts the mechanical energy of rotation of the shaft into electrical energy.

2.2 Mathematical description of the wind wheel model

Since the wind turbine is a converter of mechanical wind energy into electrical energy, it is first necessary to determine the energy itself, the wind. Wind energy is the kinetic energy of a large number of air particles with a total mass M moving at speed v. Assume that the wind moves with the same speed and direction to hit the blades of the wind wheel (WW), then the kinetic energy of the wind can be given by the expression [24]:

$$E = \frac{Mv^2}{2} \qquad (2.1)$$

where E - kinetic energy of air particles,

M - mass of air particles,

v - wind speed.

Mass of air particles M per unit time t what falls on the turbine blade is determined by the expression:

$$M = \rho A v t = \rho \pi r^2 v t \qquad (2.2)$$

where ρ - air density,

r - rotor radius.

Substituting expression (2.2) in (2.1), we obtain the expression for determining the kinetic energy of wind.

$$E = \frac{\rho \pi r^2 v^3 t}{2} \tag{2.3}$$

Then the wind power at the time t defined as:

$$P_в = \frac{E}{t} = \frac{1}{2}\rho \pi r^2 v^3 \tag{2.4}$$

where, R_v - wind power.

From the given equation (2.4) the power is directly proportional to the cube of wind speed and directly proportional to the square of the radius VK.

The power in equation (2.4) is the total wind power. Because after hitting the blades of the wind wheel, the wind speed decreases. This means that the wind wheel can only capture part of this power.

Capacity factor is the ratio of the power captured by a windmill P_k, to maximum wind power.

$$C_p = \frac{P_k}{P_в}. \tag{2.5}$$

It can be expressed as;

$$C_p = c_1\left[\left(\frac{c_2}{a} - c_3\beta - c_4\right)e^{-c\frac{c_5}{a}} + c_6\lambda\right], \tag{2.6}$$

where the values of the coefficients (c1, c2, c3, c4, c5, c6) depend on the shape and type of wind wheel, and

$$\frac{1}{a} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{1+\beta^3} \tag{2.7}$$

Here β is the angle between the plane of rotation of the windmill and the chord of the wing, λ is the coefficient which is defined as the ratio between the angular velocity of the rotor and the wind speed. But can be determined by equation [29]:

$$\lambda = \omega_t r / v \qquad (2.8)$$

where ω_k - angular speed of the rotor,

When developing a model of wind turbines in the first place are the tasks of determining the basic parameters of the windmill. Namely, the dependence of Capacity factor on the angle of the blade. For a three-bladed wind wheel with a horizontal axis of rotation, the values of the coefficients will be as follows;

c1 =0.5176, c2 = 116, c3 = 0.4, c4 = 5, c5 = 21, c6 = 0.0068.

The block diagram of the joint solution of equations (2.6), (2.7) is shown in Fig. 2.2

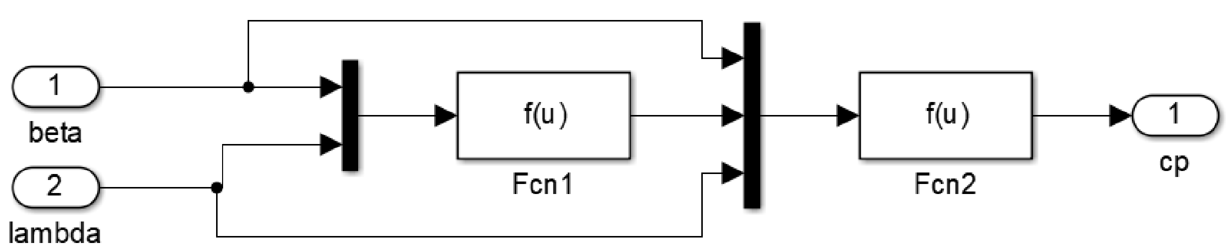


Figure 2.2 - Block diagram of the model to determine the capacity factor

Fcn- function setting unit. Specifies the expression used by the unit to calculate the output signal based on the input. With the help of this unit, the power factor of the wind wheel is calculated, as well as the coefficient $1/a$. The input parameters for the model are the angle of the blade and the coefficient λ and the initial wind energy utilization factor C_p.

The results of modeling the dependence of the coefficient of use of wind energy on the speed of the wind wheel are shown in Fig.2.3.

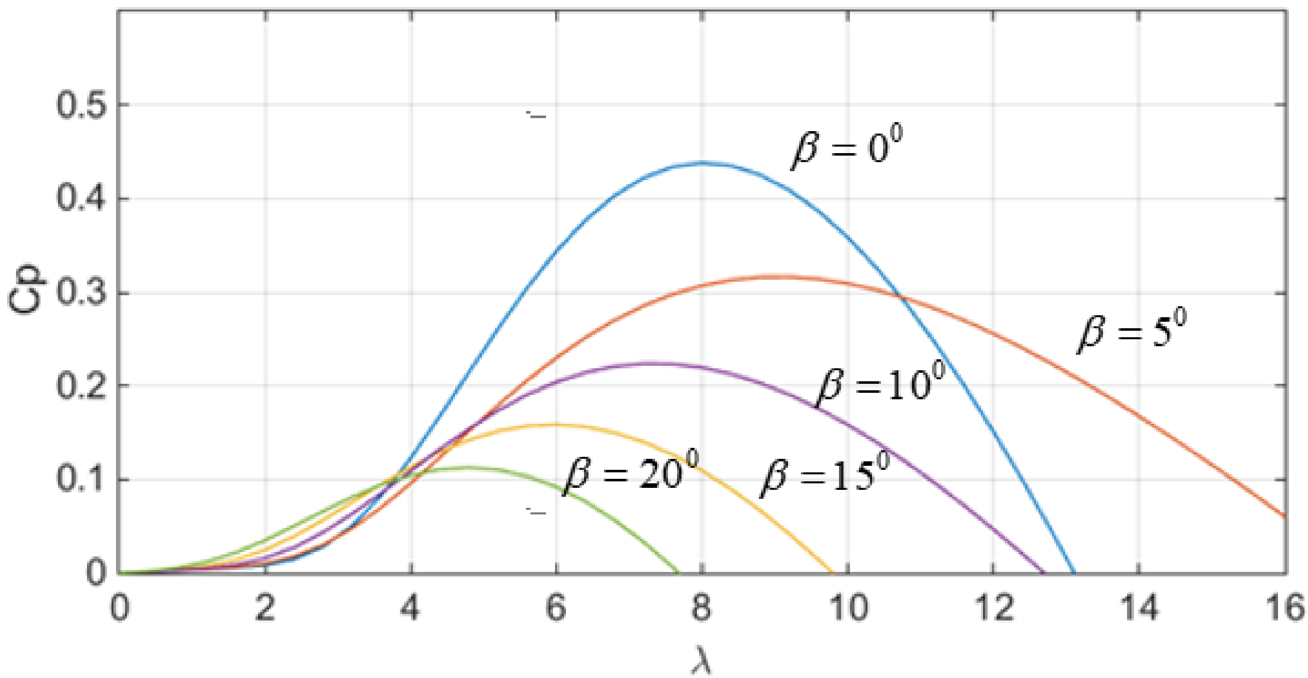


Figure 2.3 - Dependence of the efficiency of the wind turbine on the speed for different values of the angle β

The wind energy utilization factor has a maximum value for each value of the angle of inclination. When the angle of inclination is zero, the blade is completely affected by wind speed, and the wind wheel captures the maximum wind power.

For this design of the wind turbine Cp does not exceed 0.43.

The wind wheel is used to convert the kinetic energy of wind into mechanical. The wind passes over the blades, begins to rotate them. The blades of the wind wheel rotate the shaft, which enters the gearbox. A simulation model of a wind turbine was developed to calculate the mechanical moment of the wind wheel.

Figure 2.4 shows a block diagram of a wind turbine, which is a common solution of equations (2.4), (2.8).

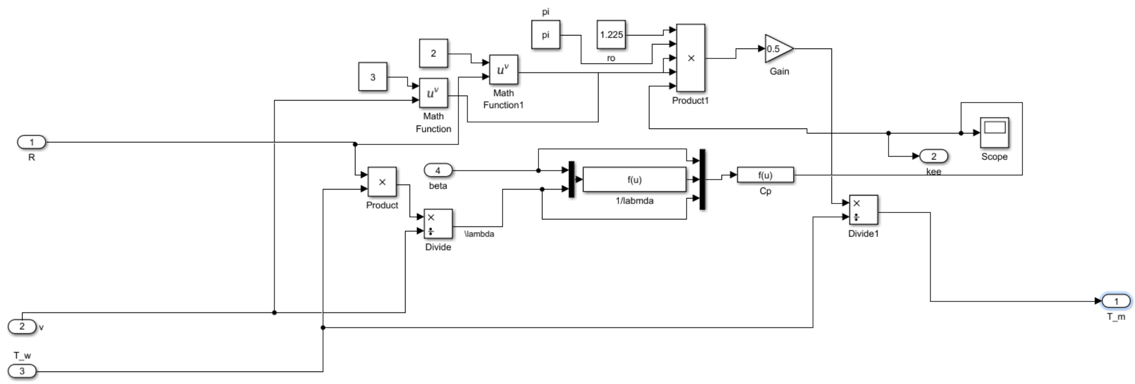


Figure 2.4 - Block diagram of a simulated model of a wind turbine

The input parameters of the model are wind speed, rotor speed, and the output is the mechanical torque of the wind turbine.

The Product block multiplies or divides the input signals. This block outputs results using either element-by-element or matrix multiplication, depending on the parameter value.

Avoid division by zero- a block that prohibits division by 0.

Block func1 - calculates the power of the wind turbine.

cp (lambds, beta)- subsystem that implements the model of the efficiency factor of the wind wheel fig. (2.2).

The electromagnetic power of the generator connected to the wind wheel is determined primarily by the power supplied from it. When designing wind turbines, it is necessary to agree on the operating characteristics of the wind wheel and generator. These characteristics reflect the change in power that develops the VC and converts the generator depending on the speed. The following characteristics for the 1.6 m VC model are shown in Figure 2.5.

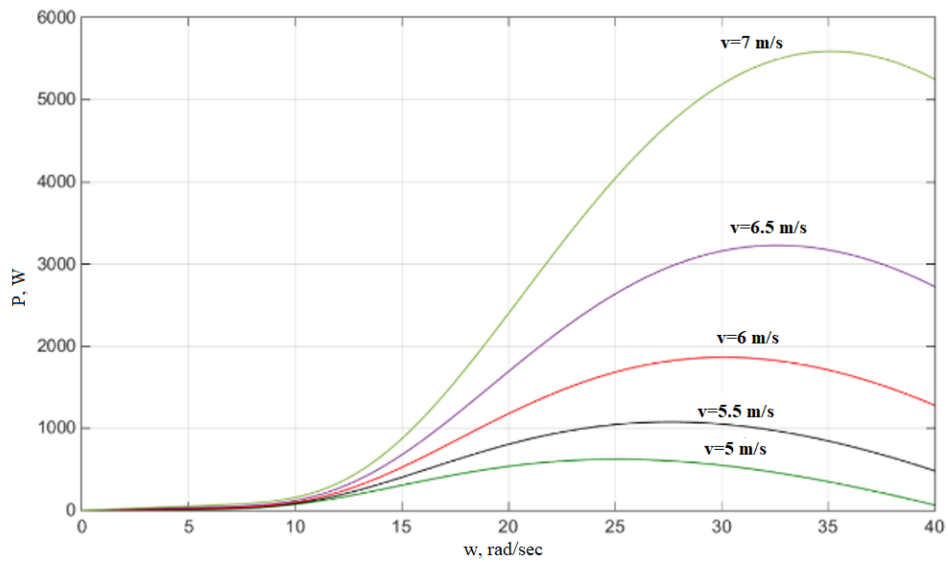


Figure 2.5 - Characteristics of wind wheel power from speed for different values of wind speed, at $\beta = 0^0$

The figure shows the power dependences of the wind wheel for different wind speeds. The maximum power of wind wheel at constant wind speed is reached at a certain speed. This power will be fully absorbed by the generator if its load corresponds to this power and is achieved at a given speed wind wheel. This is possible if the gear ratio and the drive element of the mechanical transmission provides such a number of revolutions of the generator, at which the power dependence curve passes through the top of the power curves wind wheel. At inflated values *i* wind turbines will be unstable. At low values *i* wind turbines will operate in underloaded mode.

2.3 Selection and calculation of the generator

Analysis of different types of electric machines suitable for use in wind turbines shows that the choice of type and design of the generator is not clear [14; 15; 22]. There are three main types of generators used in wind turbines. These are DC generators, synchronous generators, asynchronous generators.

Each of the above types of generators can operate both at a fixed wind speed and at variable. We compare the specifics of the use of these types of generators in their use in wind turbines.

DC generator.

In DC machines, the magnetic field occurs in the stator. The rotor is an anchor. The stator has distinct poles that are excited either by permanent magnets or by an electromagnet having a DC winding. Quite often this winding is connected in parallel to the armature - then it is a DC generator with parallel excitation.

In a DC generator with parallel excitation, the current is magnetized, therefore, the magnitude of the magnetic flux depends on the speed of rotation of the wind wheel. The actual speed of the rotor of the DC machine is determined by the balance between the torque generated by the wind and the braking moment of the load. As the load increases, the magnitude of the magnetic flux will decrease, which will reduce the magnitude of the EMF produced.

Another significant disadvantage of the DC generator is the presence of a collector-brush device. During operation, DC generators require regular maintenance and replacement of brushes. Therefore, the operation of DC generators itself due to the presence of switches and brushes is relatively expensive.

In general, the use of DC generators in wind turbines is impractical. An exception may be receivers with low power consumption. For example, these are battery chargers or power sources for the autonomous heating system of an individual building.

Synchronous generator.

This type of electric machines is most often used as generators in power plants in general and in windmills in particular. Their main advantage is the ability to generate not only active but also reactive power. Designs of synchronous generators are different: explicit and non-explicit. They also differ in the excitation system. For wind turbines, the use of excitation from a DC source is not promising. Because in this case we will have all the shortcomings of the system with contact rings and brushes. It is preferable to use a circuit of generators on permanent magnets or a circuit with contactless electromagnetic excitation.

Recently, synchronous generators on permanent magnets (SGPM) are increasingly used in wind turbines. Neodymium permanent magnets are currently the strongest permanent magnets on the market. In addition, in the wind turbine with SGPM it is important that you do not need to use self-excitation systems.

Because it provides higher performance due to higher efficiency, it is possible to get more power, the structure is strong and stable, as it has magnets on the rotor and no brushes. The structure of SGPM is relatively simple. “Strong permanent magnets are mounted on the rotor to create a permanent magnetic field, and the generated electricity is removed from the armature (stator) through the use of collector, contact rings. Permanent magnets can be installed in a cylindrical rotor made of cast aluminum to reduce costs. The principle of operation of generators on permanent magnets is similar to a synchronous generator except that generators on permanent magnets can work asynchronously "[35, 42] The advantage of SGPM is that they have no collector, contact rings and brushes, so machines are strong, reliable and simple .

It is advisable to use these machines with permanent magnets for direct use in wind turbines. SGPM has minimal friction losses, long service life, no noise and vibration during operation. Obviously, in this case, the synchronous generator on permanent magnets is advantageous to use for wind turbines.

Asynchronous generator.

"Asynchronous generator, has a simple design, reliability in maintenance, low cost compared to SGPM. The use of asynchronous generator (AG) in wind turbines was previously less common due to the lack of small capacitors that provide excitation of the generator and compensation of reactive load power, as well as the difficulty of stabilizing the output voltage. With the advent of more compact capacitors and new voltage stabilization systems, these problems have been solved "[26].

This type of generators can be used only with devices that do not have high starting currents and are resistant to small voltage drops. Such generators are cheaper than synchronous and have a higher class of protection against external influences.

Depending on the type of winding, there are short-circuited and phase rotors. The magnetic field created by the auxiliary stator winding induces a magnetic field on the rotor, which, rotating together with the rotor, induces EMF in the working stator winding. The rotating magnetic field always remains unchanged and cannot be adjusted, so the frequency and voltage at the output of the generator depend on the speed of the rotor, which in turn depends on the stability of the VC of the wind farm.

The choice of generator depends on the type of connection of the wind turbine to the network. In the case of stand-alone wind turbines where the energy produced by the generator is used to charge the battery, it is best to use generators with permanent magnets as they do not require the use of additional expensive rectifiers and voltage stabilizers. In the case of direct connection of the wind turbine to the network, the use of generators on permanent magnets introduces the need to install powerful inverters, which in turn leads to a significant increase in the cost of the structure as a whole and is impractical. With this type of wind turbine connection, cheaper asynchronous generators are usually used.

According to the results of the study, asynchronous generators are gaining popularity in the design of wind turbines.

For further modeling of wind turbines, an asynchronous machine with a short-circuited rotor of the AIR 132M8 brand was selected, the technical characteristics of which are given in Table 2.1.

Table 2.1. Technical parameters of AG AIR 132M8

Rated current at 380 V	Power	Speed of rotation	Efficiency	$\cos\varphi$	$\frac{M_{пуск}}{M_н}$	$\frac{M_{макс}}{M_н}$	$\frac{I_{пуск}}{I_н}$	Dynamic moment of inertia
13.6 A	5.5 kW	720 rpm	83	0.74	1.9	2.0	6	0.0935

2.4 Mathematical model of an asynchronous machine in Simulink environment

The wind turbine model uses a virtual model of an asynchronous machine with a short-circuited rotor Asynchronous Machine SI Units from the SimPowerSystem library of the MATLAB / Simulink package.

The electrical part of the model in coordinates (dq) is described by the equations:

$$V_{qs} = R_s i_{qs} + \frac{d\varphi_{qs}}{dt} + \omega\varphi_{ds},$$

$$V_{ds} = R_s i_{ds} + \frac{d\varphi_{ds}}{dt} + \omega\varphi_{qs},$$

$$V'_{qr} = R'_r i'_{ds} + \frac{d\varphi'_{ds}}{dt} + (\omega - \omega_r)\varphi'_{dr},$$

$$V'_{dr} = R'_r i'_{dr} + \frac{d\varphi'_{dr}}{dt} - (\omega - \omega_r)\varphi'_{qr},$$

The equations are used for flow splitting:

$$\varphi_{qs} = L_s i_{qs} + L_m i'_{qr},$$

$$\varphi_{ds} = L_s i_{ds} + L_m i'_{dr},$$

$$\varphi'_{qr} = L'_r i_{qr} + L_m i_{qs},$$

$$\varphi'_{qs} = L'_r i_{ds} + L_m i_{qs},$$

where $L_s = L_{ls} + L_m$, - total stator inductance;

$L'_s = L'_{lr} + L_m$, - total inductance of the rotor;

L_m - inductance of the magnetization link;

L_{ls} and L'_{lr} - scattering inductance of each phase.

The electromagnetic moment is defined by the expression:

$$T_a = \left(\frac{3}{2}\right)\left(\frac{p}{2}\right) L_m (i_{qs} i_{dr} - i_{ds} i_{qr}),$$

where T_e is the electromagnetic moment.

$$T_d = T_e + J\left(\frac{2}{p}\right)\frac{d\omega}{dt},$$

where Td- input torque on the shaft AG;

J - moment of inertia;

P - number of poles.

The graphic image of the AG block is shown in fig. 2.6.

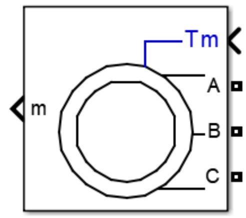


Figure 2. 6 - Graphic representation of the Asynchronous Machine SI Units block

The input signal Tm is designed to transmit torque from the gearbox, which in turn is associated with the mechanical torque of the wind wheel. If the input signal is positive the asynchronous machine operates as a motor. If negative - as a generator of electricity. Terminals A, B, C are used to connect to three-phase voltage. Port m is a measuring on which the vector of signals is formed, consisting of 10 elements:

1-3 - stator winding currents;

4-5 - projections of the stator current on the axis q and d ;

6-7 - projections of the stator voltage on the axis q and d ;

8 - rotor speed;

9 - rotor rotation angle;

10 - electromagnetic moment.

2.5 Determining the parameters of the asynchronous generator according to the catalog

Nominal slip:

$$s_н = \frac{n_s - n_н}{n_s},$$

where n_s - synchronous speed;

$n_н$ - rated engine speed.

Critical slip:

$$s_k = (m_{\max} + \sqrt{m_{\max}^2 - 1})s_н,$$

where $m_{\max} = M_{\max} / M_н$ - the ratio of the maximum moment (critical) to the nominal moment.

Construction factor:

$$c_1 = 1 + \frac{L_{1s}}{L_m}.$$

The pre-design factor is set in the range $c_1 = 1.02...1.05$ to calculate the parameters of the substitution scheme. Refinement of the calculation occurs after obtaining numerical data of inductors. The process of selecting the design factor lasts three to four iterations.

Coefficient of viscous friction:

$$B_m = \frac{\Delta P_{мех}}{(2\pi n_н / 60)^2}.$$

Mechanical losses. If we assume that total losses consist of constant and variable losses, and constant losses are approximately equal to 1/3 of total losses, and mechanical losses are half of constant losses, then mechanical losses $\Delta P_{мех}$ are determined by the expression:

$$\Delta P_{мех} = P_н \left(\frac{1}{\eta_н} - 1 \right) \frac{1}{6}.$$

Sum $P + \Delta P_{мех}$ can be defined as

$$P_н + \Delta P_{мех} = P_н \left[1 + \left(\frac{1}{\eta_н} - 1 \right) \frac{1}{6} \right]. \quad (2.9)$$

Stator resistance:

$$R_s = \frac{1}{2} \frac{U_н^2 (1 - s_н)}{c_1 (1 + c_1 / s_k) m_k (P_н + \Delta P_{мех})}, \quad (2.10)$$

where $m_k = M_k / M_н$ - multiplicity of starting torque (catalog parameter).

Rotor resistance:

$$R_r = \frac{1}{3} \frac{(P_н + \Delta P_{мех}) m_k}{(1 - s_н) i_k^2 I_н^2},$$

where $i_k = I_k / I_н$ - the ratio of short-circuit current (starting) to the rated current.

Stator and rotor inductance:

$$L_s \cong L_r = \frac{1}{2\pi f_н} \frac{U_н / \sqrt{3}}{I_н \left(\sqrt{1 - (\cos\varphi_н)^2} - \cos\varphi_н s_н / s_k \right)}. \quad (2.11)$$

Stator and rotor scattering inductance:

$$L_{ls} \cong L_{lr} = \frac{1}{4pf_н} \sqrt{\left(\left(U_н / \sqrt{3} \right) / (i_k I_н) \right)^2 - \left(R_s + R_r \right)^2}. \quad (2.12)$$

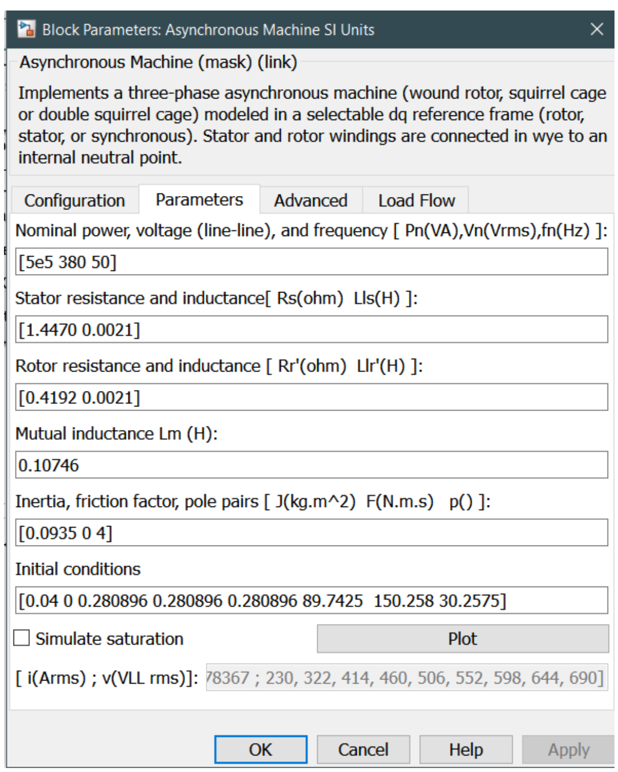
Mutual induction:

$$L_m = L_s - L_{ls}.$$

A program in Matlab was developed to calculate the parameters of AG substitution according to expressions (2.19) - (2.29). The input data are the parameters of the asynchronous machine according to the manufacturer, and the output; stator resistance and inductance, rotor resistance and inductance, mutual induction.

```
PH=5500; UH=380; f=50; n=720; eff=0.83; cosfi=0.74;
IH=13.6; ik=6; mk=1.9; mmax=2.0; J=0.0935; p=4;
 Uf=UH/1.73; n1=60*f/p; sn=(n1-n)/n1;
sk=(mmax+sqrt(mmax^2-1))*sn;
 w1=2*pi*f; w=pi*n/30; MH=PH/w;
 for c=1:0.01:1.08;
 Rr=(1.015*PH)/(3*IH^2*((1-sn)/sn));
 Rs=((Uf*cosfi*(1-eff))/IH)-(Rr*c^2)-(0.015*PH/(3*IH^2));
 LI=Uf/(2*w1 *( 1 +c^2)*ik*IH);
 Ls=Uf/(w1 *IH*sqrt( 1 -cosfi^2)-(2*w1
*mmax*MH*sn/p)/(3*Uf*sk));
 Lm=Ls-LI;
 c1 = 1+LI/Lm;
 [Rs Rr LI Lm c c1]
end
```

The window of parameters of the asynchronous generator with a short-circuited rotor of the AIR 132M8 brand in the Simulink environment is shown in fig. 2.7.



Drawing. 2.7 - Asynchronous generator parameters window

2.6 Self-excitation of an asynchronous generator

To excite a working asynchronous generator, it is necessary to have a source of reactive power - a battery of capacitors connected to the stator winding. Modern methods of self-excitation of hypertension using static capacitors are based on three approaches. One of them is based on the principle of residual magnetization of the magnetic branch of the machine, the initial EMF from which is then amplified by the capacitive current in the stator.

Autonomous operation of AG in the self-excitation mode from the residual magnetization flow is possible if capacitors are connected to the stator winding terminals as a source of reactive power Q_L to excite the AG magnetic field, and when operating on active-inductive load Fig. 2.10.

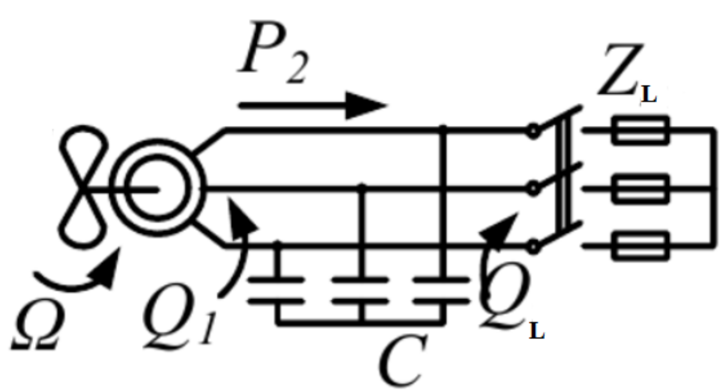


Figure 2.10 - Scheme of capacitor excitation of an asynchronous generator

This current, being capacitive, flowing through the stator winding, magnetizing the AG, amplifies the Fz, which leads to an increase in the EMF Ez, a further increase in current and current (Fig. 2.11, a).

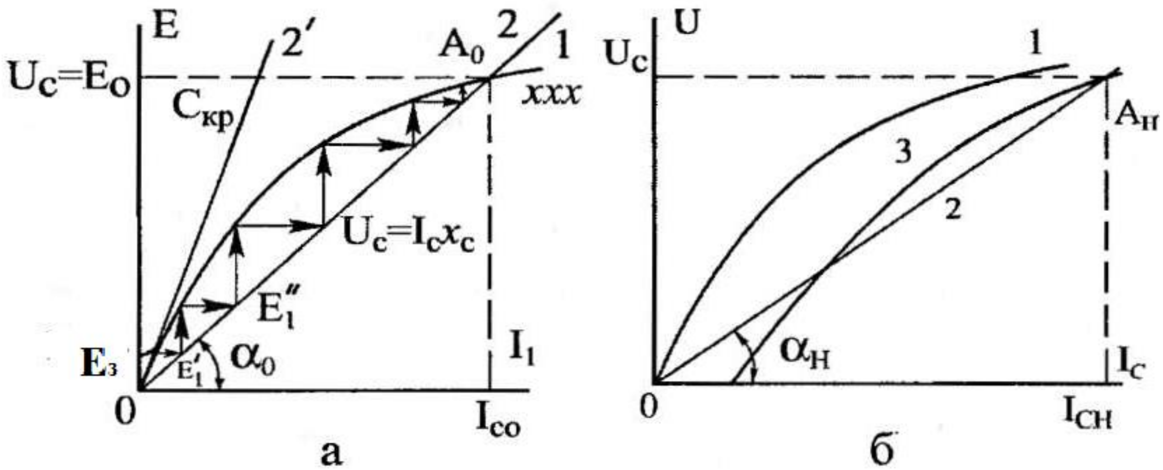


Figure 2.11 - The process of self-excitation of an asynchronous generator from a capacitor bank

Completion of the self-excitation process corresponds to the point Ao which is the intersection of the no-load characteristic of the AG and the volt-ampere characteristic of the capacitor bank (I_{CS}). In this case, the electromotive force is equal to Eo and the stator current IC0.

The voltage on the generator depends on the capacitance of the capacitors: the smaller the capacitance C, the greater the angle α_0. At low SCR capacitance values, the ICS characteristic does not intersect with the idling characteristic and the generator is not excited.

In some cases, the beginning of the process of self-excitation of the AG can be provided by discharge to the winding of a pre-charged capacitor bank.

Angle α_0 determined by the ratio

$$tg\alpha_0 = \frac{U_0}{I_{c0}} = \frac{x_{c0} I_{c0}}{I_{c0}} = x_{c0} = \frac{1}{\omega_1 C_0} \qquad (2.13)$$

Self-excitation of AG under load requires an increase in capacity C, as shown in Fig. 2.11, b, where curve 3 is the ability to load characteristic of the AG. Point An is the end point of self-excitation. With,

$$tg\alpha_н = \frac{U_c}{I_{сн}} = \frac{1}{\omega_1 C_н} \qquad (2.14)$$

Because $tg\alpha_0 > tg\alpha_н$ then $C_н > C_0$.

The reactive power of the capacitors is determined by the sum of the reactive powers of the generator Qr and the load Q_H,. In this case, the reactive power of the capacitor bank is determined from the expression

$$Q_c = P_н(tg\varphi_r + tg\varphi_н). \qquad (2.15)$$

If the capacitance of the capacitors is determined by the direct method, then use the passport data of the AG. This method does not require complex calculations, so it is practical if you know the nominal values of voltage, current, power factor and frequency.

$$C = \frac{I_н \sin\varphi}{2\pi U_н f_н}, \qquad (2.16)$$

2.7 Selection of the gearbox and development of its model

"Wind, as an alternative source of energy, has recently become increasingly popular. One of the most important characteristics that determine the value of this natural phenomenon is its direction and speed. But with the instability of natural conditions have to resort to various techniques to eliminate existing problems. One of such problems in wind energy is the low speed of rotation of the wind wheel, and the larger its dimensions, the more pronounced this shortcoming. The solution may be a reducer or multipliers "[5-10].

Wind turbines are divided into two types: reducer (connection of the rotor with the generator through the reducer) and gearless (with a direct connection of the generator and VC).

Consider the benefits of gear wind turbines:

- Allow to receive big moments on unit of weight;
- Low cost.

Disadvantages:

- Low efficiency;
- Short service life;
- Create a high noise level;

Advantages of gearless wind turbines:

- Low noise level;
- Can operate at low wind speeds;
- Durable in use;
- The design allows to avoid the losses characteristic of reducer wind power plants;

Drawback:

- The high price;

Despite the simple principle of operation, gearboxes are a complex mechanical device for transmitting and converting mechanical power.

Reducers come in different types of transmission:

Cylindrical - the most common type of gearbox. They are characterized by high efficiency (95-98%) and long service life. The efficiency of such a gearbox depends on the gear ratio. Such reducers should be used in low-power wind turbines that have a short wind wheel length.

Worm - the gearbox is called worm-type worm gear, which is located inside the gearbox, which transmits and converts torque. Such gearboxes have a high gear ratio, high heat dissipation and relatively low efficiency. This type of gearbox is not used at high loads.

Planetary - are characterized by high nobility to withstand loads, have low weight, and relatively small size, as well as to obtain a large gear ratio.

Conical - this type of gearbox is used if there is a need to change the direction of kinetic transmission. The conical reducer has the following parameters: low circumferential speed, average level of reliability, accuracy and metal consumption, relatively low cost and complexity. Can work continuously at high speeds.

Combined - is a combination of gears and worm gears. They have a favorable ratio of technical characteristics, dimensions and cost.

In gearless wind turbines, the installation of an electromagnetic rotor suspension is envisaged. This allows you to ensure: increase the wear resistance of work surfaces, reduce vibration, noise, energy loss due to friction.

According to preliminary calculations, the maximum power of the VC is 5500 W, at a wind speed of 7 m / s. In this case, its speed is equal $\omega_k = 35$ rad / s. According to the passport data AG rotor speed $n = 720$ rpm then its frequency will be $\omega_g = \dfrac{2\pi \cdot n}{60} = 75.397$ rad / s. Therefore, to increase the angular velocity of the generator, choose a cylindrical gearbox. Gear ratio i will be determined:

$$i = \frac{\omega_k}{\omega_g} \text{ or } \omega_k = i \cdot \omega_g \tag{2.17}$$

To simplify further calculations, we assume that the losses in the gearbox are zero. Then,

$$P_k = P_н \tag{2.18}$$

or,

$$\omega_k T_k = \omega_g T_g \tag{2.19}$$

where, T_k, and T_g - mechanical torque of the windmill and generator, respectively. Given the expressions (2.36) and (2.34), we obtain:

$$T_g = i \cdot T_k \tag{2.20}$$

The block diagram of the simulation model of the gearbox is shown in Fig. 2.12.

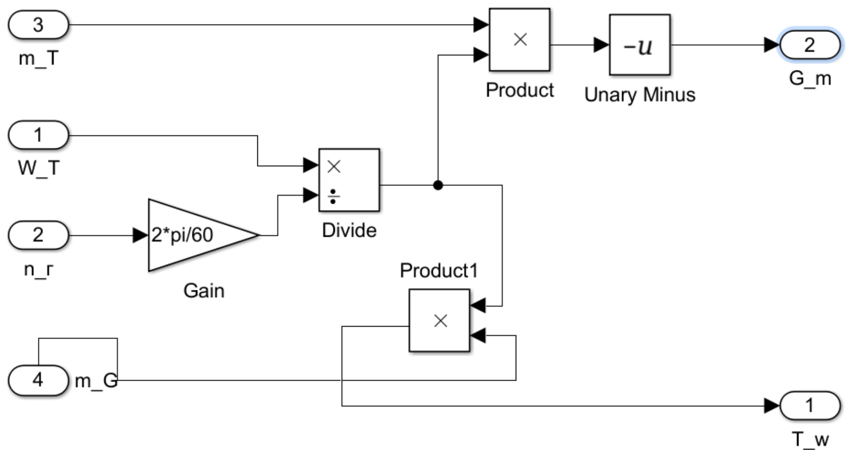


Figure 2.12 - Block diagram of the simulation model of the gearbox.

The input parameters of the block diagram are; mechanical moment of the wind wheel, frequency of the generator, nominal frequency of the wind wheel, nominal speed of the rotor. The output is the mechanical torque of the generator and the frequency of the wind wheel.

The Gain unit converts the units of measure (rpm to rad / s).

Unary Minus- multiplies the input signal by -1, thereby giving a negative value of the mechanical torque to the generator.

2.8 Conclusions to the section.

As a result of work on development of computer models for simulation modeling in the MATLAB / Simulink environment universal models of elements of wind power plant were created.

1. A module of a three-bladed wind turbine of a wind power plant has been developed, which converts wind energy into mechanical energy of wind turbine shaft rotation. It is shown that the maximum value of the wind energy utilization factor VC of this design does not exceed 0.43.

2. The calculation of parameters for the model of an asynchronous generator with a short-circuited rotor based on an asynchronous machine brand AIR 132M8.

3. A model of mechanical transmission has been developed, which transmits mechanical energy from the wind turbine to the electric energy generator. What is the intermediate link between the wind turbine and the generator, which increases the speed of the generator shaft and provides coordination with the speed of the wind wheel.

3 PROJECT DESIGNING SECTION

3.1 Presentation of a mathematical model of a wind turbine in the environment MATLAB \ Simulink.

The simulated visualized mathematical model of a wind turbine module with an asynchronous generator is presented in Fig. 3.1.

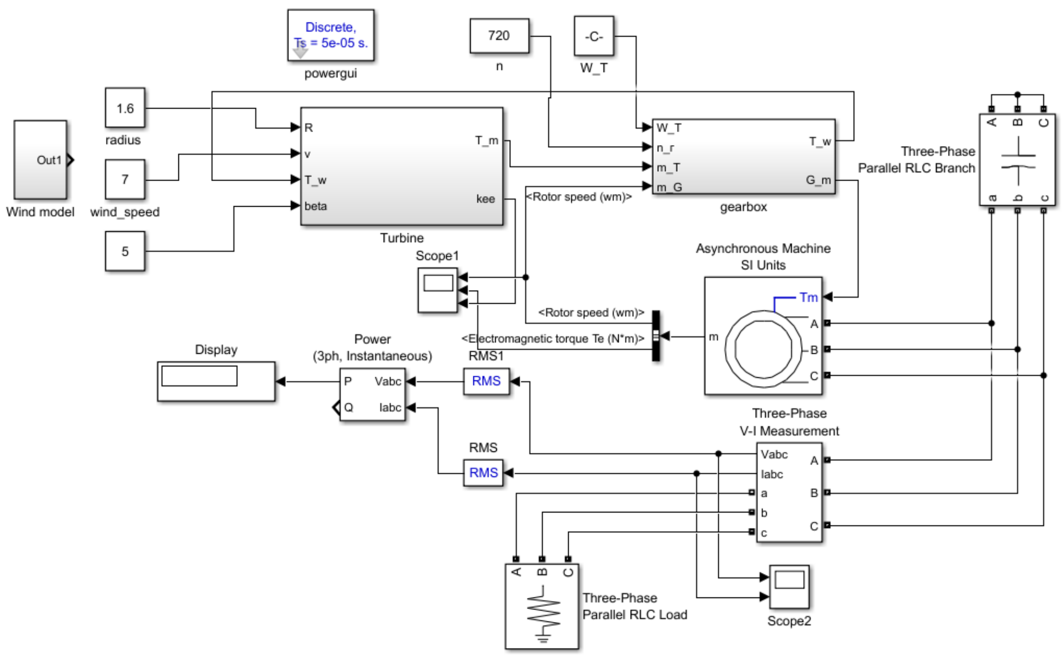


Figure 3.1 - Model of wind power plant

The wind turbine model consists of the following blocks:

Asynchronous Machine SI Units- model of asynchronous machine from SimPowerSystems library, Detailed description of which and its parameters are made in section 2.

Three-Phase Parallel RLC Branch- Simulates a three-phase circuit consisting of three RLC links. The link configuration may have the following parameters: RLC, R, L, C, RL, RC, LC. In this case, the unit is configured as a capacitor, excitation of an asynchronous generator. All capacitors have the same rating, with a capacity of 119 uF.

Machines Measurement Demuxdesigned to extract machine variables from the output vector of the measured parameters. In this block, the type of machine is selected and, depending on the type, the required parameters are marked in the parameter window.

Three-Phase Series RLC Load- three-phase serial RLC load. The unit simulates a three-phase circuit consisting of three consecutive RLC loads. The connection scheme of the links may be different. The parameters of the links are set through the power of the phases at rated voltage and frequency. In this model, only an active load of 5 kW is selected

RMS- the value calculates by expression (3.1) the current value of current or voltage that enters its input.

$$RMS(f(s)) = \sqrt{\frac{1}{T}\int_{t-T}^{t} f(t)^2\,dt}$$

where, $f(t)$ - input signal;

T - the period of the fundamental harmonics of the signal.

Only the fundamental frequency of the signal is entered in the settings window.

Three- Phase VI Measurement -three-phase meter. Measures currents and voltages in three-phase circuits in SI units.

3-phase Instantaneous Active & Reactive Power- unit for calculating the instantaneous values of active and reactive power in three-phase circuits by the magnitude of currents and voltages supplied to its input. In this case, the inputs of the unit are fed to the vectors of linear voltage and currents. At the output of the unit, a vector is formed, the first component of which is the active power consumed by the load, and the second is reactive. The block settings window has no parameters.

Calculation of reactive power is possible only in the case of symmetrical load and the absence of harmonics in the curves of current and voltage. The calculation is carried out according to the formulas;

$$P = \sqrt{3}\frac{1}{T}\int_{t-T}^{t} V(\varphi t)\cdot I(\varphi t)dt;$$

$$Q = \sqrt{3}\frac{1}{T}\int_{t-T}^{t} V(\varphi t)\cdot I(\varphi t - \frac{\pi}{2})dt,$$

where, P - active power in W;

Q - reactive power in Var;

T - period in 1 / s;

V - current voltage value. IN;

I - current value of current, A;

φ - phase shift angle, deg ;

t - time of calculation, p.

Scope- oscilloscope. Designed to plot the studied signals over time. Allows you to monitor changes in signals during the simulation process.

Display- digital display. Displays the signal value as a number.

Powergui- graphical user interface of the energy systems modeling package. It is part of the SimPowerSystems package. This block is a graphical user interface tool for many tasks. In particular:

- calculation of schemes by a complex method;
- steady state calculation;
- model sampling;
- setting initial conditions;

- initialization of three-phase circuits containing electric machines, so that the calculation began with the steady state;
- circuit analysis using the Simulink LTI-Viewer tool;
- determination of impedance (impedance) of the circuit;
- creating a file of magnetization characteristics for the model of a nonlinear transformer;
- calculation of parameters of power transmission lines according to their geometrical characteristics.

Mandatory parameter in the calculation of energy systems is the type of calculation:

- Calculation of the scheme by vector method (Phasor Simulation)
- Discretize electrical model
- Continuous calculation mode

The presented simulation mathematical model allows to study the operation of wind turbines at different wind speeds, angles of inclination and blade length.

3.2 Research of wind turbine operation at constant input parameters

The input parameters of the model are given in table 3.1.

Table 3.1 - Input parameters of the wind turbine model.

Wind speed. m / s	7
Radius of the blade wind wheel, m	1.6
The angle of the blade,	0^0
Load power, kW	5

Time dependences of phase voltage and current on the generator. shown in fig. 3.2.

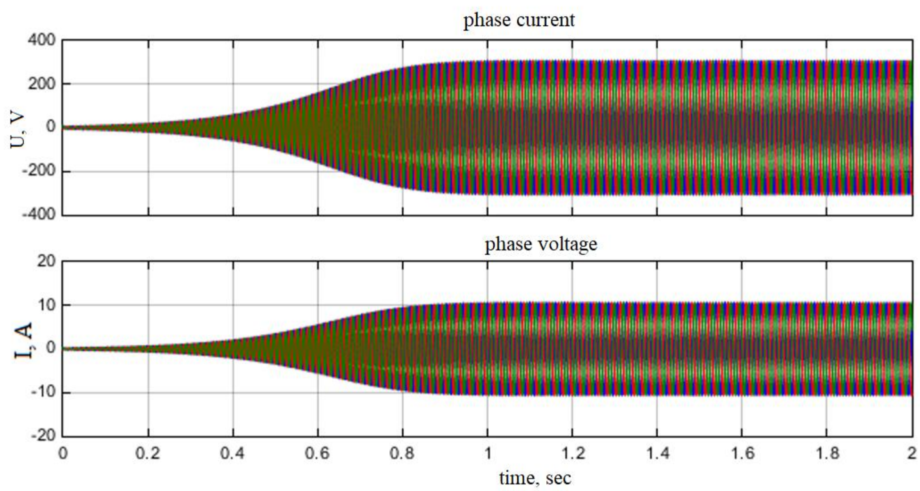


Figure 3.2 - Time dependences of phase voltages and currents on the generator

The figure shows a gradual increase in voltage and current in the time interval from 0 to 0.9 s. After a time of 1 s, the current and voltage stabilize and reach the nominal values, $U_{\phi} = 310$ V. at load current $I_{\phi} = 10.7$ A. In steady state, the voltage frequency is 50 Hz, which can be seen in Fig. 3.3, which shows the time dependences of phase voltages and currents in a shorter time interval.

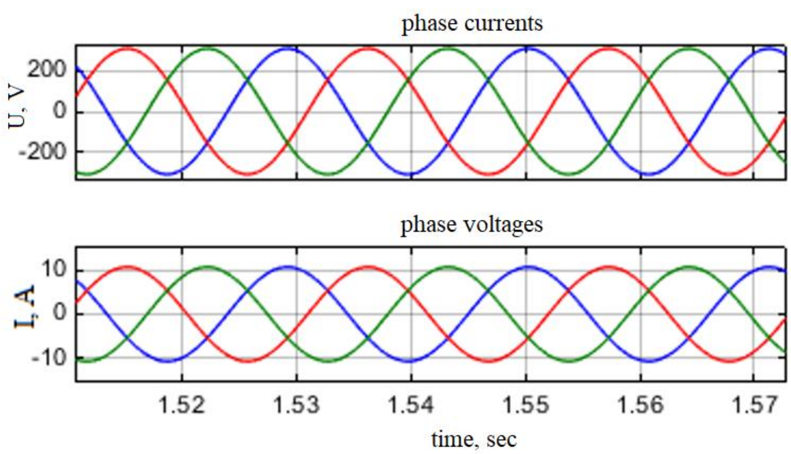


Figure 3. 3 - Graphs of phase currents and voltages at a load of 5 kW

In fig. 3.4 shows the time dependences of the rotor frequency and the electromagnetic moment of the generator, as well as the coefficient of use of wind energy.

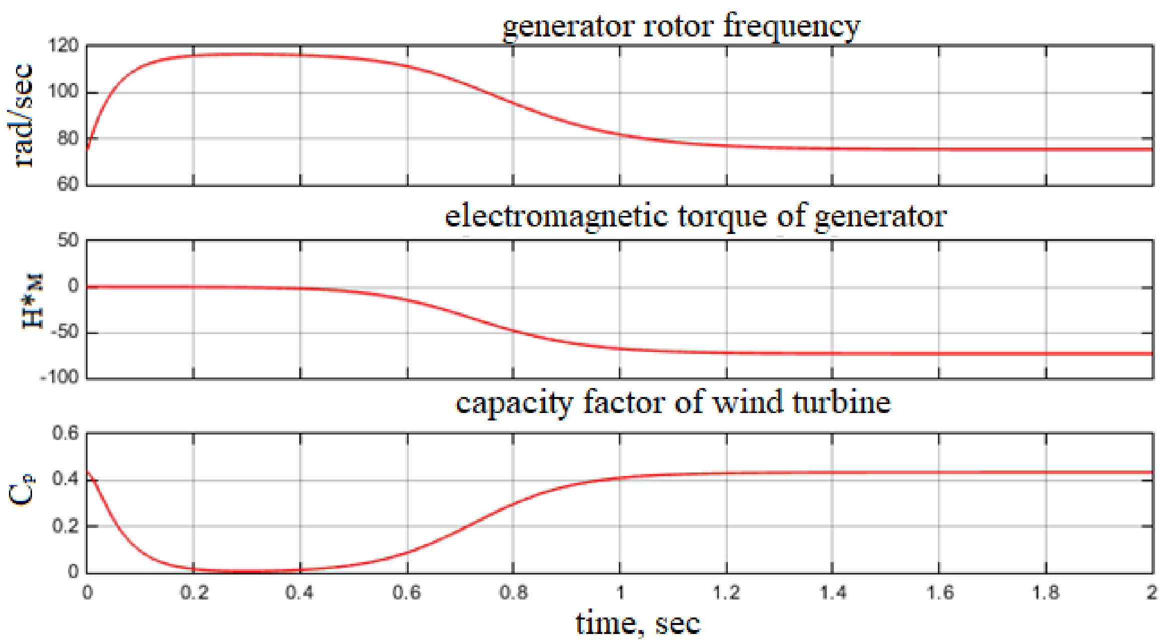


Figure 3.4 - Time dependences of the rotor frequency and electromagnetic moment of the generator, C_p

From Fig.3.4 it follows that the rotor frequency reaches a steady state value of 74.5 rad / sec at t = 1.4 sec, at a load of R = 5 kW and at a capacitance of compensating capacitors C = 119 μF per phase.

In steady state, the electromagnetic torque of the generator is equal to the mechanical torque of the wind wheel. The wind turbine operates at maximum power.

The third graph shows that the coefficient of use of wind energy increases over time and in steady state is close to a maximum of 0.43. High value of KVEV at $t = 0$c, due to the initial settings of the asynchronous generator model.

3.3 Simulation of wind turbine operation with variable input parameters

The simulation results at variable wind speeds are shown in Fig.3.5. The input parameters, except for wind speed, are the same as in the previous simulation

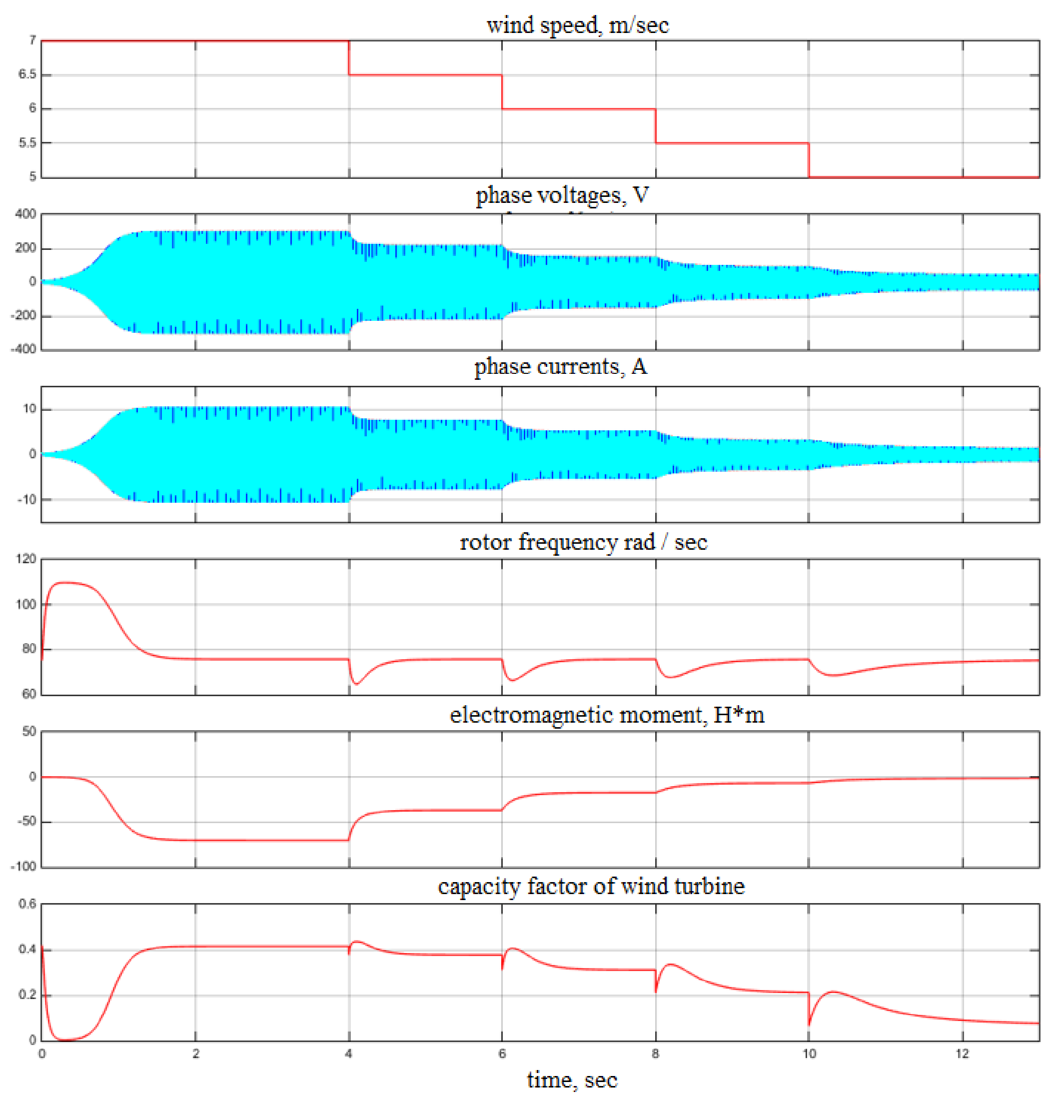


Figure 3.5 - Simulation results at variable wind speeds

The upper graph shows the wind speed, which has a stepped shape, with a change in speed of 0.5 m / s, and a time interval of 2 s.

The next two graphs show the change in phase and line voltages. It is seen that with decreasing wind speed the amplitude values of currents and voltages decrease and at a wind speed of 5 m / s are 50 V and 1.5 A, respectively.

Stabilize the output voltage of the AG is possible by changing the magnetic flux, which can be achieved:

- changing the capacitance of capacitors connected to the stator or phase rotor windings;
- the use of controlled reactors or nonlinear capacitors;
- magnetization of the stator core.

The fourth graph shows that the rotor frequency is constant at fixed time intervals, abrupt changes in frequency are observed only when the wind speed changes. Given that in real operating conditions of the wind turbine, the wind speed changes frequently, it is worth waiting not only for changes in voltage and current, but also its frequency.

The graph below shows the value of the wind energy utilization factor. The graphs show that when the wind speed changes, the generated power decreases with decreasing wind speed, reaches its maximum at maximum wind speed. The maximum efficiency of the wind power plant is observed in a fairly narrow range of wind speeds. At speeds less than 5 m / s. it does not exceed 0.1.

Similar studies at variable wind speeds have been conducted at different angle values β - the angle between the plane of rotation of the windmill and the chord of the blade.

The simulation results are shown in Fig. 3.6.

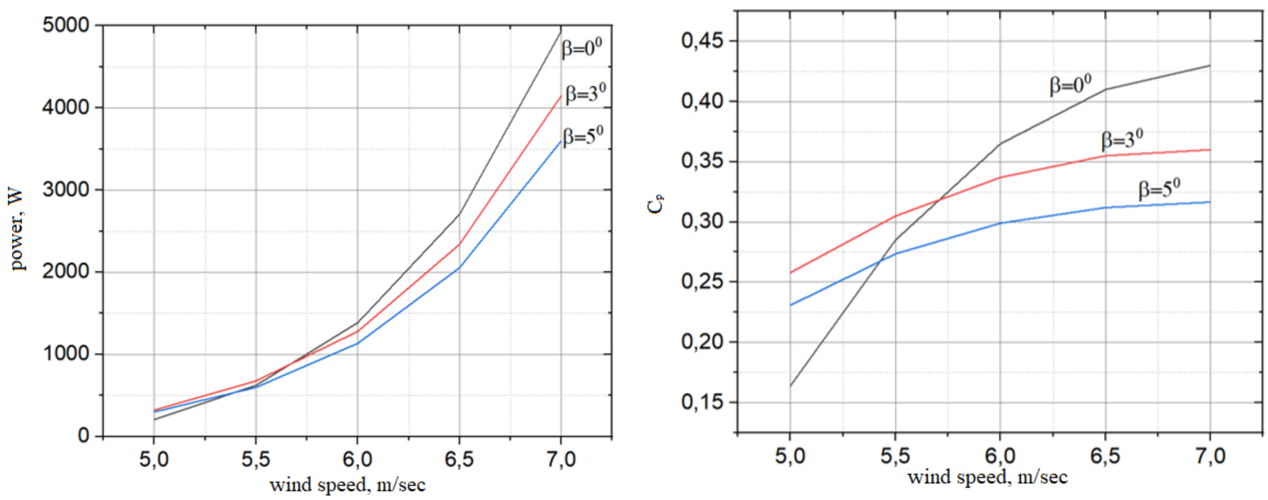


Figure 3.6 - Dependence of power (a) and Cp (b) on wind speed at different angle values β

It can be seen (Fig. 3.6a) that changing the angle by 50 for wind speeds up to 6 m / s has almost no effect on the output power of wind turbines. At a wind speed of 7 m / s, the power difference at $\beta = 0^0$, and $\beta = 5^0$ is about 1000 watts. Changing this angle is the regulation of the aerodynamic characteristics of the windmill. On the other hand, this leads to a decrease in the utilization of wind energy (Fig. 3.6b). With increasing β the dependence of KVEV on wind speed decreases.

3.4 Methods of optimal management of wind turbines by the criterion of energy efficiency.

Dynamic modes of wind turbine operation are determined by changes in the kinetic energy of the rotating parts of the wind turbine and changes in electromagnetic energy in the power supply system, so to study the dynamic stability, it is advisable to separate electromagnetic and mechanical processes.

It is obvious that mechanical transients, mainly due to the inertia of rotating masses, are longer in time and determine the dynamics of wind turbines.

Changes in wind speed occur gradually and over a long period of time compared to a step change in load power, so when increasing or decreasing wind speed more significant electromechanical transients, and when changing power - electromagnetic transients.

There are two main control methods for controlling wind turbine modes: regulation of wind turbine aerodynamic characteristics, regulation of electric load of wind turbine generator.

Adjusting the aerodynamic characteristics of the VC is to change the angle of attack of the entire blade and / or its individual parts, in some cases by changing the length of the blade. However, aerodynamic control has disadvantages: the complexity and increase in the mass of the entire system, reducing the reliability of wind turbines, large control errors, the complexity of mechanical regulators.

The most promising method today for the formation of energy-efficient modes of wind farms is to regulate the load of the generator, which is facilitated by a number of reasons:

- favorable thermal ventilation conditions of the wind turbine generator:

-incomplete use of generator power, as the nominal wind speed of wind turbines is almost always greater than the actual wind speeds in the operating range:

-possibility to use simple, reliable and relatively cheap VCs;

-fast flow of electromagnetic processes and high speed electrical and electronic control and switching devices.

Thus, to ensure sustainable and energy-efficient modes of wind turbines, it is advisable to use methods of regulating its load, taking into account the characteristics of wind turbines, weather conditions and characteristics of electricity consumption.

In order to determine the optimal values of power for operating wind speeds, the values of angular velocity (speed), power and torque of the wind wheel at the maximum value of the wind utilization factor are determined analytically, resulting in an analytical expression of dependence $P_{onm} = f(\omega_k)$.

The values of optimal power are determined from the expression:

$$P_{onm} = \frac{\rho \pi C_{p\max} r^5}{2\lambda_{onm}^3} \omega_k^3 = k_{onm} \cdot \omega_k^3. \tag{2.21}$$

where, λ_{onm} - the optimal value of speed, which corresponds to the maximum value of KEV.

k_{onm} - optimal wind wheel ratio.

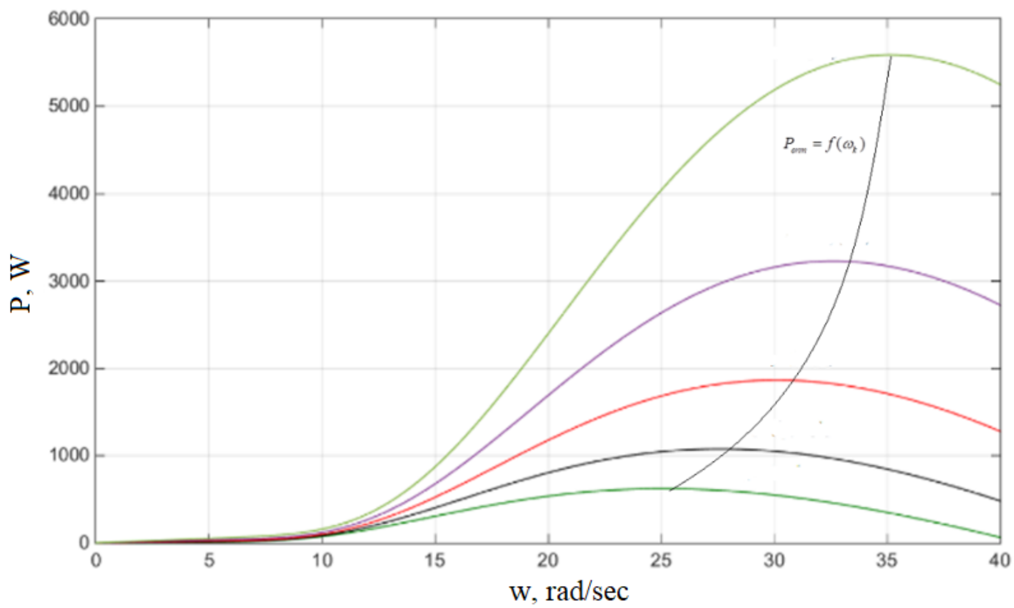


Figure 3.7 - Curve of the dependence of the optimal power of the wind turbine on the speed of the wind wheel

The optimal value of the angular velocity is determined from the expression:

$$\omega_{k\_onm} = \frac{\lambda_{onm}}{r} v,$$

The algorithm of the optimal mode is as follows. At a certain point in time, the current values of the wind turbine power are compared with the optimal value of power, which corresponds to the current value of the angular velocity. If the current power of the wind turbine is less than the value of the optimal power, the wind wheel operates in underload mode, and it is possible to increase the load on the wind turbine. Otherwise, it is necessary to unload the wind turbine, as the operating point may move to an unstable part of the characteristic.

The disadvantage of this method is the need for a wind speed sensor (anemometer) to determine the optimal power, which creates certain difficulties in the design of wind turbines, as well as increases the cost of the entire system.

3.5 Conclusions to the section.

1. The proposed simulation model of a wind turbine with an asynchronous generator allowed to determine its electrical characteristics at both constant and variable wind speeds.
2. It is shown that the use of an asynchronous generator provides stability of the output voltage frequency in the wind speed range of 5-7 m / s. The efficiency of wind turbines depends more on the wind speed, the greater the angle between the plane of rotation of the windmill and the chord of the blade.
3. Based on the dependence of wind turbine aerodynamic power on wind speed and speed, it is shown that for any given wind speed there is a rotor speed at which the power of the wind turbine will be maximum.

4 LABOUR OCCUPATIONAL SAFETY AND SECURITY IN EMERGENCY SITUATIONS

4.1 General safety rules when installing a wind turbine

“The process of operating a wind power plant requires careful and responsible attitude. Devices that are part of it can be a source of increased danger in case of improper operation or in severe weather conditions ".

Regularly maintain the equipment.

Do not attempt to repair or service the wind turbine yourself. These works must be performed by professional staff.

Check the condition of the main components of the equipment upon receipt.

Do not allow persons who have not received the necessary instructions to operate the wind turbine.

Keep children out of the components of the wind turbine, regardless of the condition of the system.

Before the start of operation it is necessary to examine carefully the wind generator, to be convinced of reliability of fastening of blades, masts, and all flange connections.

Check the insulation of the wires for damage;

During the operation of the wind turbine is not allowed to touch the wires and the working turbine.

The wind turbine must be started without a connected load.

The power of the expected load should not exceed the power of the inverter connected to the system.

2) Electrical safety

“The wind generator is equipped with sophisticated electronic devices, the development of which provided protection against electrical hazards associated with high currents. When connecting these and any other electrical devices, keep in mind that there are risks to people from electric shock. Heat generation in electrical systems is often the result of excessive current flowing through wires with insufficient cross-section or through poor contacts. Batteries can emit dangerous currents. In the event of a short circuit in the wires coming from the battery, a fire may occur. To eliminate this risk, it is necessary to install fuses or circuit breakers of the appropriate rating in the circuits connected to the battery ”[39, 40].

Do not touch bare electrical wires and connected connectors.

Do not touch wind turbine components with wet hands.

Do not allow liquid to come into contact with the components of the wind turbine (except for the wind turbine and mast) and do not place them on a wet surface.

Make sure that the electrical wires and connectors are in good condition.

Do not use faulty equipment: this may result in an accident or electric shock.

Do not use the wind turbine to other power sources, such as the local power supply. In cases where a backup connection of another source is provided, it must be performed by qualified personnel, taking into account the specifics of the equipment.

Connection to the distribution networks of the facility should be carried out during the installation of the wind power plant by qualified personnel in strict accordance with the norms and rules of installation of electrical installations.

Keep flammable and explosive substances (petrol, oil, rags, etc.) away from wind turbine components.

It is forbidden to operate components of wind turbines in an explosive atmosphere, as sparking is possible in its electrical parts.

Mechanical safety

"Rotating blades are a great danger. The blades of the wind turbine rotor are made of very durable material.

The speed of movement of the blades on the outer diameter of rotation may exceed. At this speed, the blades can cause serious injury. Under no circumstances should the turbine be installed in places where human contact with the movable rotor blades is possible. "

Do not install the turbine in such a way that anyone could get in the way of the blades.

It is forbidden to stop the wind wheel while the wind turbine is working, it is very dangerous.

It is necessary to carry out all maintenance work on the wind turbine only when the wind turbine is completely stopped and in windless weather.

4.2 Organization of civil protection at the object of economic activity

Object of economic activity (enterprise, institution, organization) - the main link in the system of the Central Committee of the state. Economic and protective measures are being taken at the facility where human and material resources are concentrated.

According to the law, the management of enterprises, institutions and organizations, regardless of ownership and subordination, provides its employees with personal and collective protection, a place in protective structures, organizes evacuation measures, creates forces to eliminate the consequences of emergencies and ensures their readiness, performs other measures bears the associated material and financial costs. Owners of potentially dangerous facilities are also responsible for alerting and protecting the population living in areas of possible damage from the consequences of accidents at these facilities.

The head of the facility is the head of the facility. he is responsible for the organization and condition of the CZ of the object, manages the actions of the bodies and forces of the CZ during rescue operations on it. The deputy chiefs of the facility's Central Command assist him in matters of evacuation, logistics, engineering and technical support, etc.

The body of day-to-day management of the CA is the department (sector) for emergencies and CA, which organizes and provides day-to-day management of the tasks of the CA on the site.

In order to prepare and implement measures in certain areas, communication and notification services, shelters and shelters, fire protection, public order protection, medical care, radiation and chemical protection, emergency technical and logistical support, etc. are created. Heads of services are appointed heads of institutions, departments, laboratories on the basis of which they are formed.

The communication and notification service is created on the basis of the communication node of the object. The main task of the service is to ensure timely notification of the management and employees about the threat of accident, catastrophe, natural disaster, enemy attack; to organize communication and keep it in a state of constant readiness.

The fire service is created on the basis of departmental fire departments. The service develops fire prevention measures and monitors their implementation; organizes localization and firefighting.

The medical service is formed on the basis of a medical point, a polyclinic of the object. It is responsible for organizing sanitary and hygienic and preventive measures, providing medical care to victims and evacuating them to medical institutions, medical care for workers, employees and their families in places of dispersal.

The service of protection of a public order is created on the basis of divisions of departmental protection. Its task is to organize and ensure reliable protection of the object, public order in the event of an emergency, during the liquidation of the consequences of an accident, natural disaster, as well as in wartime.

The service of radiation and chemical protection is organized on the basis of a chemical laboratory or shop. It is responsible for the development and implementation of measures to protect workers and employees, sources of water supply, radiation and chemical monitoring, measures to eliminate radiation and chemical contamination and dosimetric control.

The service of shelters and shelters is organized on the basis of the department of capital construction, housing and communal services department. It develops a plan for the protection of workers, employees and their families through the use of shelters and shelters, ensures their readiness and proper operation.

The emergency technical service is created on the basis of the production and technical department or the department of the chief mechanic. The service develops and implements preventive measures that increase the stability of major structures, utilities and communications in the emergency, organizes work to eliminate and localize the accident on utility networks.

The logistics service is created on the basis of the logistics department of the facility. It organizes the timely provision of formations with all means of equipment, supply of food and basic necessities of workers and employees at the facility and in places of dispersal, repair of equipment and property.

The transport service is organized on the basis of the transport department, the garage of the object. it develops and implements measures to ensure transportation related to the dispersal of workers and their delivery to the place of work, rescue operations.

Each service creates, provides, prepares the formation of the service (teams, groups, units) and manages them during the work. Formation of general purpose -

rescue teams (teams, groups, units), consolidated rescue teams (teams), subordinated directly to the chief of the facility. each of them has its own structure and capabilities. For example, the Consolidated Rescue Team (SAM) has units for various purposes, such as communications and intelligence, two rescue teams, a mechanization team, a medical team, and so on. SAM can independently perform basic rescue and other emergency work (PHP) in the lesion.

CONCLUSIONS

The qualifying work presents the results of theoretical research and solved the scientific and technical problem, which is to develop a simulation model of a wind farm. Based on the results obtained, the following conclusions were made:

1. A model of a three-bladed wind turbine of a wind power plant has been developed, which converts wind energy into mechanical energy of wind turbine shaft rotation. It is shown that the maximum value of the wind energy utilization factor does not exceed 0.43.
2. The calculation of parameters for the model of an asynchronous generator with a short-circuited rotor based on an asynchronous machine brand AIR 132M8.
3. The developed simulation model of a wind power plant with an asynchronous generator allowed to determine the operating modes at active load at both constant and variable wind speeds.
4. Based on the dependence of wind turbine aerodynamic power on wind speed and speed, it is shown that for any given wind speed there is a rotor speed at which the power of the wind turbine will be maximum.
5. Developed and proposed measures for labor protection and safety in emergencies during the installation of wind turbines.

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