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TEST BENCH OF AXIAL GENERATORS OF WIND POWER PLANTS

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Abstract*—This article is devoted to the construction of a test bench for quality control of an axial generator, which is a part of a low-power wind power plant. The axial generator reaches the working power at a wind speed of 3–3.5 m/s, ensuring high efficiency of the wind power plant. To conduct the quality control of axial generators it is suggested to use a test bench composed of the following elements: wattmeter; rpm (or rotation speed) regulator; collector motor; ammeter; voltmeter; tachometer (or rotation speed sensor); controller. The proposed bench provides the determination of the generators power at different speeds of rotation of the engine and simulates the effect of wind. The introduction of such a test bench allowed to obtain experimental data that would improve the quality of axial generators and thereby improve the efficiency of the wind power plant.*

Index Terms—Wind power plants; generator; speed controller; wattmeter; motor; axial flux.

I. INTRODUCTION

Wind power developed in independent Ukraine from 1993 to 1996 [1]. However, this direction of alternative energy has not been developed, including because of low energy tariffs from traditional sources. The development of alternative energy in Ukraine began in 2009 with the introduction of a green tariff in the Law of Ukraine "On Electricity". The development of wind energy began in 2011 –2012. This is due to the fact that at least one year of wind monitoring is required to start wind power plants.

Ukraine is characterized by sufficiently high energy potential of the wind stream in the Carpathian Mountains, Crimea, on the Black Sea and the Sea of Azov, in Donetsk Oblast, where the average annual wind speeds of 10 m are 5 and more m/s, which puts wind energy to the first place among renewable sources for generating electricity

As of 2018, the power output of wind power is more than 500 MW. Taking into account the projects that are creating, by 2020 there will be 1 GW of wind power.

II. CLASSIFICATION OF WIND POWER PLANT

There are two fundamentally different designs of wind power plants:

1) Wind power installations with a horizontal axis of rotation.
2) Wind power installations with a vertical axis of rotation.

Wind power plants with a horizontal axis of rotation – one of the most common wind power plants thanks to the traditions that have developed over the years of development of wind energy. Such generators can be used to generate electricity from wind energy, thanks to the lifting force and resistance strength. Wind power plants which use lifting force to increase energy can produce more energy than devices that work without lifting force. It is also worth noting that wind power plants that use lift force can not move at a speed higher than the speed of the wind itself.

The wind power plant with a vertical axis of rotation has advantages over the wind power plant with a horizontal axis, which consists in the fact that the need for orientation devices in the wind disappears, construction is simplified and reduced gyroscopic loads which are caused by additional tension in the shoulder blades, transmission system and other elements of the wind power plant. There is a chance to install the reducer and generator at the base of the tower.

III. STRUCTURE OF WIND POWER PLANT

Figure 1 shows the structural scheme of the wind power plant.

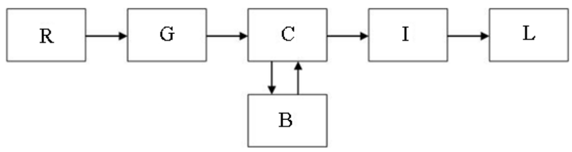


Fig. 1. The block diagram of the wind power plant: R is the rotor; G is the generator; K is the controller of charge; I is the inverter; L is the load; B is the battery

For this wind turbine, we used an orthogonal rotor with three straight blades. The diameter of the rotor is 2 m and the height of the rotor is 2 m. The rotor starts to rotate at the wind speed of 0.7 m/s.

Hybrid battery controller Hefei Win Power WWS0412 – a device that can control the process of charging batteries from solar panels and wind turbine – wind generator. Thanks to this opportunity we can increase the efficiency of the all system, and in particular, the process of charge – because the number of sources of energy increases.

For this wind power plant was considered various generators of different types and sizes, but we chose the axial generator.

The advantage of axial generators is that they do not have a magnetic sticking, which allows them to start at a relatively small speed of wind (about 2 m/s). Because this generator was designed for a low wind speed, and goes to work power already in low winds (3–3.5 m/s).

The advantages of the axial generator are related:

– minimal losses in friction;
– long service life;
– no noise and vibration when working;
– low cost of installation;
– no need for constant maintenance of the installation.

Also, this generator is easy to install on a wind power installation because it does not require gearboxes, and the axis of the windmill is connected to the rotor of the generator.

The axial generator differs from ordinary generators through a different path of the magnet flux. In ordinary generators, the current flows radially through the air gap between the rotor and the stator. However, in this generator flows flow parallel to the generator's axis. This type of rotor is often called a rotary pancake, and it can be made much thinner and lighter than other types.

IV. MATHEMATICAL MODEL

The mathematical model of a permanent magnet synchronous generator (PMSG) is generally based on the following assumptions [3].

1) The stator windings are positioned sinusoidally along the air-gap as far as the mutual effect with the rotor is concerned.

2) The stator slots cause no significant variations of the rotor inductance with rotor position.

3) Magnetic hysteresis and saturation effects are negligible.

4) The stator windings are considered symmetrical.

5) Damper windings are not considered.

6) Capacitance of all the windings is neglected.

7) Resistances of the coils are assumed to be constant.

The dynamic model of a PMSG is derived from a two-phase synchronous reference, direct (d) and quadrature (q) axis frame in which the q-axis is 90° ahead of the d-axis with respect to the direction of rotation. In the case of a balanced three phase system, the d and q reference frame transformation reduces three AC quantities to two DC quantities, allowing simplified calculations to be performed. The d and q transformation applied to a three phase system is as shown by equation

$$\begin{bmatrix} F_d \\ F_q \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \sin\omega t & \sin\left(\omega t - \frac{2\pi}{3}\right) & \sin\left(\omega t + \frac{2\pi}{3}\right) \\ \cos\omega t & \cos\left(\omega t - \frac{2\pi}{3}\right) & \cos\left(\omega t + \frac{2\pi}{3}\right) \end{bmatrix}\begin{bmatrix} F_a \\ F_b \\ F_c \end{bmatrix}, \quad (1)$$

And its inverse transform is given by equation

$$\begin{bmatrix} F_a \\ F_b \\ F_c \end{bmatrix} = \begin{bmatrix} \sin\omega t & \cos\omega t \\ \sin\left(\omega t - \frac{2\pi}{3}\right) & \cos\left(\omega t - \frac{2\pi}{3}\right) \\ \sin\left(\omega t + \frac{2\pi}{3}\right) & \cos\left(\omega t + \frac{2\pi}{3}\right) \end{bmatrix}\begin{bmatrix} F_d \\ F_q \end{bmatrix}. \quad (2)$$

Where F can represent voltages, currents or inductances whose values depend upon the rotor position.

The d- and q-axis currents in the frequency (s) domain can be represented as in equations respectively which can be obtained through equivalent circuit model of PMSG as shown in Fig. 2 [3].

$$I_{\text{ds}} = \frac{\left(-V_{\text{ds}} - R_s I_{\text{ds}} - \omega_{\text{r}}\right)}{sL_{\text{ds}}}, \quad (3)$$

$$I_{\text{qs}} = \frac{\left[-V_{\text{qs}} - R_{\text{s}} I_{\text{qs}} - \omega_{\text{r}}\left(L_{\text{ds}} + L_{\text{is}}\right) I_{\text{ds}} + \omega_{\text{r}}\varphi_{\text{r}}\right]}{sL_{\text{qs}}}, \quad (4)$$

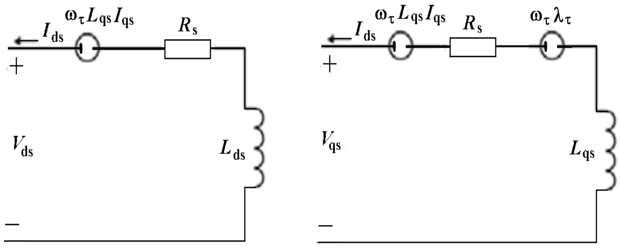
where, V_{ds} and V_{qs} are the d- and q-axis stator voltages, I_{ds} and I_{qs} are the d and q-axis stator currents, R_{s} is the stator resistance and ω_{r} is the angular speed of the generator, L_{ds} and L_{qs} are the stator d- and q-axis self inductances and φ_{r} is the rotor flux. L_{ds} and L_{qs} are given by equations respectively [2].

$$L_{\text{ds}} = L_{\text{ls}} + L_{\text{dm}}, \quad (5)$$

$$L_{\text{qs}} = L_{\text{ls}} + L_{\text{qm}}, \quad (6)$$

where, L_{ds} and L_{qs} are the magnetizing inductances in d- and q-axis, and L_{ls} is the leakage inductance.

For a non-salient pole PMSG, d- and q-axis magnetizing inductances are equal (i.e. $L_{ds} = L_{qs}$), whereas for a salient pole PMSG, d-axis magnetizing inductance is normally lower than the q-axis magnetizing inductance (i.e. $L_{ds} < L_{qs}$). The simplified d- and q-axis model in the rotor-field synchronous frame is as shown in Fig. 2.



(a) (b)

Fig. 2. Simplified dq-axis model of PMSG in the rotor field synchronous reference frame: (a) d-axis circuit; (b) q-axis circuit

The electromagnetic torque (T_e) and the rotor speed (ω_r) of the PMSG are calculated as shown in equations respectively [2].

$$T_e = \frac{3N_{pp}}{2}\left[\varphi_r i_{qs} - (L_{ds} - L_{qs}) I_{ds} I_{qs}\right], \quad (7)$$

$$\omega_r = \frac{N_{pp}}{jS}\left(T_e - T_m\right), \quad (8)$$

where, N_{pp} is the number of pole pairs of the rotor, j is the rotational inertia of the generator and T_m is the mechanical torque for the generator (in the case of the PMSG connected to a wind turbine, T_m is the torque from the turbine).

Using equations from (1) to (7), a PMSG model is developed in Matlab / Simulink. Inputs for the model are d- and q-axis voltages and mechanical torque. Rotor speed (ω_r), is calculated through equation (8) and is used as feedback to the system. Number of pole pairs, d- and q-axis inductances, leakage inductance, magnetic flux of the rotor magnets, stator resistance and moment of inertia of rotor and load can be initially set for a particular size of the generator. The d-axis current (I_{ds}) q-axis current (I_{qs}) and electromagnetic torque (T_e) are the outputs from the system as calculated by equations (3), (4) and (7), respectively.

V. Structure of the Test Bench

To assess the quality of the generator and in order to improve the efficiency of the generator, it was necessary to create a stand. In this article a model of a test stand is proposed. The block diagram of the test bench is shown in Fig. 3.

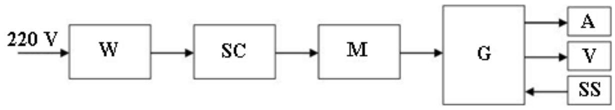


Fig. 3. Structure of the test bench: W is the wattmeter; SC is the speed controller; M is the motor; G is the generator; A is the ammeter; V is the voltmeter; SS is the speed sensor

The design of any collector engine includes several basic elements: collector, brushes, rotor, and stator.

For a collector electric motor, an AC or DC power supply can be used. An additional advantage is the effective starting torque. In this case, the work of an AC or DC current of the electric motor is accompanied by a high frequency of rotation, which is not suitable for all users.

In order to establish a match between wind speed and engine revolutions, a lowering reducer with a gear ratio of 11 was used. So, at a maximum engine rotate of 3300 rpm will have of the generator speed 300 rpm or 5 r/s. To be able to change the engine rotate from 0 to 5 mps with discretion of 0.1 m/s used a speed control and a speed sensor.

Control of speed rotating [4].

This device is intended to regulate the speed of rotate on collector motors. The feature of this regulator is the ability to maintain a given engine speed, regardless of the change in load on the shaft. Thus, throughout the rev range is the maximum engine power. From 0 rpm to the maximum on which the engine is capable. Ideal for engines from washing machines.

The board has a symistor installed on 40 A, this will allow the engines to connect not only from washing machines, but also more powerful up to 2.5 kW. There is a possibility to arrange a reverse.

Standard circuit diagram of the speed regulator (Fig. 4).

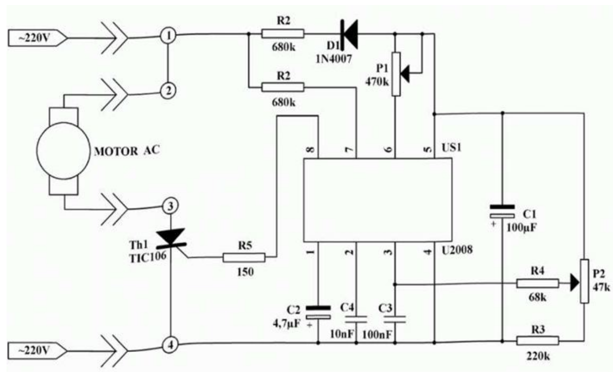


Fig. 4. Circuit diagram of the speed regulator

System of measuring parameters of the generator. To measure the parameters of the generator, the stand is equipped with:

– wattmeter (for measuring motor power);
– voltmeter (for measuring the voltage of the generator);
– ammeter (for measuring the power of the generator current).

Test bench is shows Fig. 5.

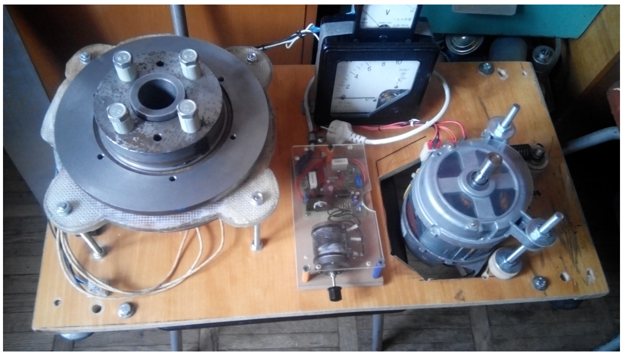


Fig. 5. Test bench

Dependence of current strength on the frequency of rotation shown in the Fig. 6.

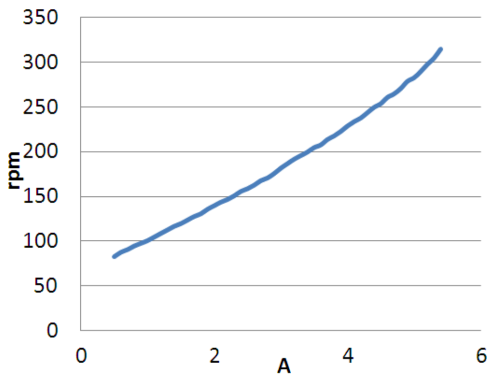


Fig. 6. Dependence of current strength on the frequency of rotation

Measure current and voltage because it is the main parameters of the generator. With this stand, it is possible determine the best generator by changing its parameters, such as:

– number of coils on the stator;
– number of magnets on the rotor and their size;
– number of turns and diameter of the wire in the coil;
– air gap between rotor and stator.

VI. Conclusion

This stand allows regulate the rotation in a given range and with a given discreteness. Consequently, it is possible to analyze the dependence of power on the wind speed, as well as determine in which turns the efficiency of the generator will be the highest.

Thanks to this stand can get a generator with the best power parameters.

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В. М. Синєглазов, В. В. Климнюк. Випробувальний стенд аксіальних генераторів вітроенергетичних установок
Дану статтю присвячено побудові випробувального стенду для контролю якості аксіального генератора, який є складовою вітроенергетичних установок малої потужності. Аксіальний генератор забезпечує високу ефективність вітроенергетичної установки завдяки тому, що при швидкості вітру 3–3,5 м/с він виходить на робочу потужність. Для забезпечення перевірки якості аксіальних генераторів запропоновано використовувати випробувальний стенд, який включає наступні елементи: ватметр; регулятор швидкості обертання; колекторний двигун; амперметр; вольтметр; датчик швидкості обертання; контролер. Запропонований стенд забезпечує визначення потужності генераторів на різних швидкостях обертання двигуна, що імітує вплив вітру. Впровадження такого випробувального стенду дозволило отримати експериментальні дані, які дозволять підвищити якість аксіальних генераторів і тим самим покращити ефективність роботи вітроенергетичної установки.
Ключові слова: вітроенергетична установка; генератор; регулятор обертів; ватметр; двигун; аксіальний потік.

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В. М. Синеглазов, В. В. Климнюк. Испытательный стенд аксиальных генераторов ветроэнергетических установок
Данную статья посвящена построению испытательного стенда для контроля качества аксиального генератора, который является составной ветроэнергетических установок малой мощности. Аксиальный генератор обеспечивает высокую эффективность ветроэнергетической установки благодаря тому, что при скорости ветра 3–3,5 м/с он выходит на рабочую мощность. Для обеспечения проверки качества аксиальных генераторов предложено использовать испытательный стенд, который включает следующие элементы: ваттметр; регулятор скорости вращения; коллекторный двигатель; амперметр; вольтметр; датчик скорости вращения; контроллер. Предложенный стенд обеспечивает определение мощности генераторов на различных скоростях вращения двигателя, имитирует воздействие ветра. Внедрение такого испытательного стенда позволило получить экспериментальные данные, которые позволят повысить качество аксиальных генераторов и тем самым повысить эффективность работы ветроэнергетической установки.
Ключевые слова:ветроэнергетическая установка; генератор; регулятор оборотов; ваттметр; двигатель; аксиальный поток.

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