Zbigniew GORYCA

A 500 W VAWT WIND POWER MICROPLANT

ABSTRACT *The paper presents a small wind power plant with vertical axis (VAWT). This power plant is composed of: a wind turbine, a multi-pole generator and circuit charging the batteries. The investigation was conducted both in the laboratory and in outdoor conditions. The characteristics of the power plant in no-load mode, the outer characteristics and the cogging torque have been measured in the laboratory. The paper contains the images of the power plant prototype.*

Keywords: *VAWT wind power plant, generator, controlling circuit*
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1. INTRODUCTION

The numerous queries concerning previous machines – power plants rated at 1 kW and 3 kW led the author to build a much smaller wind power plant designed to charge batteries used in power circuits of low wattage and in hybrid power sources far from the electrical grid. An example of such receivers (far from the grid) are electrical devices used on railway crossings. In case when a railway crossing is at least 1 km away from a power source, it is not economical to build a cable line and a much cheaper solution is to build a hybrid power source that uses solar and wind energy. In order to drive down costs, allow for easier maintenance and improve the efficiency of converting wind energy into electrical energy, one builds gear-free generators [1, 3, 6, 8, 9, 11, 12] in which the wind turbine is mounted directly on the generator shaft. Special interest is afforded to small wind power plants with vertical pivot (VAWT). Turbines of this kind are characterized by low rotational speeds, which means that they produce only a small amount of noise and are thus less burdensome to their environment. In addition, turbines of this type do not need to be set up to face the wind, the generator is immobile and one need not control for the torsion of the cable carrying the energy from the generator, which is necessary in HAWT power plants. VAWT micro power plants can be

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mounted directly on house rooftops (they do not require a separate tower), which reduces the necessary financial outlay. In this paper, we present the construction of a micro power plant with vertical pivot, which can be mounted on the rooftops of detached houses, motorway gates, blocks of flats, manufacturing plants and buildings belonging to enterprises of various kinds. In this plant, we use a generator setup which ensures a low cogging torque, which enables for starting the plant with a low wind velocity. An advantage of this generator is small mass, which results from using a light rotor and aluminium housing. The unique patented [7] construction of the magnetic circuit allows us to ensure a particularly low cogging torque while using straight-teethed stator segments. This allows for an efficient use of the surface of the slot as well as avoids problems associated with making the coils, as is the case with stators which have skewed slots. In the presented version, the plant is designed to charge batteries, but one can convert it to supply energy to the grid by using an inverter.

2. DESIGN ASSUMPTIONS BEHIND THE PLANT

When designing the plant, we assumed the use of the existing "Sea Hawk" wind turbine, which is characterized by high efficiency for a vertical pivot turbine [12], a small mass, and the associated low price. The manufacturer specifies the power output of this turbine at 500 W for the wind speed of 14 m/s and the associated rotational speed is 250 rpm. Because of the parameters of the turbine the following technical assumptions were made when designing the generator.

- generator power 500 W
- output voltage 3X50 V
- frequency 50 Hz
- rotational speed 250 rpm

A low rotational speed coupled with the frequency of the output voltage set at 50 Hz necessitates the number of rotor poles to be set at 24. As was mentioned beforehand, the plant is designed for charging. Thus, in order to fully utilize the energy provided by the turbine a charging circuit was used which utilizes Maximum Power Point Tracking (MPPT).

3. THE MAKEUP OF THE GENERATOR

The wind speed at which the wind plant begins to rotate depends on the sum of resistances is the mechanical system. When the wind turbine is mounted directly on the generator shaft, this speed depends on the cogging torque of the generator and friction in its bearings. It is therefore critically important to have low cogging torque in the generator. The easiest and the most frequently used way of minimizing it is to use oblique slots in the stator [2, 3]. This can be done when the length of the stator stacked core is large. If it is small, one is confronted with a significant reduction in the usable area of the slot and therefore there are problems placing the coils in it. Another popular way of minimizing the cogging torque is the use of slanted or pseudo-slanted magnets (by pseudo-slanted we mean that a number of magnets are placed along the length of the rotor twisted with respect to one another by a given angle) [8, 9]. This solution necessitates the use of expensive instruments to glue the magnets and does not give results as good as using oblique stator teeth. In the described generator the minimization of the cogging torque was obtained by using an atypical, odd number of the stator teeth different by three from the number of magnetic poles of the rotor. Design calculations of the flat model were done using the Comsol Multiphisics software. The photos below show the rotor of the generator prototype (Fig. 1) and the power plant using this generator (Fig. 2).

Fig. 1. Rotor of the generator prototype

Fig. 2. The 500W VAWT power plant

4. LABORATORY TESTS

Laboratory tests of the generator included the measurement of: the cogging torque, voltage at idle as a function of the rotational speed, phase voltage as a function of the load current and the shape of the phase and line-to-line voltages. The examined generator was driven via gearing by an asynchronous squirrel-cage engine powered through an inverter. The maximum value of the cogging torque was measured using a balanced lever and accurate weights. We conducted 10 measurements for different locations of the rotor and took the arithmetic average. The average value of the cogging torque and the friction torque in the bearings equals 0,57 Nm, which amounts to 2,7% of the rated torque. For a multi-pole device, this is a very low value. Powering the engine via an inverter allowed for the control of rotation speed and determination of the idle characteristics and external characteristics of the generator. The torque was measured with a balanced lever and a pressure sensor, and rotation speed was determined from the output voltage frequency. The generator was loaded with resistances (heaters) equally in all phases.

Fig. 3. Our lab stand

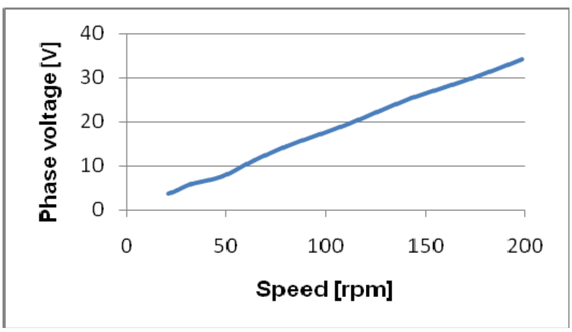

Fig. 4. Voltage dependence on rotation speed at idle

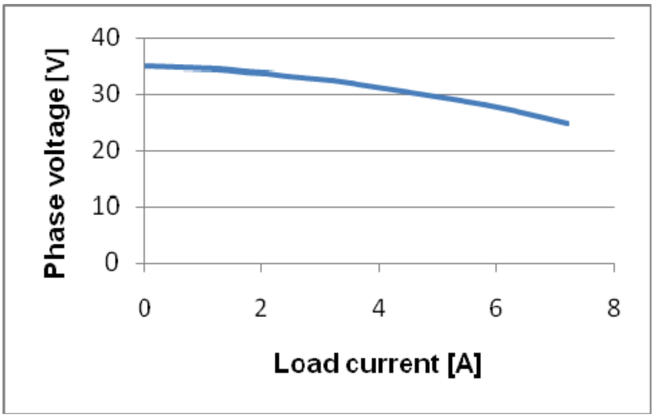

Fig. 5. External characteristics at rotation speed of 250 rpm

As it is shown the phase voltage of the generator decreases with increasing load current and this is a typical relationship for sources characterized by low power and a large internal impedance. A marked improvement of this dependence can be achieved by compensating the inductance of the generator coils with load dependent capacitances. A better solution is to load the generator with an active rectifier, which allows for no phase shift between the rotation voltage and load current. In this case one obtains a considerable improvement of external characteristics, since the output voltage is the rotational voltage decreased only by voltage drop on the low resistance of the coil. The shape of output voltage at a rated load is shown in Fig. 6.

The conducted Fourier analysis confirms that the shape of the output voltage for resistive load does not deviate from the sine wave and includes mainly the first harmonic.

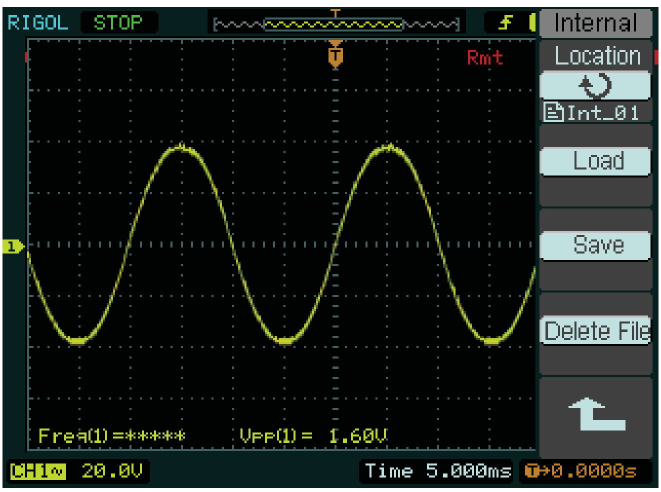

Fig. 6. The shape of the phase voltage

5. CONCLUSIONS

Small wind power plants with vertical pivots enjoy a growing interest chiefly because they are not burdensome to their environment. These turbines have a small starting torque and therefore the low-rpm gearless generators used in them should have low cogging torque. The design presented in this paper has a low cogging torque while having straight stator slots and straight magnets. Thanks to this, the plant can start even with very weak winds. A further advantage of this device is a low rotational speed of 250 rpm, which allows for placing the wind turbine directly on the generator shaft. As was remarked, this design can be used in hybrid, island power systems, for example on motorway gates. The presented design is small with a diameter of 308mm and length of 80 mm. It also has a small mass of 33 kg. The battery charging controller used in the plant allows the effective use of electrical energy. With a few changes, it is also possible to measure many parameters of the plant, monitor its condition and notify the owner of some malfunctions as they occur.

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MIKROELEKTROWNIA WIATROWA O MOCY 500 W I PIONOWEJ OSI OBROTU

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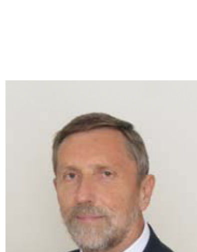
STRESZCZENIE *W pracy przedstawiono małą elektrownię wiatrową o pionowej osi obrotu (VAWT). Elementami składowymi elektrowni są: turbina wiatrowa, wielobiegunowy generator oraz układ ładowania akumulatorów. Badania laboratoryjne i terenowe obejmowały pomiary parametrów generatora na stanowisku badawczym oraz sprawdzenie działania elektrowni w terenie. W wyniku badań laboratoryjnych określono charakterystykę biegu jałowego, wyznaczono charakterystykę zewnętrzną oraz zmierzono maksymalną wartość momentu zaczepowego generatora. Na załączonych zdjęciach przedstawiono wykonany prototyp elektrowni.*

Słowa kluczowe: *Elektrownia wiatrowa VAWT, generator, układ sterowania*



Zbigniew GORYCA Ph.D., D.Sc., Assoc. Prof., a graduate of the Faculty of Electrical Engineering of the Warsaw University of Technology, author of 180 publications, 11 patents and 6 patent applications in the area of power engineering, control and electric machines. In his work, he concentrates on designing and implementing practical solutions. He is the builder of over 50 machines with permanent magnets and numerous power electronic systems working with them. Recently, he has been the builder of many low-rpm generators used in small wind and water power plants.