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MOBILE WIND TURBINE

PRZENOŚNA TURBINA WIATROWA

A b s t r a c t

The paper describes the function of a wind turbine, and different aspects you have to take into consideration during construction. A computing programme has been used to design and optimise the wind turbine, so it can be as light as possible.

Keywords: *energy saving*, *wind turbine*, *generator*, *computer aided design*

S t r e s z c z e n i e

W artykule opisano funkcjonalność turbiny wiatrowej oraz różne aspekty, które muszą być wzięte pod uwagę w czasie jej projektowania. Projekt i optymalizację parametrów wykonano za pomocą oprogramowania obliczeniowego, dzięki któremu proces projektowy został maksymalnie skrócony i uproszczony.

Słowa kluczowe: *oszczędność energii*, *turbina wiatrowa*, *generator*, *komputerowe wspomaganie projektowania*

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1. Introduction

When oil and gas are transformed into energy, they produce climatic gases, such as CO_2. Renewable energy is a clean substitute which does not emit any climatic gases, and the sources are unlimited. In about 100 years the non-renewable energy sources like oil and gas will be critically reduced. We must think of sources to meet the increasing need of energy and start using more renewables.

Wind power is a way to provide the world with renewable energy, and can be an important resource to cover the increasing need of energy. The kinetic energy of wind can be changed into other forms of energy, mechanical or electrical.

The history of using wind energy in Norway does not go very far back, because we used more water power than wind, and we still do.

In Norway we have a long coast with a lot of wind, and several companies are working on how to exploit the energy there in the best possible way. There have been so far installed about 260 Megawatt wind power plants in Norway, and many projects are under way.

Developing new wind farms brings a lot of technical and political challenges. They have to be built where the wind conditions are best. The climate and the terrain in Norway will often contribute to changes in the weather. Expensive measurements and exact calculations are therefore important for finding the right locations.

Several companies are working on how to make the windmill smaller and functional to use as a contribution for a single household energy use. In this way we can make use of the energy we have around us every windy day. It is small and light enough to be easily attached to most building structures. Given average wind speeds at the site of around 10 meter per second, it could realistically provide 15–25% of the average home annual electricity requirement. The turbine can be connected directly to the current net or to a battery.

Our project is to make this kind of windmill more mobile and easier to use in any locations. There are several frames and requirements we have to meet for the calculations.

2. Goals and requirement

2.1. Goals

Our assignment will be to calculate the size of the wind turbine that can be used on every household, cabin or boat as a power supplement. This wind turbine will give enough effect to contribute with about 15–25% of the use of electric power for a regular household with a wind speed of 10 mps. The calculation for the wind turbine will be used later during the design. All the parts of the wind turbine will be drawn in the 3D program Pro-Engineer, assembled and animated. Our last goal is to make the wind turbine more mobile by making it easier to move and put together.

2.2. Requirements

The project had some requirements that we had to follow:

– Diameter from one blade tip to another shall not exceed 1,8 meters.
– The windmill shall generate an effect that will correspond to 15–25% of the electric power use to a regular household at a wind speed of 10 mps.

– Calculated for at top wind speed at 15 m/s.
– When it is mounted on the ground, the length from the ground to the lowest tip of the blade shall be at least 2,8 meter.
– When it is mounted on a roof, the length from the roof to the lowest tip of the blade shall be at least 1 meter.
– It shall be easy to mount and to transport.

The wind turbine can be made for higher wind speeds than 15 m/s, but then all the different parts in the mill have to be recalculated. The windmill we have made will have a brake in front of the generator that will start to function when the wind blows higher than 15 m/s.

3. System

In Figure 1 we can see the system block diagram of the mobile wind turbine. The turbine extracts kinetic energy from the wind (see Fig. 2 and 3) and transforms it into mechanical energy. The velocity transmitter signals the load controller which will start the electromagnetic brake if the wind speed exceeds 15m/s. The three-phase generator transforms the mechanical energy into electrical energy, and if the generator temperature rises

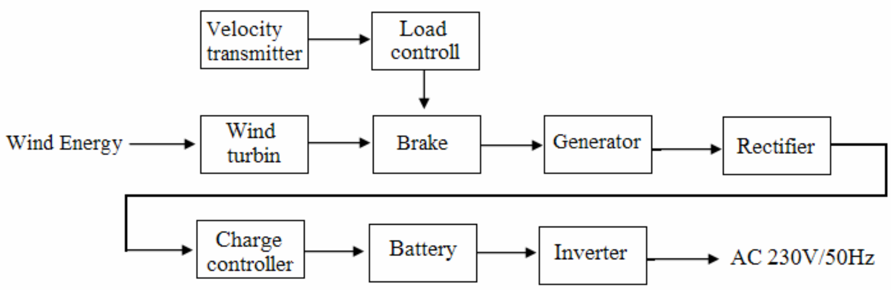

Fig. 1. System block diagram
Rys. 1. Schemat blokowy systemu

too high, a sensor will signal the load controller that will stop the turbine. The electric power is rectified and a charge controller prevents the wind generator from overcharging the batteries. The inverter, invest from 12VDC to 230VAC.

4. Wind power

A wind turbine obtains its power input by converting the force of the wind into torque (turning force) acting on the rotor blades. The amount of energy which the wind transfers to the rotor depends on the density of the air, the rotor area, and the wind speed.

At normal atmospheric pressure and at 15° Celsius air weighs some 1,225 kilograms per cubic meter, but the density decreases slightly with increasing humidity. All calculations are made under normal atmospheric pressure and temperature at 15° Celsius.

The wind turbine rotor must obviously slow down the wind as it captures its kinetic energy and converts it into rotational energy. This means that the wind will be moving more slowly at the back of the rotor than the front of the rotor.

In Figures 2 and 3 you can see a diagram of wind turbine model and block diagram of a wind turbine system. In what follows we will try to explain the process of the system you can see in Figs 2 and 3.

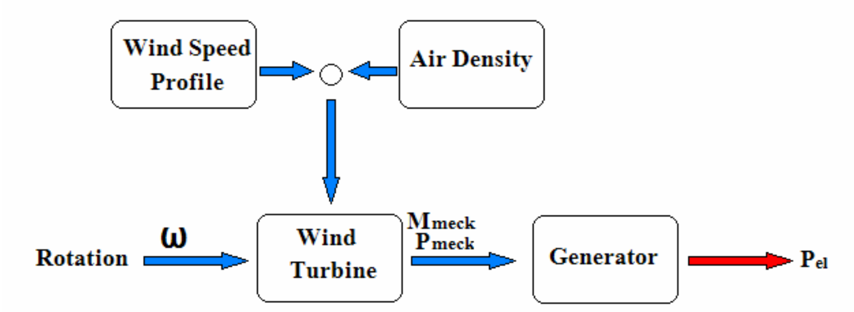

Fig. 2. Diagram of wind turbine model
Rys. 2. Diagram modelu turbiny wiatrowej

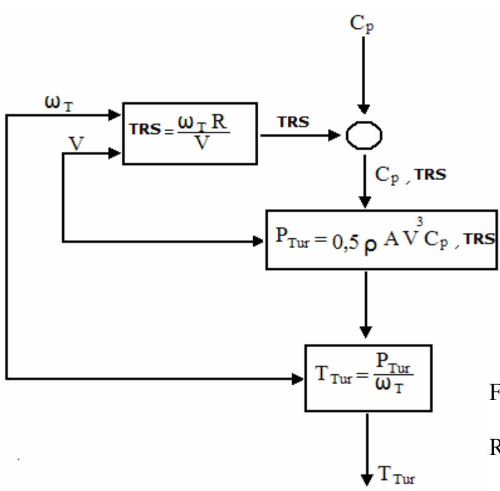

Fig. 3. Block diagram of wind turbine system
Rys. 3. Schemat blokowy modelu turbiny wiatrowej

Betz's law says that you can only convert less than 16/27 (or 59%) of the kinetic energy in the wind to mechanical energy using a wind turbine.

Betz's law

$$P_{\max} = (16/27) * (\delta_{\text{air}}/2) * (D^2_{\text{blades}} * \pi/4) * V^3_{\text{wind}} \quad (1)$$

where:

D_{blades} – diameter of swept rotor area,
δ_{air} – density of air,
V_{wind} – wind speed,
$P_{\max}$ – the manpower possible to extract from the wind.

The wind turbine we have calculated has a swept diameter of 1,8 m, as we can see in Fig. 4 the maximum power possible to extract at a given wind speed (Betz limit) is 3,117 KW at the wind speed of 15 m/s, but that high power is not realistic to extract from the wind turbine power output.

Wind turbines are designed to produce electrical energy as cheaply as possible. Wind turbines are therefore generally designed so that they yield maximum output at wind speeds around 15 meters per second. It does not pay to design turbines that maximize their output at stronger winds, because such strong winds are rare.

It is important that the machine is operating below its speed and power limits, in our case 15 m/s. Exceeding either one above the design limit, can damage and even destroy the machine. In these cases it is normal to use a power controller in order to avoid damaging the wind turbine. All wind turbines are therefore designed with some sort of power control. Our wind turbine has an electromagnetic brake that will stop the wind turbine at high winds or when the generator temperature is too high.

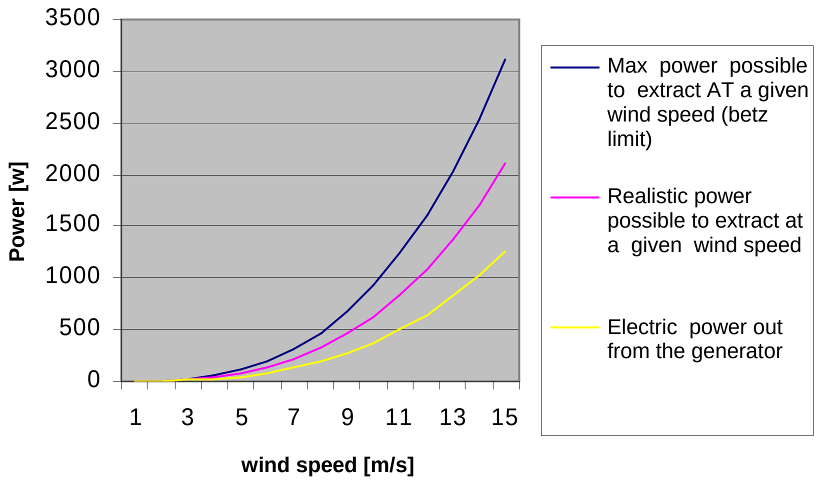

Fig. 4. Power extracted from the wind in a swept area where the diameter is 1.8m
Rys. 4. Moc turbiny wiatrowej odzyskiwana z wiatru w przestrzeni omiatania dla średnicy 1,8 m

4.1. Calculation of turbine power

The Tip Speed Ratio (often known as the TSR) is of vital importance in the design of wind turbine generators. If the rotor of the wind turbine turns too slowly, most of the wind will pass undisturbed through the gap between the rotor blades. Alternatively, if the rotor turns too quickly, the blurring blades will appear like a solid wall to the wind. Therefore, wind turbines are designed with optimal tip speed ratios to extract as much power out of the wind as possible.

When a rotor blade passes through the air it leaves turbulence in its wake. If the next blade on the spinning rotor arrives at this point while the air is still turbulent, it will not be able to extract power efficiently from the wind. However, if the rotor span a little more slowly the air hitting each turbine blade would no longer be turbulent. Therefore the tip speed ratio is chosen so that the blades do not pass through turbulent air.

The optimum tip speed ratio depends on the number of blades in the wind turbine rotor. The fewer the number of blades, the faster the wind turbine rotor needs to turn to extract maximum power from the wind. A two-bladed rotor has an optimum tip speed ratio of around 6, a three-bladed rotor around 5, and a four-bladed rotor around 3.

Highly efficient aerofoil rotor blade design can increase these optimum values by as much as 25–30% increasing the speed at which the rotor turns and therefore generating more power. A well designed typical three-bladed rotor would have a tip speed ratio of around 6 to 7. The tip speed ratio we are using in our construction, are 6,5 at a wind speed of 15 m/s.

The power efficiency of the rotor is a fraction of the total power available which the blades are able to convert. The theoretical maximum is 0,59. This is known as the Betz limit. Ideally we want a wind turbine that operates at a Cp as close to the Betz limit of 0,59 as possible, but the more realistic maximum rotor efficiency for a three-blade wind turbine is about 0,46.

Now that we have established all the information we need to calculate the power transferred to the turbine\main shaft, we can see that the power in the turbine is a lot smaller than the power in the Betz limit. Using equation (1) but changing the Betz limit to 0.45 (see Fig. 4) realistic power possible to extract at a given wind speed.

4.2. Electric power

The realistic power possible to extract at the given wind speed (Fig. 4) is not realistic power that the generator generates.

In most wind turbines, a gear box is placed between the rotor of the wind turbine and the rotor of the generator. This has important disadvantages:

– The efficiency of the gearbox will reduce the power extracted from the wind.
– The gearbox appears to be a vulnerable component of the wind turbine.

These disadvantages are eliminated by using a generator which rotates at the same speed as the rotor of the wind turbine, so that the gearbox is not necessary. The electro-mechanic system without gearbox is called direct-drive. We have calculated the speed on the wind turbine to be approximately 1035 rpm at a wind speed of 15m/s. The generator must then have 6 poles, to give a rotational speed of 1000 rpm. So it is not necessary to use a gearbox in our wind turbine. We are assuming the efficiency in the generator to be 0,6, which is a normal size for a generator in that power range. It is normal that the efficiency in the generator varies when the power varies, but we are assuming that it is steady at 60 percent. We can now calculate the total electrical power possible to extract from the generator. We use equation (1) with 0,46 instead of Betz limit, and multiply by the efficiency in the generator. As we can see in Fig. 4 it is just a littlie percent of the power [w] that is extracted as electrical power.

5. System design

The wind turbine is design in the 3D program Pro Engineer (Fig. 5) and most of the parts have been optimized for the lowest weight by using the program Pro Engineer Mechanica. This helped us in making a much lighter wind turbine.

5.1. Mounting parts

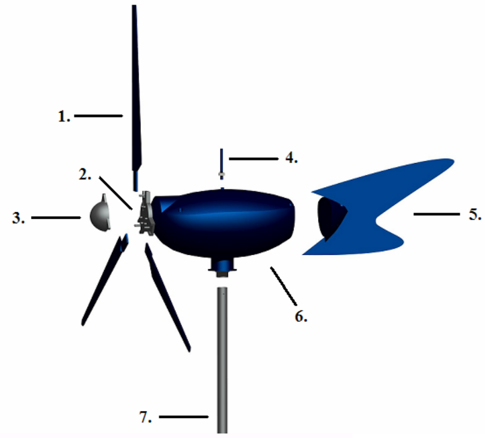

Fig. 5. Mounting parts on the wind turbine. The parts that have to be mounted together before use: 1 – blades, 2 – main shaft, 3 – rotor tip, 4 – velocity transmitter, 5 – steering wing, 6 – nacelle, 7 – mast

Rys. 5. Proces montażu turbiny wiatrowej. Części, które należy złożyć przed użyciem: 1 – łopatki, 2 – główny wirnik, 3 – pokrywa wirnika, 4 – przetwornik prędkości, 5 – ster kierunkowy, 6 – gondola, 7 – maszt

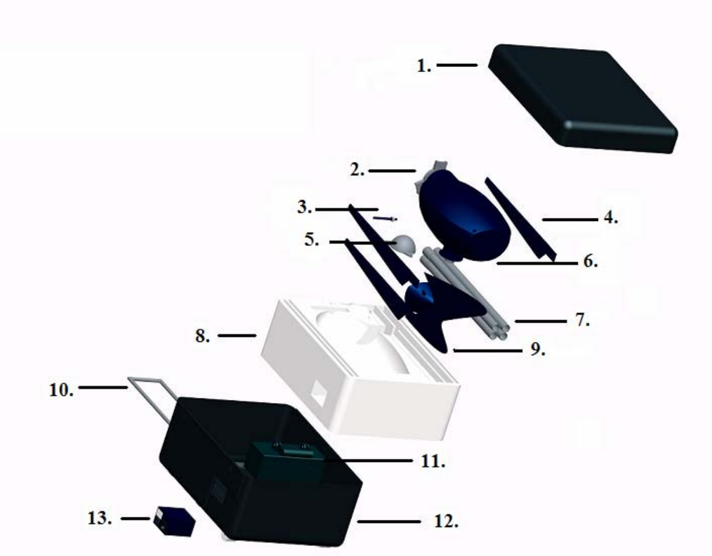

Fig. 6. The mobile wind turbine: 1 – suitcase top, 2 – main shaft, 3 – velocity transmitter, 4 – wing, 5 – rotor tip, 6 – nacelle, 7 – mast, 8 – windmill holder, 9 – steering wing, 10 – handle, 11 – battery box, 12 – suitcase,13 – controller

Rys. 6. Części składowe turbiny: 1 – pokrywa walizki, 2 – główny wirnik, 3 – przetwornik prędkości, 4 – łopatka, 5 – pokrywa wirnika, 6 – gondola, 7 – maszt, 8 – futerał, 9 – ster kierunkowy, 10 – uchwyt, 11 – akumulator, 12 – walizka, 13 – sterownik

5.2. The mobile solution

To make the wind turbine more mobile, we have designed a suitcase where all the parts for the wind turbine are placed inside. At the bottom of the suitcase there is placed a box of batteries, these are for a smaller use of electricity. It is possible to take the battery box out of the suitcase, so it won't take up too much space. There are also cables, controller and a transformer in the suitcase with a 12VDC and a 230VAC outlet. These parts are also possible to remove from the suitcase, in case someone wishes to have the wind turbine stationary.

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