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Study on the efficiency of a low-power vertical wind turbine

P Popov[1] , F Deliu[2], V Dobref[3], P. Burlacu[4]

[1]Lecturer PhD, Naval Academy “Mircea cel Bătrân”, Constanța, RO
[2] Associated professor PhD, Naval Academy “Mircea cel Bătrân”, Constanța, RO
[3] Professor PhD eng , Naval Academy “Mircea cel Bătrân”, Constanța, RO
[4] Associated professor PhD, Naval Academy “Mircea cel Bătrân”, Constanța, RO

E-mail: petrica.popov@anmb.ro

Abstract. The present paper addresses the theoretical calculation of electricity production for a low power wind turbine with a vertical shaft, as well as the effective design of the system and the choice of constituent components.

In this respect, the calculation have been made on the turbine efficiency at different wind speeds, based on the statistical data of the wind speed in the installation area, taken over a one-year period. The design of the entire system has taken into account the characteristics of: the inverter, the controller and the electric accumulators, so that the energy, provided by the wind turbine, been used in a most efficient way.

Keywords: vertical wind turbine, efficiency

1. Introduction

The production of electricity from renewable sources has meant the independence of consumers from the major energy producers and distributors. Due to low raw material prices, the technology of wind turbine manufacturing processes and their efficiency for power generation, we now have more accessible systems on the market. For not connected areas to the power grid or isolated areas that can only be branched with huge costs, wind turbines can become the perfect investment.

In the current context, characterized by the alarming increase of the pollution caused by the production of energy from the burning of fossil fuels, it is becoming increasingly important to reduce the dependence on these fuels.

Wind energy has already proven to be a very good solution to the global energy problem. The use of renewable resources addresses not only the actual generation of energy, but the particular mode of generation also intuited the development model, by decentralizing the sources. Wind energy, in particular, is among the renewable energy forms that lend itself to small-scale applications. Reduced costs for decommissioning is also an advantage. Unlike nuclear power plants, for example, where costs may be several times higher than the costs of the unit, in the case of wind generators, which can be fully recycled, the costs at the end of the normal operating period are minimal,.

The obligations to reduce greenhouse gas emissions for Romania, as a member of the European Union, are in line with its objectives [1]:

• reducing, by 2020, by 20% of greenhouse gas emissions at EU level compared to 1990;

• reducing the energy consumption of hydrocarbons by 20% by improving energy efficiency to levels estimated for 2020;

• increasing the renewable energy amount in the total energy consumption by up to 20% over the same period.

In recent years, the use of wind energy has made a great breakthrough, over the past 25 years, energy efficiency has doubled, and the cost of one kWh product has gone from 0.7 euros to about 0.32 euros today.

According to a study by the European Wind Energy Association, the largest wind energy producer in the EU is Germany with 25,777 MW installed in 2009, followed by Spain with 19,149 MW and Italy with 4,850 MW [2]

1.1 The Dobrogean wind energy potential. Dobrogea is one of the richest areas in terms of its energy potential, having three very powerful sources of energy: the sun, the wind and the waves, all of which can be exploited to the maximum, bringing a great benefit to the region.

The average wind intensity for the Dobrogea region is 7.2 meters / second throughout the year, making it the ideal place for wind turbines.

Dobrogea is considered to be the most promising region in Europe as a wind potential [2]. In Constanta County, the average wind speed is around 12 m / s, with the predominant direction in the SE of the region.

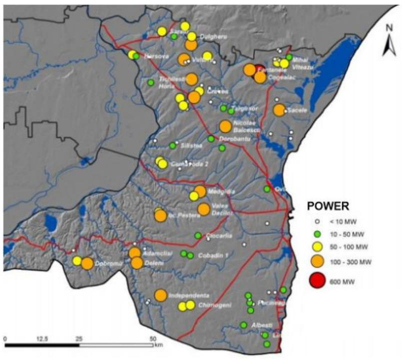

Figure 1. Map of wind farms in Constanta county
(source: http://old.unibuc.ro/prof/dobre_r_r/docs/res/2014iularticole_eolian.pdf)

1.2 Wind turbines with vertical axis. Wind turbines with vertical axis rotation, especially the Savonius rotor and its various variants, are well suited for electricity generation, considering their operating parameters and the wind regime in the studied area.

The main problem with vertical wind turbines operating on aerodynamic friction is that they are not produced in series, and there are currently only handicrafts that use these types of rotors to produce electricity. So, it is very important to achieve some experimental studies to show which of the rotors, and which constructive parameters are best suited for the production of electricity.

Recent research on the behavior of different types of wind turbines under real-life conditions highlights a number of advantages of vertical-axis conversion systems such as: wind direction orientation, electromechanical system placement at the base of the installation, possibility of taking small bursts of wind, the possibility of fixing the blades in several positions, helping to reduce the resistance and stiffness requirements.

The most known vertical wind turbine models, are:

- *Darrieus* - concept based on the lift-type principle, the blades having an aerodynamic profile, making it possible to rotate the rotor at a higher speed than the wind. Vertical axle turbines, based on the load principle, can also be divided into several constructive solutions: Darrieus classic; Giromill; H-Darrieus; H-Darrieus with helical blades. The modern commercial variants of the Darrieus concept are characterized by aerodynamic blades, the ends of which are fixed to the top and bottom center axes, placed in a flow of air and depending on different angles, are subject to forces whose intensity and directions are different [3]. This allows the increase of the wind energy utilization coefficient to Cp = 0.43.

- *Savonius* - concept based on the drag-type principle - the wind "pushes" cup-shaped blades. This implies limitations of the possible maximum rotation speed, which is always equal to or less than the speed of the wind [4]. The turbine has a higher solidity and lower end speed ratios, providing an increased start-up time, and an optimal geometry can achieve a Cp estimated at 0.24-0.30. It requires the lowest wind speeds (3-5 m/s) to start.

The analysis of the separate concepts regarding the advantages and disadvantages offered highlights for relatively good conversion efficiency, which allows their operation in areas with a high wind energy potential, such as Dobrogea.

2. Experimental set-up and results

2.1 Calculation of efficiency. For a real wind vertical turbine has considered the following characteristics**:**

- Blade length = 1.4 m
- Air density = 1.23 kg / m3
- η = 0.25
- The area described by the blade = 2 sq. meters

For wind speed of 11 m/sec, the calculation of power is made with the expression below:

$$P = \frac{1}{2}\rho \cdot A \cdot v_1^3 \cdot \eta = 167\ W \qquad 1.1$$

Table 1. Power dependence on the turbine shaft relative to wind speed

Wind speed (m/sec)	Calculated power (W)
7	31,642
9	87,425
11	**167,806**
13	249,964
15	311,344
17	377,687
19	358,554
21	341,731
23	336,722

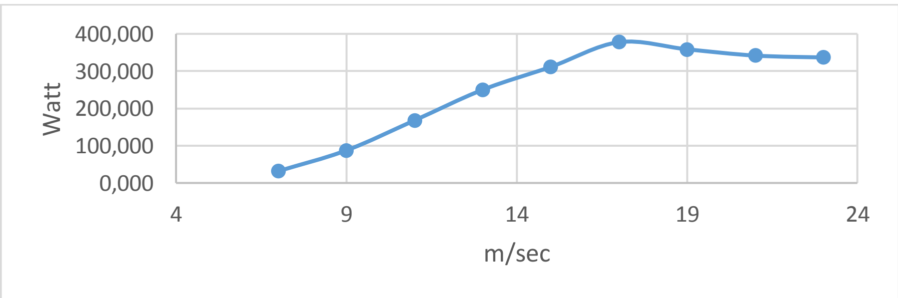

Figure 2. Power dependence on shaft versus wind speed

Actual power dependence on the chosen turbine shaft from wind speed:

$$\lambda = \frac{blade\ speed}{wind\ speed} \tag{1.2}$$

$$blade\ speed = \frac{angular\ velocity \times \pi \times D}{60} \tag{1.3}$$

where, angular velocity =15 rpm.

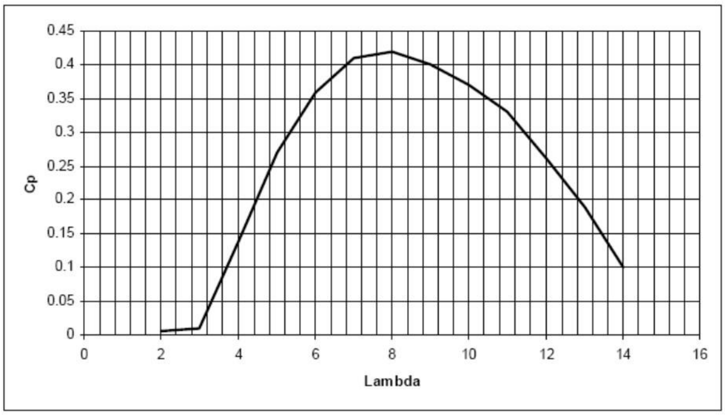

Figure 3. Turbine efficiency Cp dependence on computed lambda coefficient

Table 2 Calculated data for electricity produced over a year

Wind velocity (m/sec)	Time (hours)	Lambda	Efficiency	Power (W)	Energy (W h)
1	531				
3	1407				
5	1831				
7	1769	11,66286	0,3	31,64175	55974,25575
9	1386	9,071111	0,39	87,425325	121171,5005
11	913	7,421818	0,41	167,805825	153206,7182
13	524	6,28	0,37	249,963675	130980,9657
15	249	5,442667	0,3	311,34375	77524,59375
17	105	4,802353	0,25	377,686875	39657,12188
19	39	4,296842	0,17	358,554225	13983,61478
21	12	3,887619	0,12	341,7309	4100,7708
23	3	3,549565	0,09	336,721725	1010,165175
25	1				
27	0				
Total	**365 days**				**597.609,7065**

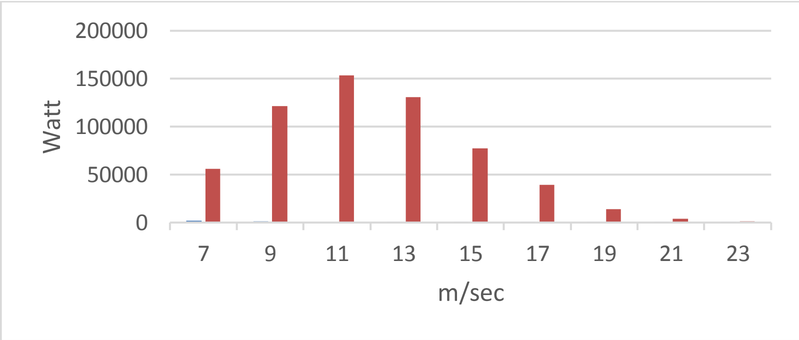

Figure 3. Electricity generation based on wind speed (one year)

From a total of 8,544 hours per year, it was found that the wind speed range for which the turbine becomes effective (7m/sec < v_{ax} < 23m/sec) is approx. 5000 hours.

The estimated electricity production calculated for the selected turbine parameters and the wind speed (in terms of efficiency) per year, in the area where it was installed, is approx. 600 KW/year.

2.2 System design and component description

The wind turbine system with a vertical shaft will be installed in the vicinity of an electrical and electronic engineering laboratory, so that the production of the electric power will ensure its autonomy.

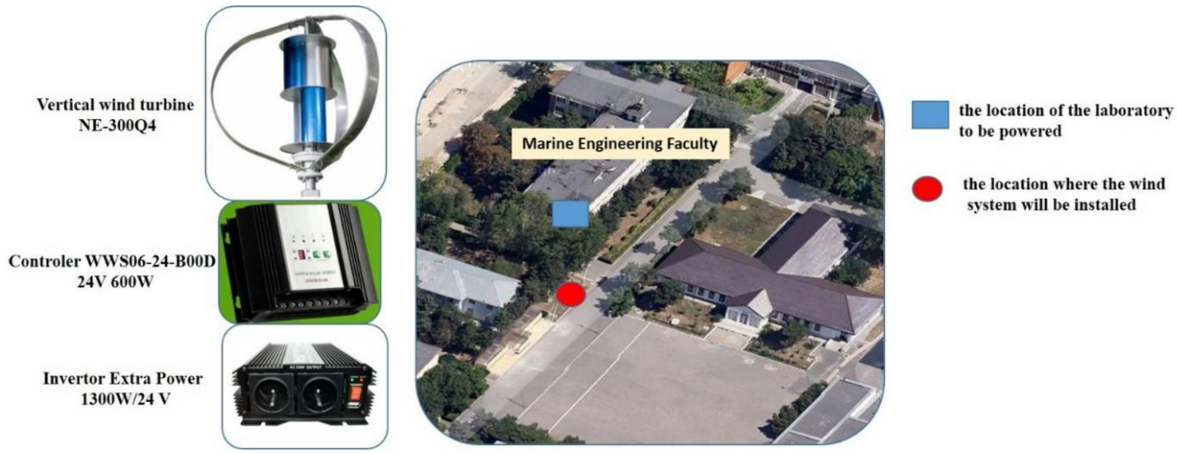

Figure 4. System layout and composition

The constituent elements of the system are:

A. ***Vertical wind turbine NE-300Q4 24V 300W***. Wind turbine for power generation, JIANGSU NAIER, type NE-Q4, model 300Q4. The blades capture the kinetic energy of the wind that they transmit to the three-phase, synchronous AC magnet generator. It converts kinetic energy into electrical energy. [5]

Technical specifications:

- rated power [kW] - 0.3 kW;
- output voltage - 24 V;
- start-up wind turbine 2 [m/s];
- rated wind speed 11.5 [m/s];

- survival wind speed 45 [m/s];
- wheel diameter - 1,380 [mm];
- number of blades - 7 [pcs];
- generator type – PMG three phase, synchronous.

The vertical shaft wind turbine was mounted on a cylindrical support column 60 mm in diameter and 6 m in length.

B. **Hibrid controller** - WWS06-24-B00D/24V/600W. The wind / solar hybrid controller is a device that simultaneously controls efficient charging of wind turbine batteries and photovoltaic solar panels. It assures the protection of the battery system both at overloading and deep discharge. The operating performance of the controller is:

a. *No step discharge mode type Pulse Width Modulation.* PWM mode is used to dissipate residual energy on discharge electric resistors in the "DUMP LOAD" module. For various residual energy values, it is possible to switch through thousands of adjustment stages without switching between actual sockets to segment the discharge resistors. This keeps the battery charge voltage at the proper value, regardless of the variable voltage at the generator terminals.

b. *Limiting voltage and charging current.* If the battery pack voltage exceeds the initially set value, the controller enters the load limitation mode via the PWM voltage. If the turbine exceeds the revving speed in the normal operating mode, the load current increases uncontrollably, the controller automatically starts the electromagnetic brake, thus protecting the system and the battery set.

The chosen controller has the following features [6]:

- Nominal voltage - 24 V;
- Wind turbine power input 600 [W];
- Max. power input wind turbine 900 [W];
- Wind turbine load interruption voltage 29 [V];
- Reset wind turbine charging voltage [V];
- Wind turbine load interruption current 25 [A];
- Modulation load voltage 27 [V];
- Battery discharge protection voltage 21.6 [V]

C. ***Inverter EXTRA POWER 1300W /24 V.*** Continuous voltage controlled by the controller to keep batteries charged is taken over by the inverter to convert to AC/ 220V; 50 Hz required for general purpose consumers. It is possible that at certain times, when the wind turbine and photovoltaic panels can not provide electricity, the inverter will require the batteries until they are discharged. When the battery system voltage reaches 19.8V, the inverter automatically disconnects the batteries.

In this case, the power supply to the consumers is interrupted and this will prevent the batteries from being discharged. Deep discharge significantly shortens the life of any battery. The inverter automatically recovers into the system when the battery voltage (two 12V series battery packs) has reached 24V. The inverter is also decoupled when the controller fails to limit the voltage at the input. The decoupling voltage is 26.6 VDC. Disconnection protects the inverter and, implicitly, consumers from an abnormal operating mode.

Inverters must be equipped with filters and overvoltage protection circuits. To avoid malfunctions of the inverters, they are provided with control blocks, which are designed for: variations in AC voltage, frequency, network impedance and current intensity. The facilities of inverters are:

- short circuit protection on input and output, overload protection and overheating;

• power consumption display and battery voltage. Inverters have as their main feature the nominal power, which represents the maximum allowable consumption at the 230 V output;

• the shape of the output wave. There are inverters with pure sinusoidal wave or modified sine wave. Modified sinusoidal inverters are more affordable, but are not suitable for electrical or electronic equipment using 230 V powered motors, for which pure sinusoidal wave inverters are used.

Technical specifications of EXTRA POWER 1300W invertor / 24 V, are [7]:

• Input voltage-24 V;

• Output voltage-230 V ± 5%;

• Output Wave Type-Modified sinusoidal wave, 50 Hz;

• Output power-1300 W;

• Power peak- 2000 W for 0.3-0.5 seconds;

3. Conclusion

Regarding the study that was done before the design and installation of the vertical wind turbine, the following conclusions were drawn:

• from a total of 8.544 hours per year, it was found that the wind speed range for which the turbine becomes effective (7 /sec < v_{sh} <23m / sec) is approx. 5000 hours;

• the production calculated for the parameters of the turbine chosen and the wind speed (in terms of efficiency) per year, in the area where it was installed, is approx. 600 KW / year;

• for the chosen site area reported in terms of efficiency on turbine construction, the best solution was a vertical axis turbine;

• the estimated power to be found in the actual production of the turbine can meet the energy needs of an electrical engineering laboratory (1.68KW / day) to a good extent.

Considering the energy values produced, according to the theoretical calculation made on such a configuration, one can say that such a solution is cost-effective. It is expected that the next time will confirm the estimated values by producing real electricity.

This configuration might be the basis for expanding such systems within the Naval Academy by using more power turbines whose effectiveness is correlated with wind conditions in the installation area.

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