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Dependence of the maximum power and wind speed

The issue paper is to present renewable energy sources insisting mainly on wind energy. This source is analyzed in the context of Romania in particular and the EU in general. A turbine with horizontal axis is usually coupled with vessel power systems. Wind energy knows an increased growth rate. At the end of the paper are presented possible structure of coupled a wind to power systems.

Keywords: *renewable energy, wind energy, wind turbine, vessel energy system*

1. Introduction

In the first part of these papers it's presented a wind turbine with power P = 5KW, mounted on the Romanian Black Sea coast. The second part comprises wind speed records for a period of three months. Active power system (wind turbine + synchronous generator) was measured experimentally and presented its evolution over time.

They determined the mechanical properties of various wind turbine and wind speeds were checked with the mathematical model of naval wind turbine. In the second papers of experimental verifications was performed power dependence of the maximum wind speed cube.

In the final papers presents the behavior Diesel Generator by recording the speed and voltage while the generator set with a Proportional-type regulator and the conclusions of the analysis of experimental results.

2. Wind turbines in the Black Sea area

From the many wind turbines "WT" mounted in Dobrogea, the turbine with horizontal axis type BWC XL.1 was analyzed:

- nominal power Pn=5[KW];
- Un=230[V] at f=50[Hz].

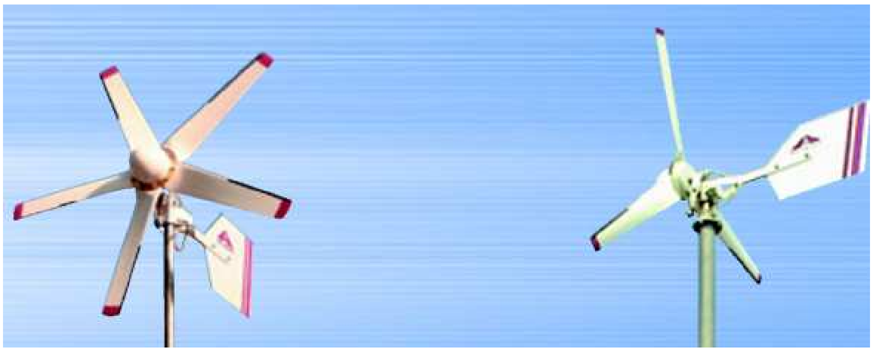

Figure 1.a) Small wind power plants for charging batteries.

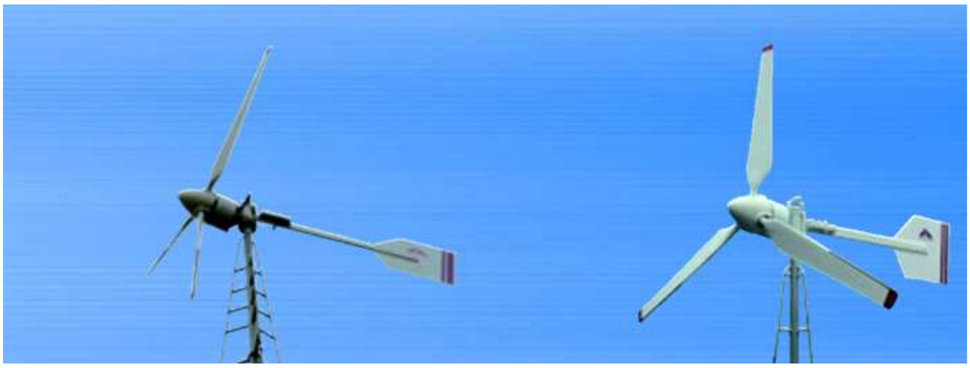

Figure 1. b) Small wind power plants for charging batteries.

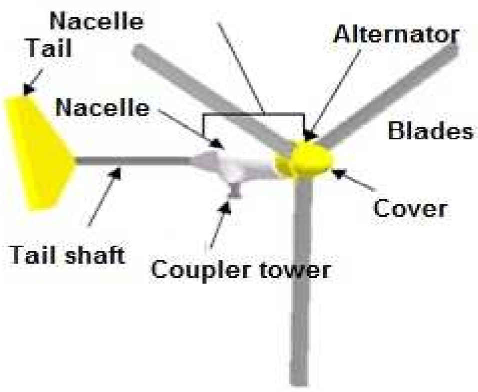

Figure 2. Main components of the wind turbine

BWC XL.1 system description

Main components are presented in figure 2.

A. The blades and the rotor

The rotor consists of a block and three palettes. Glass fiber blades are super strong because they have in their structure wires made of special glass fibers, hardened and stretched along their length. The rotor has three blades because this type works much smoother than the one with 2 blades.

B. The alternator

The alternator converts the rotational energy of the rotor into electricity. It uses permanent magnets with a special configuration, different from a normal one, so the outer casing with magnets rotates, while the central axis is fixed with the winding. This provides greater efficiency when running at lower wind speeds. The output voltage of the alternator is three phase-alternative AC, but is redressed in direct current by the rectifier of the Nacelle. By using permanent magnets, the alternator generates voltage whenever the rotor rotates, independent of an external excitation.

C. The Nacelle

The Nacelle has a fiberglass cover housing that surrounds the main body of the machine, composed of rectifier, the collector rings assembly, the rotational bearing and the coupling with the tower. The rotational bearing allows the turbine to pivot freely around the tower, so the rotor being always in the wind. The collector rings assembly makes the electrical connection between the part that rotates (the nacelle) and the fixed wires from the tower. The collector rings assembly and the rotational bearing of the nacelle, are located just above the coupling with the tower.

D. The tail assembly and the Auto Furl operation (storm protection)

The tail assembly is composed of an axis and a tail wing. It's role is to hold permanently the nacelle with the rotor in the wind, at wind speeds less than 12.5 m/s (45 km/h). At about 12.5 m/s, the Auto Furl system comes into action and rotates the nacelle aside the wind, limiting the rotation of the rotor. It seems that the tail folds, but in reality the tail sits in the wind and the nacelle rotates. However the rotor does not move entirely from wind, allowing the turbine to produce energy even at high winds.

When the wind drops in intensity, the nacelle is rotating again in the wind, in a straight position.

E. The Power Center Controller

Figure 3. The Power Center Controller for BWC XL.1

The Power Center controller serves as a central point of connection of the electrical components of system and performs important and necessary functions in controlling the entire electrical system. Not all the functions will be in used in all of the installations. The controller has status LEDs for system and a line of lights which indicates the degree of charging of the batteries group. The rotor starts to rotate at the wind speed of about 3m/s (10.8 km/h).

Strong winds – Auto Furl Protection

During strong winds, the Auto Furl system will automatically protect the turbine. When the turbine tilts aside, the generated power is reduced significantly.

In the case of winds at 13 m/s (47 km/h) up to 18 m/s (65 km/h), is normal for the turbine to tilt repeatedly aside, but at the wind strength of more than 18 m/s (65 km/h), the turbine will remain tilted aside continuously, up to the decreasing of wind's intensity under 18 m/s.

The Auto Furl System is a simple and efficient protection method from strong winds. The system is based on the aerodynamic forces of the rotor, gravitation and the geometry of the carefully chosen turbine.

The aerodynamic forces acting on the blades cause a pushing force on the rotor. These forces increase along with the increasing of wind's speed. The pushing force acts through the central line of the rotor, which is shifted towards the centre line of the axis of tower centered with the aside rotation axis of wind. That's why the pushing forces which acts on the rotor, will try to rotate the rotor aside the wind. But the rotor is maintained in the wind's direction with speeds up to 12.5 m/s (45 km/h) by the turbine's tale assembly. The turbine's tale is maintained as its own weight, because its pivot from the back of the nacelle is tilted. So the tail's weight rests on a rubber pad and holds the rotor into the wind.

The geometries of the system are carefully balanced, so that only over the wind's speed of 12.5 m/s (45 km/h), the forces of the rotor acting on the aside rotation system are large enough to overcome the force that holds the tail straight. At this point, the rotor starts to rotate aside the wind. Instead of this, the tail will always remain aligned to wind's direction. The speed of the rotor which moves aside is determined by the momentary speed of wind.

The strong wind protection system is working if the turbine is loaded or not. The Auto Furl system is completely passive, very secure and robust, as there aren't any moving parts that could wear out, as in classical braking systems.

This system was used in the 1980's on Berger turbines, since then, on every produced turbine, was an important and successful element of wind turbines.

Slow-Mode Operation (At low rotational speed)

At the time when the voltage of batteries bank reaches the nominal voltage, the Power Center controller will first try to reduce the charging of voltage by connecting the additional electrical charge. The function of extra charge deviate the current from the batteries charging to an electric heater of air or water when the batteries are charged at nominal voltage. If this action taken by the controller is not sufficient, or if the additional electric heater of extra-charge doesn't exist, the Power Center controller will reduce the rotational speed of the turbine and partially interrupt the supplying with energy from the solar panels so that batteries will not be overburdened.

The Slow-Mode function (low rotational speed) prevents operation of the turbine without consumers as soon as the batteries are charged. This reduces the noise made by the turbine and the tendency of the waving of blades. The waving of blades can occur in very strong wind conditions at high rotational speeds of the rotor. This waving does not jeopardize the system.

In Slow-Mode (low rotational speed), the turbine is reduced at about 130 rot/min on little wind, and if wind will increase in intensity, the rational speed of the rotor will decrease further. The maximum power in this operating mode is 120 W. If the energy consumption from batteries will increase, the Power Center controller will increase the rotational speed of the turbine so the charging current of batteries will increase again.

If there isn't any electrical consumer connected and the batteries are full, the wind turbine is brought to a very low rotational speed, about 20 rot/min , and the photovoltaic panels are completely disconnected.

The Power Center controller

The generator produces an alternative three phase AC current, which varies in voltage and frequency with the rotational speed of the rotor. The three-phase AC current is rectified in direct current by a rectifier located in the nacelle. So the current which departs from the turbine to the Power Center is direct current, at 24V.

The Power Center controller has two sets of light diodes for the it self Control of System and for the Control of the batteries bank's state.

3. The speed of wind in the area of the Black Sea coastline

The recordings were made in the area of the Black Sea coastline in August, September and October 2010, where a field of wind power plants was mounted by the Black Sea area.

Knowing the details about the annual average wind speed from the weather observer located in the area and doing measurements with the equipment , we could estimate, with an acceptable error, the speed of wind in the August-September-October 2012 period.

So the following variations of wind's speed were obtained during August – September – October 2012:

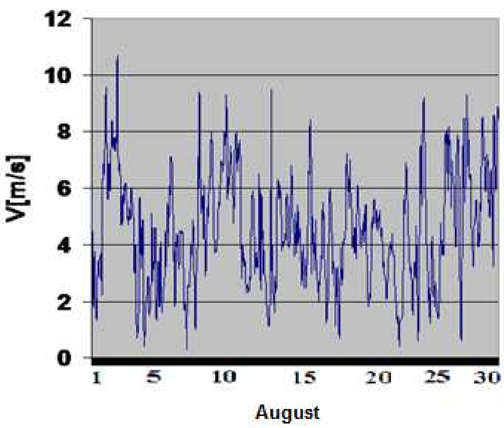

Figure 4. The speed of wind in August 2012

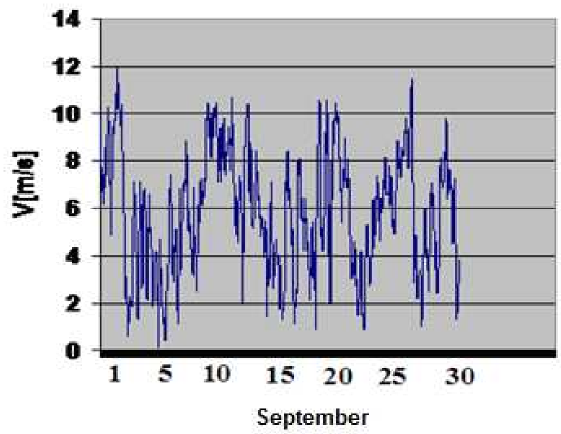

Figure 5. The speed of wind in September 2012

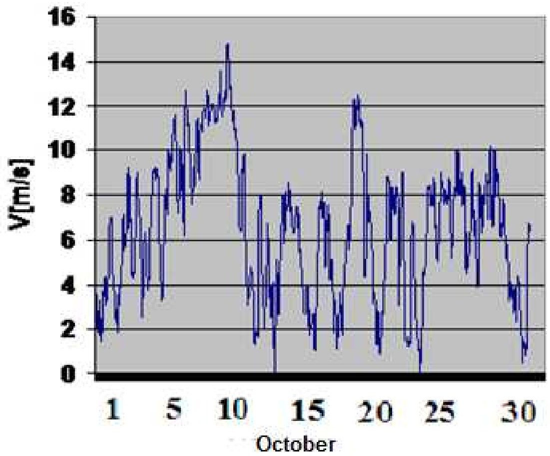

Figure 6. The speed of wind in October 2012

4. Experimental verifications of the maximum power dependence of wind speed cube

The maximum power developed by a wind turbine depends on the speed cube:

$$P_{WT} = K_{WT} \bullet V^3$$

There were differences in estimating the maximum power of the wind turbine. It also notes that on quick changes of wind speed over time, the operating point is far from the point of maximum power, and, for example, from V = 3.5 [m/s] to V = 2.2 [m/s], the load changes from 2.36 to 0.04. The use of small low inertia turbines can bring the operation closer to the point of maximum power.

5. The determination of wind turbine's mechanical characteristics

From experimental data: the "P" active power developed by the generator and rotational speed "n" at wind turbine shaft, the torque of turbine is determined. The experimental verifications were made at a wind speed value: V=4 (m/s) and V=5 (m/s) for ω angular speeds of wind turbine in the area ω=(2÷10)(rad/s).

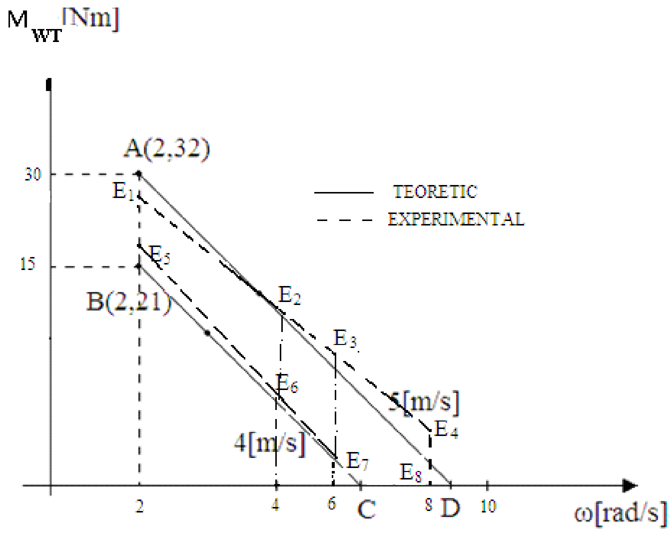

Figure 7. The mechanical characteristics of wind turbine

Knowing the power P which wind turbine is working at and rotational speed n, the values of torque were calculated in points: E1, E2, E3, E4 for the speed V=5 (m/s) and E5, E6, E7, E8 for V=4 (m/s).

For the calculation of torque was used:

$$M_{WT} = P / (2\pi n / 60)$$

where:

-p is the power measured at generator and corrected with the value of system efficiency (wind turbine + synchronous generator);

-n is the rotational speed at wind turbine shaft;

At wind speed V=4 (m/s) the mechanical characteristic of wind turbine is given by the equation:

$$M_{WT-4} = -4.2\ \omega + 29.4$$

which approximates the mechanical experimental characteristic with an error below 4 %.

At wind speed of V=5 (m/s) the mechanical characteristic of wind turbine is given by the equation:

$$M_{WT-5} = -4.5714\ \omega + 41.143$$

This approximates the mechanical experimental characteristic with an error below 3 %.

The points of maximum power are:

-P1 for V=4(m/s);

-P2 for V=5(m/s).

and is characterized by the following values of power:

P1=51.45[W] - calculated;

P1exp=52.1[W] - measured;

P2=92.573[W] - calculated;

P2exp=91.3[W] - measured.

The differences between the theoretical results and the ones measured at those two wind speeds and taking in consideration the mechanical power captured by the wind turbine, are:

ε_1=ΔP/P1=1.25% for V=4(m/s);

ε_2= ΔP/P2=1.39% for V=5(m/s).

6. The experimental determination of the optimal charge resistance

As mentioned, in the locations of the coastline, wind turbines are used for charging electric batteries and therefore, as generators were used direct current generators with permanent magnets which have the great advantage for not being necessary the redressing of alternative current and so the conversion system is much simpler.

Direct current generators with permanent magnets excitation debit directly on the electric battery symbolized in the figure below by R charge.

The optimal operation of subsystem (wind turbine + permanent magnet generator + electrical accumulators) was done experimentally by tests at various charge resistances connected to the terminals of generator, as shown in figure 8.

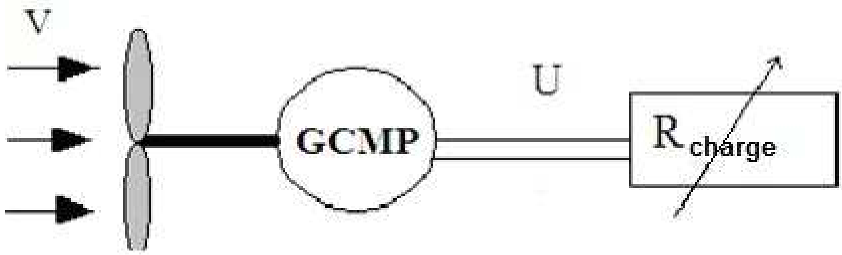

Figure 8. Wind system with resistive charge

By direct measurement of power at different values of R and V, the dependence of charge resistance from the speed of wind is obtained, while the power obtained from the turbine being maximal. Maximal power was obtained through small changes of charge resistance around the values obtained from the calculation.

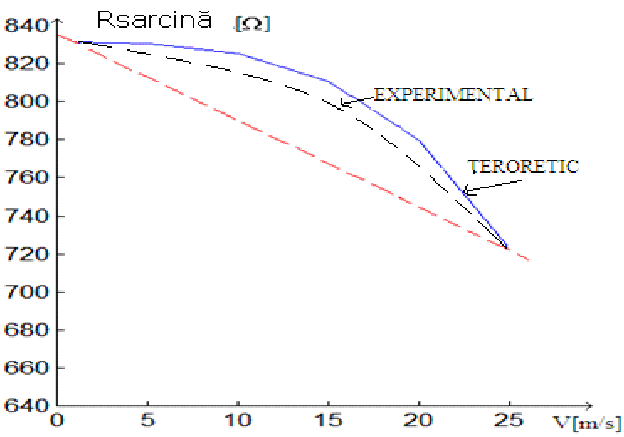

Figure 9. The dependence on charge resistance

The energy measured after a time T=5555[s] is compared with the one calculated below:

a) For $R = 831[\Omega]$: $W_{exp} = 1.1654 \times 10^6 [J]$; $W_{teoretică} = 1.156 \times 10^6 [J]$; ,

b) For $R = 931[\Omega]$: $W_{exp} = 1.1334 \times 10^6 [J]$; $W_{teoretica} = 1.124 \times 10^6 [J]$; ,

c) For $R = 531[\Omega]$: $W_{exp} = 1.2235 \times 10^6[J]$; $W_{teoretică} = 1.217 \times 10^6[J]$,

d) For $R = 231[\Omega]$: $W_{exp} = 1.0536 \times 10^6[J]$; $W_{teoretică} = 1.052 \times 10^6[J]$,

e) For $R = 31[\Omega]$: $W_{exp} = 4.3881 \times 10^5[J]$; $W_{teoretică} = 4.351 \times 10^5[J]$,

f) For $R = 1531\Omega$: $W_{exp} = 9.3638 \times 10^5[J]$; $W_{teoretică} = 9.359 \times 10^5[J]$.

The differences between the theoretical results and the experimental ones are below 1.5 % which confirms the validity of mathematical models of the naval wind turbine.

7. The Diesel-Generator system behavior

At a Diesel-Generator group on a ship from the endowment of the merchant maritime fleet experimental verifications to the system's behavior in transient regime were made.

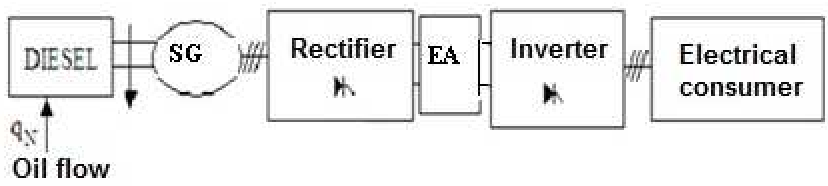

Figure 10. Diesel-Generator Group

From the simulations, result the time variation of angular mechanical speed – ω – and the – U – electric tension at the generator by use of a proportional-type regulator.

The experimental results confirm these variations as shown in figures 11. and 12.

The differences between theoretical results and the experimental ones are below 3% which confirms the validity of mathematical models of Diesel Engine and Generator.

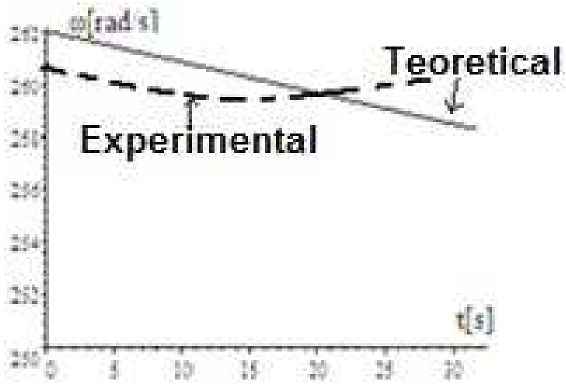

Figure 11. The time variation of ω

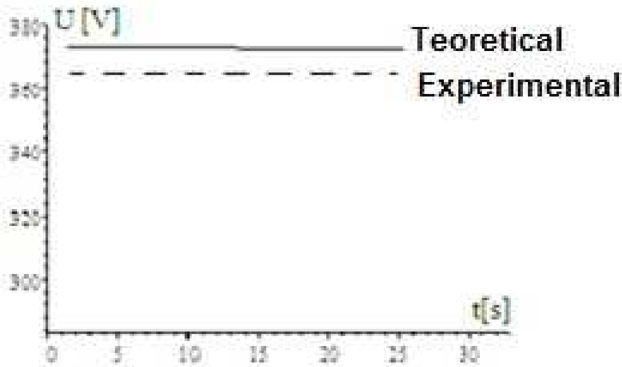

Figure 12. The time variation of electric tension

4. Conclusion

The recordings made in the area of the Romanian Black Sea coastline have demonstrated the fact that the wind potential in this area is important and so it's exploitation is economically viable both on land and sea.

From the experimental data taken from an operational wind turbine in 2012 in Dobrogea area the accuracy of equations which models the mechanical characteristics of wind turbine characteristics which were used throughout the article. In the analysis of powers, the torques were calculated and compared with those obtained from the calculation. The differences were less than 2% in estimating the maximum powers of wind turbine operating.

The experimental verifications on operating in the points of maximum power have revealed the fact that at low wind speeds and at fast and significant changes of wind speed, the wind system does not always work in the points of maximum power, because of the high mechanical inertia of the system (wind turbine + synchronous generator). These aspects have been widely analyzed during the thesis, where you can see the big influence of the equivalent moment of inertia of the electric turbine-generator system. Important roles in ensuring the stability in operation have regulators whose award is made after careful analysis of the system behavior.

References

[1] Ackermann, Solder L., *An overview of wind energy-status*, Renew. Sustain. Energy Rev., vol. 6, no. ″, pp. 67-128, 2002.

[2] Andreescu G.D., *Observers for speed, acceleration and load torque in motion control of electrical drives*, Proc. Automatic Control and Testing Conference A' 96 THETA 10, Cluj-Napoca, vol.1, pp. 307-312, May 1996.

[3] Babescu M., *Synchronous Electrical Machines - Modeling-Identification-Simulation*, Politehnica Timişoara, 2003.

[4] Boldea I., *Unified treatment of core losses and saturation in the orthogonal axis model of electric machines*, IEEE Proceedings, Vol. 134, Pt.B., No.6, 1987.

[5] Deliu F., *Transitory phenomenons into naval electrical equipment hybrid powered*, Ph.D. Thesis, Politehnica Timişoara, 2011.

[6] Deliu F. , Burlacu P., *Black Sea meteorological factors analysis for implementing renewable energy sources into naval power systems*, Nav-Mar-Edu, Constanţa, 2013

[7] **** Monsson Alma, Catalog.

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