
ELABORATION OF WIND ENERGY CONVERSION SYSTEMS

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Abstract: *The largest energy reserves are stored in the oceans - a large area of water currents continuously moving and covering about 71% of the planet's surface. The Planet Ocean has a huge energy potential that can be employed to produce electricity. The main sources of the ocean energy considered, at least in the current technical level, refer to: tides, currents, waves, temperature differences of the seawater layers. Some technical solutions have been developed for wave energy capture devices at conceptual level. These solutions are protected by six patents. Future development is expected based on these inventions, namely, laboratory samples and their testing in laboratory conditions.*

Keywords: *wind energy, wind turbine*

1. Introduction

Wind energy has been used by mankind over thousands of years. For over 3000 years the windmills have been used for pumping water or grinding (milling). And nowadays, in the century of information technologies, nuclear energy and electricity, thousands of windmills are used for pumping water and oil, for irrigation and production of mechanical energy to drive low-power mechanisms on different continents. The electricity produced from the wind is not differing from the electricity produced from fossil or nuclear fuels. The wind as a fuel is essentially different – it is free of charge and does not pollute the environment.

Nowadays, the phrase „*use of wind energy*” means, primarily non-pollutant electrical energy produced at a significant scale by modern “*windmills*” called *wind turbines*, a term that attempts to outline their similarity to steam or gas turbines, which are used for producing electricity, and also to make a distinction between their old and new destination.

The attempts to obtain electricity from the wind date back over a hundred years since the late nineteenth century. But a true flourishing of this technology is registered only after the 1973 oil crisis. An unexpected increase in oil prices has forced the governments of developed countries to allocate substantial financial resources for research, development and demonstration programmes. Over 20 years, worldwide, a new technology, a new industry and, in fact, a new market - the market of the Wind Energy Conversion Systems (WECS), have been developed. Siemens and Vestas are the leading turbine suppliers for offshore wind power. DONG Energy, Vattenfall and E.ON are the leading offshore operators. With the launch of the European Technology Platform on wind energy issues the EU Commissioner A. Piebalgs said [1]: „*Wind energy technology is certainly one of the fastest growing and plays an important role, contributing to create a sustainable and competitive energy policy in Europe*”.

The global leader is China (31,1%) followed by the European Community EU-27 with a 28,7%, USA (17,8%) share (2014) [2]. As of 2015, Denmark generates 40% of its electricity from wind [3] and at least 83 other countries around the world are using wind power to supply their electricity grids. In 2014 global wind power capacity expanded 16% to 369,553 MW [2]. Yearly wind energy production is also growing rapidly and has reached around 4% of worldwide electricity usage. In 2015, close to half of all new wind power was added outside of the traditional markets in Europe and North America. This was largely from new construction in China and India (Global Wind Energy Council (GWEC) figures show that 2015 recorded an increase of installed capacity of more than 63 GW, taking the total installed wind energy capacity to 432.9 GW, up from 74 GW in 2006. In terms of economic value, the wind energy sector has become one of the important players in the energy markets, with the total investments reaching €296.6 bn, an increase of 4% over 2014.

The wind provides electricity to more than 35 million households in the EU, but very few know it – a symptom which indicates a lack of knowledge about this technology. Globally, by 2020 about 12% of the produced electricity will be of wind origin.

To know the whole technology of the wind energy conversion into electricity, knowledge in various fields is required, including meteorology, aerodynamics, electrical engineering, mechanical engineering and civil engineering. In order to make a correct decision for investment it is necessary to have knowledge of the economic analysis of projects

2. Wind turbine in the air flow

The wind turbine converts the kinetic energy of the air flow that passes through an area swept out by the rotor into mechanical energy, then using the generator - into electricity. The question arises: what happens by placing the turbine rotor in an air flow? It is obvious that the air flow gives up only part of the kinetic energy (see the next paragraph), the remaining energy is consumed so as the air leaves the area of flow - turbine interaction.

Figure 1 shows an airflow with the initial speed V_0 , which crosses the circular area A_0 and interacts with the turbine rotor with the scavenged area A_1 . In section A_1 , the air flow encounters resistance, the pressure increases, and the speed decreases to V_1 . Giving up part of the energy the air flow leaves the turbine with the speed V_2 lower than V_1 . As the air mass that passes through sections A_0 , A_1 and A_2 remains constant and the speed drops, it follows that $A_2 > A_1 > A_0$, i.e., there is deflection of the air flow that passes through the turbine rotor, forming a funnel. The airflow formed immediately after the propeller is called the propeller slipstream, in which the static pressure is lower than in the free zone of the atmosphere. The static pressure is repressuring at longer distances from the propeller.

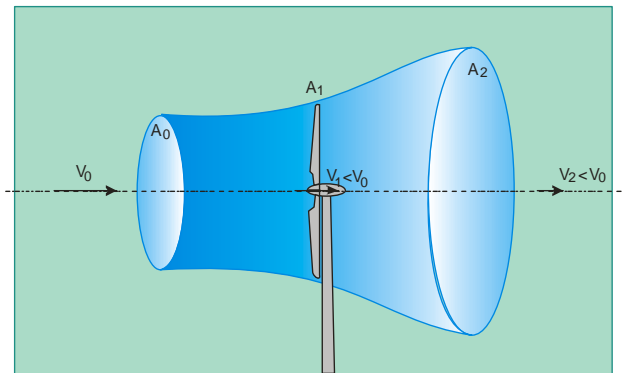


Fig. 1. The effect produced by the wind turbine on the air flow

3. Betz limit

In 1919 the German physicist Albert Betz formulated the law that answers the question: what part of the kinetic energy of the air flow can be converted into mechanical energy? Betz analysed a turbine with an ideal rotor: it is assumed that the rotor presents a disk with an infinite number of thin blades, energy losses are neglected, the flow of air runs through imaginary sections without turbulence in Figure 1. Velocity V_0 is the speed of airflow till the rotor, V_2 is the speed of air flow leaving the rotor area, V_1 is the flow velocity in the A_1 section of the rotor. In accordance with the Newton's second law the variation of motion quantity is equal to the force acting on the body:

$$F = \frac{d(mV)}{dt} = m \frac{dV}{dt} \quad (1)$$

The variation of the air flow velocity for the above model during one second ($dt=1s$) will be, $dV = V_0 - V_2$, so

$$F = m \cdot (V_0 - V_2). \quad (2)$$

We introduce the concept of air flow braking factor in the turbine $e = V_1 / V_0$ and, assuming that the wind speed varies linearly, determine the air flow speed of the A_1 area of turbine:

$$V_1 = \frac{V_0 + V_2}{2}, \longrightarrow V_2 = 2 \cdot V_0 \cdot e - V_0. \quad (3)$$

Take into consideration that $m=\rho SV$ the air mass crosses area A_1 in a second:

$$m = \rho \cdot A_1 \cdot V_1 = \rho \cdot A_1 \cdot V_0 \cdot e. \quad (4)$$

Let substitute in (2) velocity V_2 and mass m according to (3) and (4):

$$F = 2 \cdot \rho \cdot A_1 \cdot V_0^2 \cdot e(1-e). \quad (5)$$

Power developed by turbine is the product of force and velocity:

$$P = F \cdot V_1 = 2 \cdot \rho \cdot A_1 \cdot V_0^3 \cdot e^2(1-e). \quad (6)$$

Take into consideration that $P=0,5\rho SV^3$ the air flow output with velocity V_0

$$P_0 = \frac{1}{2} \rho \cdot A_1 \cdot V_0^3 \text{ or } 2P_0 = \rho \cdot A_1 \cdot V_0^3. \quad (7)$$

Substituting in (6) we obtain

$$P = 4 \cdot P_0 \cdot e^2 (1-e) = P_0 \cdot C_p, \quad (8)$$

where

$$C_p = 4 \cdot e^2(1-e) \quad (9)$$

is called the power factor (efficiency factor) of Betz limit. Differentiating the expression (8) with respect to e , we determine its value for which power P will be the maximum. The result is $e=2/3$, $C_p=16/27=0.593$.

We can draw the following conclusion: the air flow will give up to an ideal turbine not more than 59.3% of its original power P_0 and this will be achieved when the braking factor $e = 2/3$ and air flow velocity after the turbine will be $V_2 = 1/3 V_0$. In fact, the best three-bladed wind turbines have the Betz coefficient equal to 0.45 – 0.50.

4. Small power wind turbines

4.1. Global market overview, manufacturing companies and incentive policies

Small systems for wind energy conversion were among the first used by humans for their own or community energy needs. Further over-centralisation of power distribution system led to a substantial costs increase in the case of isolated consumers. From this point of view, the idea to de-centralize power supply systems for isolated consumers is appropriate.

It is noticeable that most of the Third World countries do not have centralized electricity distribution networks. Therefore, the area of small power wind turbines tends to enlarge, especially with account of the inevitable fuel costs increase and environmental issues the mankind is challenging. In this case, the state policy promoting green energy production is of major importance. The USA, pioneer of small wind industry, adopted for this purpose in 1985 an incentive system for green wind energy production, which, since 1990 recorded an annual 14-25% increase. About 30% of federal investment tax credit will bring an annual 40% growth of small power wind turbines sales [4]. About half of small power wind turbines manufactured in USA were exported, and this shows that the small wind turbine industry is one of the dominant renewable energy technologies in the US.

The term “*small power wind turbine*” is defined as an electricity generator with up to 100 kW capacity. A small wind system can include, if necessary, a turbine, a tower, an inverter, batteries, foundation, etc. To examine what the market for small power wind turbines in the US is about, one should consider the following. According to [41], the number of small wind turbines sold in the US in 2006 was 6807 units, of which 6639 (about 98%) produced in the USA, with a total installed capacity of 17543 kW (including 16093 kW of US produced units). In 2006 outside US, 9502 turbines were sold having a total installed capacity of 19483 kW [5]. The correlation analysis of turbines connected to the network and installed separately shows that the great majority (5933 to

only 706) of turbines are not connected to the network, thus they are employed by isolated consumers.

The cost of small wind turbines remains the only major factor affecting the market growth. For small wind turbines, the generation volume is not the only question, the increasing costs of construction materials, such as copper and steel, also has to be considered. Market growth is also a major function of state policies in the field, particularly regarding ways to exempt companies of various taxes, other financial incentives, etc.

Producers of small wind turbines. In the context of action taken to solve the imminent energy crisis, to stop the global environmental impact and the trend towards decentralization (especially for isolated consumers) of power supply and of other types of energy, the small wind turbine industry is continuously growing. Presently, in the world there are a number of companies producing a wide range of small wind turbines rated less than 1 kW and up to 100 kW. The USA and China became the largest producers of small wind turbines. The American Wind Energy Association (AWEA) has made a compilation of companies manufacturing and selling wind turbines for residential applications, industrial/commercial and farms use.

4.2. Small power wind turbines designed at the Technical University of Moldova

Small wind turbines should be mostly robust and simple, have maximal resistance and little maintenance, and optimal wind energy conversion efficiency. Given the topical interest and relatively high costs of imported wind turbines, a team of authors developed two types of small power wind turbines. The wind turbines with servo motors have the ability to track wind direction and remove the bladed rotor out of the wind action at wind speeds exceeding 15-25 m/s. The advantages of these turbines compared to vane wind turbines are:

- angular positioning stability of the bladed rotor at dynamic fluctuations of air currents direction;
- bladed rotor protection from overloads, caused by wind speeds exceeding the highest allowed values.

4.2.1. Wind Turbine Equipped with Servo Motor

Based on the study of wind energy potential and specific orographic terrain surface of Moldova, characterized mainly by gorges oriented along North-South direction, the authors developed the concept of a three-bladed rotor with asymmetric aerodynamic profile [6,7]. Theoretical research on the developed rotor was carried out using modern software ANSYS CFX5.7 and Autodesk MotionInventor. As a result, the basic parameters of the aerodynamic profile characterizing the efficiency of wind energy conversion by the rotor blades were determined [8-10].

The choice of three blade rotor scheme provides a greater dynamic stability, minimizing related vibrations and sonic background, thus resulting a longer life period of all components. Direct connection of the rotor to the generator ensures rotor start up at lower wind speeds, production of a larger amount of energy, requires less demanding maintenance compared to turbine multiplier case. Specially designed permanent magnet generator combines efficiency with the simplicity of construction. The outer coverage of blades featuring asymmetric aerodynamic profile, also the gondola cone and the vane are manufactured from composite materials reinforced with glass fibre employing modern technologies in the CESCER laboratory, TUM.

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- Angular positioning stability of the bladed rotor at dynamic fluctuations of air currents direction;
- Bladed rotor protection from overloads, caused by wind speeds exceeding the highest allowed values.

Figure 2 (a,b) shows a 3D model and industrial prototype of the servo motor wind turbine, developed by a team of authors. Both wind direction rotor orientation and its removal out of the action of air currents is done by means of a device, called servo motor, which performs the kinematical liaison of gondola with tower and which is controlled by a wind vane electronic

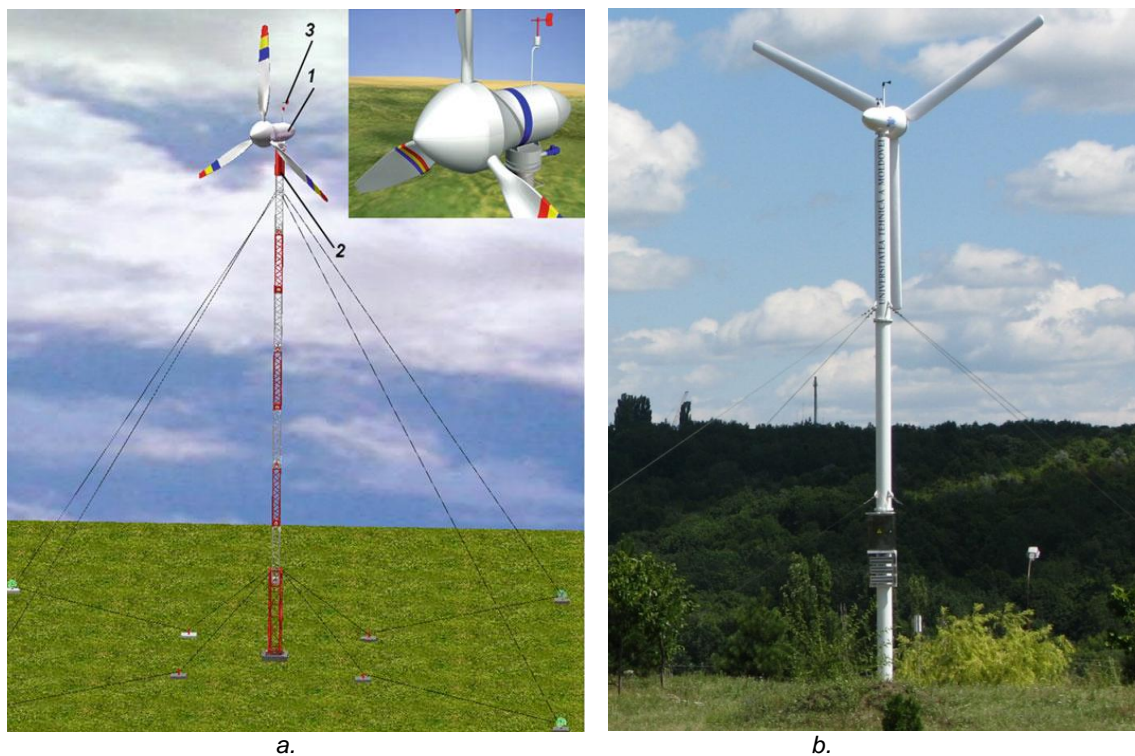


Fig. 2. 3D model (a) and industrial prototype (b) of wind turbine with servomotor ($P=10$ kW).

transducer .When the wind direction is changed the vane performs an angular re-positioning, a deviation signal occurs and the control system starts the servo motor, that rotates gondola with rotor in one direction or another until the rotor axis coincides with the direction of air currents.

Angular positioning stability is ensured by a certain time delay of the servo motor switch depending on the wind flow action in one direction or another. Repositioning period of bladed rotor perpendicular to airflow velocity vector depends on the kinematical characteristics of the driving mechanism (the servo motor), and actually determines time repositioning stability of the gondola.

Kinematical characteristics of the servo motor were determined by the dynamics of the airflow velocity vector variation.

The tower has modular construction with telescopic height advancing, or tubular with special hydraulic device, due to which lifting cranes are not required when changing the turbine installation height.

The electricity generation depend on the turbine power characteristics (Figure 3) and wind speed probability density function.

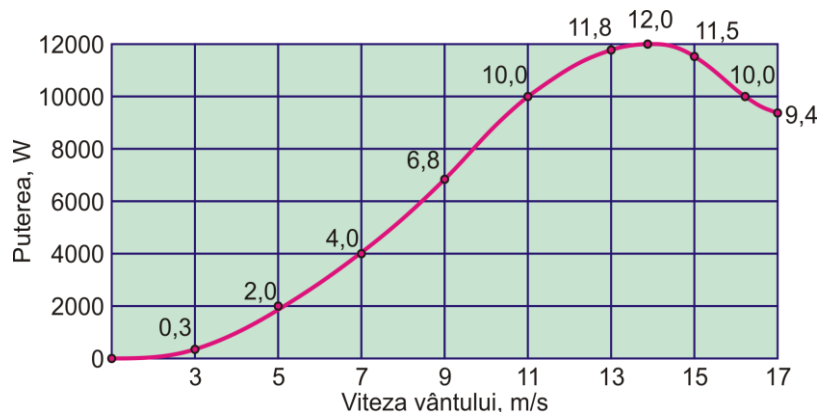


Fig. 3. Wind turbine power characteristic.

4.2.2. Dendrologic park lighting system of the Technical University of Moldova

Figure 4 shows the dendrologic park lighting system of the Technical University of Moldova integrated with two wind turbine for electricity supply of more 200 low consumption lamps.

4.2.3. Wind energy supply of the dripping irrigation system

The electricity supply of agricultural land irrigation systems from the public power grid becomes inefficient, that is why various autonomous sources of energy are becoming more widespread [7, 50-52]. Fig. 4.50 shows a drip irrigation system powered by electricity from a wind turbine 1 designed by the authors and described in p. 7.2.1 and 7.2.2. Centrifugal pump 2 with productivity parameters Q (m^3/h) and pumping height H corresponding to the needs for irrigation is supplied with electricity from a wind turbine generator 1. Centrifugal pump 2 sucks water from the lake (or river) and pumps it into the system through the fertilizing dispenser 3 and filtering device 4 connected consecutively in the pump discharge pipe. Fertilized and filtered water under pressure is

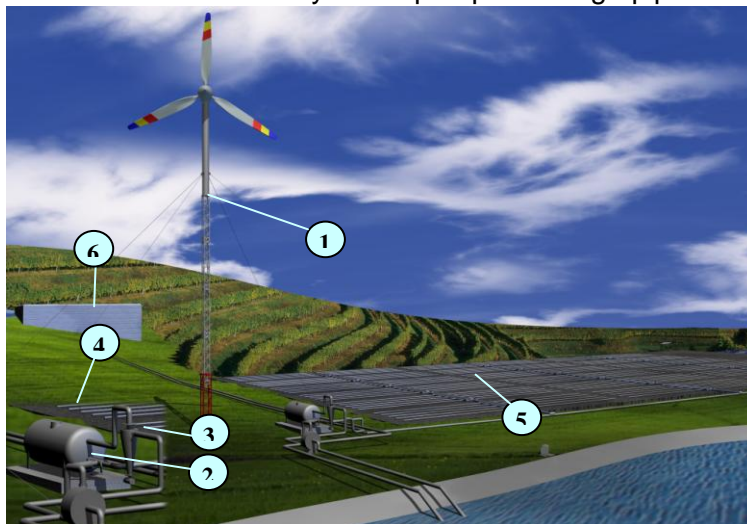


Fig. 5. Drip irrigation system powered with electricity produced by the wind turbine.

pumped into the pipe network 5. The irrigation system must include a water storage tank 6 located at an altitude higher than the irrigated ground. Water in the tank may be used during the periods when the wind speed is insufficient to produce the demanded electricity. Subject to the launch of a new generation of electric batteries on the market, more efficient and cheaper, the irrigation systems equipped with batteries could be an alternative that will load at times when irrigation is not appropriate.

References

- [1] A. Piebalgs, "Wind energy for future", *Mesagerul Energetic J* 66:14–16. 2007;
- [2] "GWEC Global Wind Statistics 2014" (PDF). GWEC. 10 February 2015;
- [3] "Denmark breaks its own world record in wind energy". Euractiv.com. Retrieved on 2016-07-20;
- [4] www.mkw.co.uk;
- [5] J.L. Edwards et al (2004), "Evaluating state markets for residential wind systems: results from an economic and policy analysis tool", Lawrence Berkeley National Laboratory, p 39. <http://repositories.cdlib.org-ibnl/LBNL-56344>;
- [6] I. Bostan, V. Dulgheru, V. Bostan [et al], Patent MD 681Y. *Wind turbine*, Publ. BOPI No 9/ 2013;
- [7] I. Bostan, V. Dulgheru, V. Bostan, I. Sobor, A. Sochireanu, Patent MD 4219. *Horizontal axis wind turbine*, Publ. BOPI No 4/2013;
- [8] I. Bostan, A. Gheorghe, V. Dulgheru, I. Sobor, V. Bostan, A. Sochirean, "Resilient Energy Systems. Renewables: Wind, Solar, Hydro", Springer, VIII, 2013. 507 p. ISBN 978-94-007-4188-1;
- [9] I. Bostan, V. Dulgheru, V. Bostan, R. Ciupercă, "Anthology of Inventions: renewable energy conversion systems", Vol. 3. Ch.: Bons Offices. 2009. – 458 p. – ISBN 978-9975-80-283-3;
- [10] I. Bostan, V. Dulgheru, I. Sobor, V. Bostan, A. Sochirean, "Renewable energy conversion systems" – Ch.: „Tehnica-Info” SRL (BONS Offices), 2007. 592 p. ISBN 978-9975-63-076-4.