WIND GENERATORS DESIGNED, BUILT, AND TESTED AT THE "ŞTEFAN CEL MARE" UNIVERSITY OF SUCEAVA

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Abstract. *The paper retrospectively presents the practical and scientific achievements of the University of Suceava in the field of wind power with a view to converting into rotation mechanical energy and, finally, into electric power. The wind turbines that have been produced and tested by the University of Suceava, together with the Electric Network Enterprise of Suceava, apply the technology of 1978-1985. Conceptually, they make a comeback due to the European programmes concerning clean energy production using renewable resources.*
Keywords: *wind power, wind generator, wind rotor, clean energy.*

History

Mankind has known the wind for an energy source for millennia. Wind power was used in maritime navigation – it is believed that the Egyptians used sails to propel their ships 5000 years ago. Windmills were used to grind corn. In the 14th century, the Dutch improved the windmills in the Middle East, which they used on a large scale.
In 1854, a wind-powered water pump was invented in the USA. Towards 1940, over 6 million wind-powered machines were used in the USA to pump water and produce electric power. It was considered a prerequisite in conquering the Wild West due to the possibility it afforded to supply farms with water. By the middle of the 20th century, however, large-scale application of wind power comes to an end, being replaced by a modern resource – oil.
Interest in wind power is renewed after a number of oil crises spanning a few decades. This happens in early 1970's due to rapid increase in the price of oil. Consequently, many governments try to solve energy problems resorting to alternative sources of energy such as atomic, geothermal, eolian, solar energy, and so on.
In Romania, research begins to be conducted after 1970 in order to implement and develop technology tapping new sources of energy. It is in this direction that the interest of the research group at the University of Suceava, coordinated by Professor E.N. Diaconescu PhD, in efficient harnessing of wind power is aimed. 'Wind energy should be regarded as a additional source of energy, as one the least expensive sources,' [1]. As a result, research contract no. 4069/78 is drawn with the Electric Network Enterprise – IRE –of Suceava, [1, 2] and a series of scientific articles are published or presented, [3-14].

The Current State of Wind Energy

Rapidly developing an economy based on renewable resources constitutes a major step in avoiding warfare over non-renewable resources such as oil, natural gas, and uranium.
The energy demand of the whole planet could be covered by a mixture of solar thermal plants and solar power plants, wind farms, hydroelectric power stations, and diversified use of biologic

mass. In order to meet the growth of global energy demand, energy should be produced using economical technologies. In the field of energy production, it is generally acknowledged that, by 2050, much more energy can be produced using renewable resources than the whole of mankind could consume nowadays. The effects of renewable resource development policies are most visible in the field of wind power, which is currently the one technology that has attained the highest rate of development, [15, 16].

In Europe, the are 34,000 MW wind-turbine plants, producing approximately 70 TWh, while in Romania, there are 900 kW, out of which the industrial park of Ploieşti employs electric energy supplied by a 660 kW wind turbine.

It is obvious that Europe consolidates its worldwide leadership in wind power, the European market growing by 39% per year for the last 5 years. Thus, at the 'Clean energy – financing and support in Central and Eastern Europe' international conference held in Hungary, it was stated that in 2003 the turnover in wind applications in the EU was of 6.9 billion euros.

Furthermore, in the Czech Republic, the quota of wind power will increase from 3.8% in 2000 to 8% in 2010, in Estonia, from 0.2% to 5.1%, in Hungary, from 0.7% to 3.6%, in Poland, 1.6% to 7.5%. However, according to a report by the International Energy Agency, in Romania, wind power programme elaboration and implementation are delayed.

Nevertheless, the European documents also highlight Romania's adjustment to the EU requirements concerning electric energy renewable sources by high-power hydroelectric plants.

The ***Intelligent Energy for Europe*** project promotes the implementation of the Green Paper strategy during 2003-2006. A major position within this project is held by the ***ALTENER*** programme, with a suggested budget of 86 million euros, aiming to set up 10,000 MW wind turbine.

Energetic Characteristics of Wind

Wind energy is a manifestation of solar energy caused by atmospheric movement triggered by uneven heating of the terrestrial crust. Air movement is generated by different temperatures in two areas, directed from the warm spot towards the cold one. The Earth receives 10^{14} KWh solar energy every hour. About 1-2% of the solar energy is transformed into wind energy. This is about 5-10 times more than the energy turned into biomass by all of the plants on the Earth.

The energetic characteristics of wind depend on air density ρ, air volume B, wind speed v, and air turbine propeller surface A, cf. Table 1.

Table 1. Energetic characteristics of wind

Specification	Mathematical equation
Wind kinetic energy	$E = \frac{1}{2}\rho B v^2$
Wind power for a cylindrical volume, having the cross-section A and length $\ell = v$, $B = A\ell = Av$	$P = \frac{1}{2}\rho A v^3$
Power per frontal surface unit	$p = \frac{P}{A} = \frac{1}{2}\rho v^3$
Wind kinetic energy per surface unit, with v = constant and duration T in hours	$e = \frac{1}{2}\rho v^3 T$

The experiments carried out on various types of wind turbines have yielded an inferior limit of wind speed of 5-6 m/s, above which wind energy can be efficiently converted into electric energy. Additionally, in order to maintain a quasi-steady state of converted energy parameters, an upper limit of the wind turbine speed is required, corresponding to a wind speed of 10-12 m/s. For higher speeds, the turbine speed is made constant by speed limiters and adjustment systems, [2, 6, 12].

Continuous recording of the wind speed in the Teişoru-Mihoveni area, district of Suceava, for one year has yielded the eolian potential, that is power distribution with respect to number of hours and wind speed, Figure 1, [1].

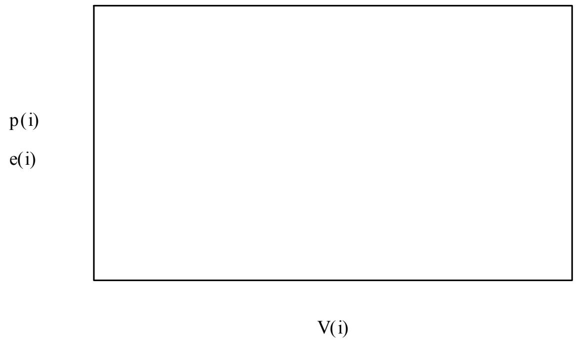


Figure 1. p [kW/m^2] and e [kWh/m^2] parameter distribution, with respect to v [m/s] in the Teişoru-Mihoveni area, district of Suceava

Obviously, only 80% of the chart is important, since the energy for speeds under 5 m/s is practically impossible to convert, while for speeds v > 10 m/s, the energy is only partially convertible due to the action of speed limiters, [2]. The experiment yield a total kinetic energy available of 1383.65 over one year. Out of this energy, the turbine can only tap at most 35-40% when it is connected to the electric generator. Taking into account that the efficiency of an electric generator is about 94%, it yields that the electric energy obtained in one year is 26% of the overall wind kinetic energy or 34% of the kinetic energy available.

These result hold for the period of time when research was conducted, but may change in time, given atmosphere dynamics on the Earth and, implicitly, in the area.

Types of wind generators conceived and built in Suceava

In order to convert the wind kinetic energy into rotation mechanical energy, wind turbines of various types are used, [1, 4, 7, 13, 14]. The mechanical power developed at the wind turbine shaft represents part of the wind power which acts on the surface covered by the rotor:

$$P_m = \xi P,$$

where ξ is a subunitary factor called wind power use coefficient , which depends on the rotor type and the absolute air speed upon entering the rotor, v. This factor may be regarded as a quality index for a specific turbine type, supplying information on its efficiency, [11].

Throughout time, numerous devices have been designed to tap wind energy, based on **direct** or **indirect** capturing of wind power.

The first category consists of devices wherein wind energy is transferred directly to the mobile motor part. The active rotor surface may move in the wind direction or at a right angle and the wind power is captured by aerodynamic lift forces, by air jet momentum variation, by wind dynamic pressure.

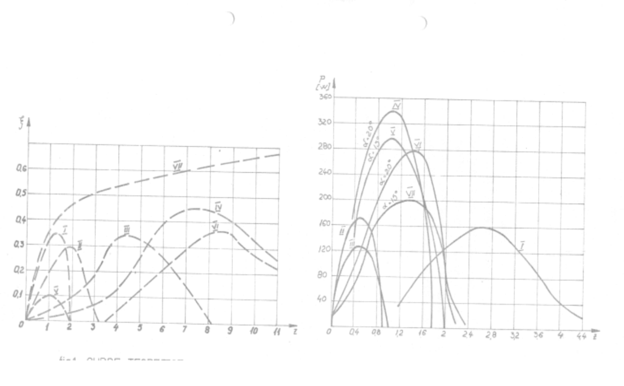
Indirect capturing of wind energy is achieved either by engines such as those presented above in conjunction with static elements or by a power transfer intermediary fluid. With the exception of the latter, these devices employ fittings in order to either increase air speed in the turbine or modify the ratio between dynamic and static pressures, the static pressure difference thus created being able to produce work.

The design of a wind turbine aims at maximizing the wind power use coefficient, ξ, [9]. In 1979 three wind rotors were designed and built for experimental study in the wind tunnel: one horizontal-shaft, three-pole, fast wind turbine and two vertical-shaft split Savonius and triple Savonius wind turbines. The details concerning the description and construction of the wind generators can be found in articles [1, 7, 11, 14]. The rotors have been tested and optimised in 1980, and the conclusion was that the easiest to build was the horizontal-shaft, flat-blade rotor [9], which reaches the required efficiency.

Testing methodology and experimental results

The aerodynamic characteristics of wind turbines may be determined either in the laboratory or in natural current. The former variant was obviously chosen, which required

that a rotor test bed should be built. The air current needed for testing was produced with a horizontal flow axis fan. In order to produce laminar air flow, a tube was connected to the fan flanges, having an interior diameter of 400 mm and a length of 3 m. Using an obturating device, the air speed at the end of the tube can be adjusted up to 26 m/s, yielding a maximum wind power of 1.32 kW, [3]. The test bed was provided with equipment such as an electromagnetic brake, a speed transducer, and a torque transducer.
The following wind rotors have been tested on this bed: triple Savonius, split Savonius, [4], NAKA-profile three-pole rotor, four-fixed-flat-blade rotor, six-fixed-flat-blade rotor. The last two were provided with variable angle of attack, [5].
Experimental results were plotted in the coordinates P = f(z), where z is the ratio between rotor peripheral speed and air speed at rotor entry point. These curves are presented in Figure 2.



I – NACA-profile rotor; **II** – triple Savonius rotor: **III** – split Savonius rotor; **IV, V** – 6-flat-blade rotor; **VI, VII** – 4-flat-blade rotor.

Figure 2. Experimental curves

Obviously, in the case of dynamic-pressure turbines and momentum transfer turbines, both working at low speed, the characteristics are in agreement with those presented in specialised literature.

Flat-blade rotors allow for optimizing by choosing the appropriate angle of attack, the optimum value of which is practically 20°.
In the case of aerodynamic lift wind turbines, however, there are considerable discrepancies with respect to data provided by specialised literature. Generally, it is found that ξ_{max} is lower and the optimum speed is reduced. This indicates increased sensitivity to blade profile construction errors and to surface quality, [9].

Conclusions and discussions

Wind kinetic energy has always been practically accessible all over the world. It is also ecologically attractive – it does not produce emissions or radioactive waste. As a primary energy resource, the wind is costless. It can also be used in a decentralised manner – it is a feasible alternative for small settlements away from traditional sources.
Wind energy depends on air density, temperature, and humidity, as well as on atmospheric pressure, altitude, and wind speed. Wind energy varies in proportion to wind speed raised to the third power.
Optimal tapping of wind energy in driving wind turbines depends on turbine type, propeller geometry, turbine aerodynamic characteristics, and location.
The main factors in reducing wind speed on the Earth surface are vegetation and buildings. The farther away from the surface, the smaller the influence of relief on air movement. At about one kilometre above sea level, relief has practically no influence on wind speed. In the lower layers of the atmosphere, wind speed is greatly influenced by contact with the Earth surface. The more complex the relief, the smaller the wind speed. The wind is slowed down by forests and cities. The buildings, the forests, and other barriers not only reduce wind speed, but also generate air turbulence currents.
The specialists classify relief surface into 9 levels, ranging between 0 and 4. This parameter is crucial in designing wind generators. Thus, if the propeller had a large diameter and the tower is relatively small, then the mass of air acting on

the propeller will reach maximum at the upper edge and minimum speed at the lower and the whole construction may be destroyed.

As a matter of fact, among low speed rotors, the most efficient are horizontal axis, flat blade rotors, which, at the optimal angle of attack, yield a wind energy use coefficient of 0.3. Horizontal axis, aerodynamic lift rotors that are precisely built are absolutely better from the point of view of wind energy conversion. The maximum wind power use coefficient may be as high as 0.42, [9]. These are very sensitive to profile deviation from the ideal shape, which may ruin the results.

For these reasons, also taking into account the technological advantages of flat-blade rotor construction, we may conclude that, for small and medium powers, these formed the preferred solution of the research group in Suceava until 1990.

As an energy resource, the wind may be more difficult to assess than the sun, but there are times when the wind is present throughout the whole day.

Consequently, the depends more on the local conditions (relief) then on the sun. In mountain settlements, for instance, two surfaces may have the same solar potential, yet the wind potential may be different, due to relief and air current direction differences. In this respect, choosing the location for a wind generator may be more difficult than it is for a solar generator. Wind energy also depends on seasonal weather changes. Such a generator is more efficient in winter, and less efficient in summer (while it is the other way around for solar plants). Thus, the optimum variant resides in combining solar and wind resources into a system. Such symbiotic systems yield better electric energy productivity as compared to eolian or photoelectric units taken separately.

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