ANNALS of the ORADEA UNIVERSITY.
Fascicle of Management and Technological Engineering, Volume IX (XIX), 2010, NR3

DESIGN ASPECTS OF THE WIND TURBINES

LATEŞ Mihai-Tiberiu, LATEŞ Raluca-Septimia, HANSEN Per Ulrik
"Transilvania" University of Braşov, Product Design and Robotics Department,
latesmt@unitbv.ro, latesr@unitbv.ro, puh@viauc.dk

Keywords: wind turbine, power curve, design process.

Abstract: The design process of the wind turbines includes aspects which are referring on: the wind data, the electric consumers, the implementation location. According to that, there are identified different types of wind turbines which can be chosen for an application. The paper presents the influence of these parameters on the wind turbines typology for a defined application.

1. Introduction

The EU members were signed an agreement in 2007 which main aim is to rich (until 2020) the 20th percentage of the renewables usage in the total energy amount used by every EU member. According to that there are open new possibilities in the field of use the wind turbines, as main components of the renewable energy systems.
The desing process of the wind turbines is influenced by some parameters which are referring on: the wind data; the implementation's location; the consumers.

2. The design process

An important parameter which is influencing the choosing process of the wind turbine is represented by the wind data (direction of the wind and the wind velocity). The rotor's axis of the wind turbine can be horizontal or vertical (figure 1) [1, 2, 5]. In the case of horizontal axis wind turbines, the rotor should be oriented (by considering the yaw motion of the nacelle) normal to the wind direction; the yaw motion is a non-actuated motion for small wind turbines (the gyroscopic effective is used) and an actuated motion for big wind turbines. In this last case, the yaw motion consumes electric energy. To reduce the consumption of energy which is used for the yaw motion of the nacelle, vertical wind turbines can be used (for the vertical wind turbines – *Darrieus* type, *Savonius* type, combined - the wind direction is not influencing the rotor's motion) [1, 2, 5].

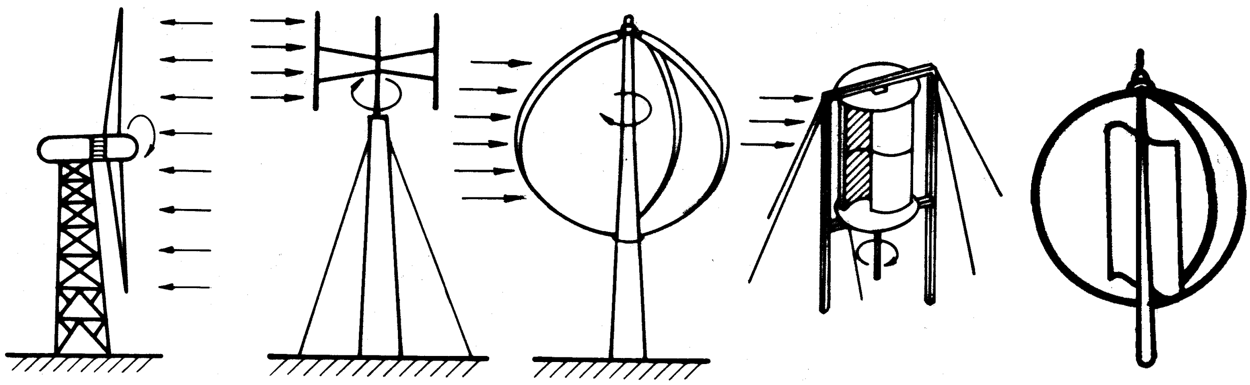

Figure 1: Horizontal axis and vertical axis wind turbines

The amount of aerodynamic energy used from the wind is depending on the rotor's constructive characteristics: with 1 blade, with 2 blades, with 3 blades, with multiblades (the farmer's wheel, the bicycle wheel) – figure 2.
Special solutions of wind turbines are used in order to increase their efficiency, in areas with high wind potential: multirotor wind turbines (on the same tower are mounted 2 or 3

rotors); wind turbines with 2 rotors mounted on the same shaft (the rortors are rotaiting in opposite directions); offshore wind turbines which are installed in the oceans – figure 3.

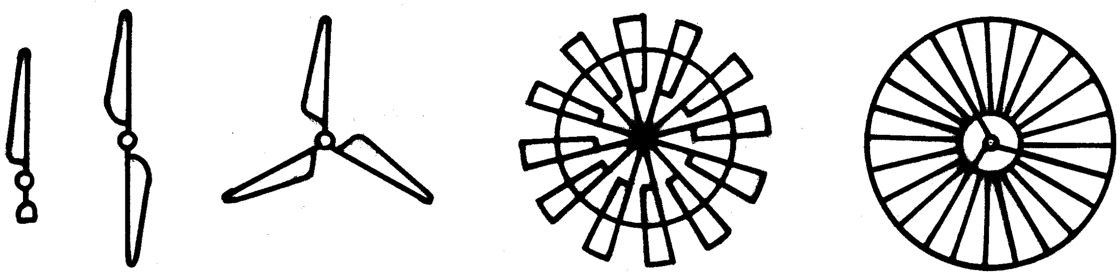

Figure 2: Types of rotors

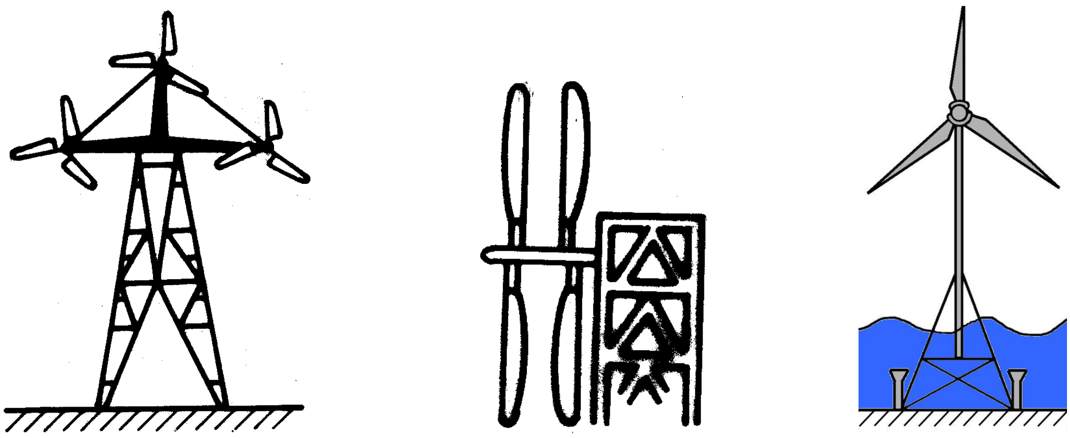

Figure 3: Wind turbines used in high wind potential areas

The produced power is classifying the wind turbines as following: small wind turbines with the output power less than 10 kW; medium wind turbines with produced power between 10 kW and 100 kW; big wind turbines with produced power more than 100 kW.
The amount of energy produced by the wind turbine is depending on its constructive characteristics and on the wind potential of the area where the turbine is installed. The amount of monthly energy is given by [4]

$$W_m = \frac{D^2 v_m^3}{10}, \qquad (1)$$

where: W_m [kWh] represents the monthly energy produced by the wind turbine; D [m] – the rotor's diameter; v_m [m/s] – the medium wind velocity.
An application for a class of wind turbines is presented in table 1; the monthly produced energy can be observed.

The monthly medium wind velocity is calculated by using

$$v_m = \frac{\sum_{i=1}^{n} v_i t_i}{\sum_{i=1}^{n} t_i}, \qquad (2)$$

where v_i is the wind velocity in the period t_i.
The needed power is obtained with the formula

$$P_C = \sum_{i=1}^{n} P_{ci}, \qquad (3)$$

where P_{Ci} is the electrical power of the consumer i.
The electrical power of some domestic consumers is presented in the table 2.

The daily amount of energy is calculated with

$$W_C = \sum_{i=1}^{n} P_{ci}\, t_i \ , \qquad (4)$$

where t_i represents the functioning period of the consumer I, in a day, expressed in hours; for a household, the monthly energy requirement is between 250 kWh/month and 300 kWh/month.

Table 1. The monthly energy

The diameter of the rotor, m	The medium wind velocity, m/s			
	3	4	5	6
	The monthly energy, kWh			
1	2	6	10	20
2	10	25	50	70
3	20	60	100	160
4	40	100	200	280
5	60	160	300	430

Table 2. The consumers electrical power

Consumer	Power, W	Consumer	Power, W	Consumer	Power, W
Economic light bulb	13	Mixer	300	Coffee maker	1000
Iron machine	1000	Microwave	1500	Fridge	200
Vacuum cleaner	500	Washing machine	250	AC	1000
TV	150	CD player	35	Desktop PC	300
Printer	35	Laptop	100	Mill saw	1100

To transform the DC current in AC current, an inverter is used; its efficiency is η_i = 80% ... 90%. The needed energy at the wind turbine's generator is

$$W_G = \frac{W_C}{\eta_i}. \qquad (5)$$

The energy which should be storage in the batteries is determined by

$$W_b = U \sum_{i=1}^{n} I_i\, t_i \ , \qquad (6)$$

where: U represents the voltage; I_i – the current in the period t_i. It is recommended to use 12 V batteries for a monthly energy requirement less than 150 kWh/month, 24 V or 48 V for a monthly energy requirement between 150 kWh/month and 700 kWh/month and 48 V batteries for a monthly energy requirement bigger than 700 kWh/month. To reduce the losses in the long cables it is recommended to use high voltage batteries.
The quantity of current given by the wind turbine's generator is

$$C_G = \frac{W_G}{U}\left(1 + \lambda_S\right), \qquad (7)$$

where λ_S = 20% ... 25% represents the losses in the system (batteries, controller, cables).
The batteries design parameters are depending on the number of days z when the wind velocity's value is under the value when the wind turbine is producing the nominal power. It is a safety recommendation that the batteries should working at a capacity of 80%. The current quantity which should be stored in the batteries is

$$C_B = \frac{C_G\, z}{0{,}8}. \qquad (8)$$

The minimum number of batteries, mounted in series, is

$$n_b = \frac{C_B}{C_b}, \qquad (9)$$

where C_b is the current quantity which can be stored in a battery, expressed in Ah.

Table 3. The required energy

Application	**Power, W**	**Nr. Items**	**Nr. functioning hours, in one day**	**Daily required energy, Wh**	**Monthly required energy, kWh**
Light bulb	13	6	4	312	9,36
TV	150	1	4	600	18
Laptop	100	1	2	200	6
Fridge	200	1	4	800	24
Coffee maker	1000	1	0,5	500	15
Total required energy				2412	72,36
Total required energy, including batteries (x 1,25)				3015	90,45
Total required energy, including inverter (x 1,1)				3316,5	**99,495**
Maximum required power, kW	**1,528**				
Medium required power, in one hour, Wh/24				**138,1875**	

The current quantity which can be stored in a battery is

$$C_b = \frac{E_z z}{DU}, \qquad (10)$$

where: E_z is the daily produce energy, in Wh; z – the number of days when the wind velocity's value is under the value when the wind turbine is producing the nominal power; D – the discharging rate (0.5 for the batteries used in cars; 0.8 for the PV batteries; 1 for Nickel Cadmium batteries). The power of the wind turbine P_t is chosen bigger than the required power P_C. According to the wind turbine's generator voltage U_t and the number of the hours t_t when the turbine is giving the nominal power, the current quantity given by the turbine is calculated with

$$C_t = \frac{P_t}{U_t} t_t. \qquad (11)$$

The number of parallel mounted turbines, necessary to produce the required energy, is

$$n_t = \frac{C_B}{C_t}. \qquad (12)$$

The inverter's power is given by

$$P_i = 1{,}35 P_C. \qquad (13)$$

Table 3 presents an application for the calculus of the required energy.
The wind turbine is chosen by considering some input data as following:

- the wind data of the implementation location are studied (the medium wind velocity is calculated for each month of the year; there are identified the month with small wind velocities and, according to that, the batteries are designed; the strength calculus are made for high possible wind velocities;
- the wind potential is calculated according to the medium monthly wind velocity (see (1));
- the required monthly energy (including the losses) is compared with the wind potential; it is identified the wind turbine;
- the batteries are designed by considering a non-activity of one week for the wind generator; alternative sources can be chosen (PV panels, a diesel generator, a micro-hydro system).

Table 4 presents the estimated energy produced by a *Whisper H80* type wind turbine, with the 3.1 m diameter of rotor, by considering 2 cases for the medium wind velocities: 3 m/s and 5 m/s.

Table 4. The estimated energy produced by a *Whisper H80* type wind turbine

	Example 1	**Example 2**
Medium wind velocity, m/s	3	5
The required monthly energy, kWh	99,495	99,495
The produced monthly energy, kWh	25,947	**120,125**

If the amount of produced energy is less than the required one, alternative solutions can be considered: the implementation of more than one wind turbine or the implementation of hybrid systems with PV panels, diesel generators, micro-hydro systems.
The instantaneous power of a wind turbine is defined as [1, 3, 4, 5]

$$P = 0.5 \rho v^3 A C_p , \qquad (14)$$

where ρ is the air density (ρ=1.2255 kg/m^3 at the see level); v – the wind velocity; A – the rotor's swept area; C_p – the power coefficient [1, 3, 4, 5]

$$C_p = \eta_m \, \eta_e \, \eta_a , \qquad (15)$$

where: η_m is the efficiency of the mechanical transmission (η_m=0.95 … 0.97); η_e – the efficiency of the electrical components (η_e=0.97 … 0.98); η_a – the aerodynamic efficiency (is depending on the implementation zone's characteristics and its maximum vallues is η_a=0.59).
The wind velocity is a parameter which has an important influence on the wind turbine's type which is chosen for an application. This parameter is influencing the power curve of the wind turbine (figure 4); the power curve of the wind turbine shows some important characteristics of the system: the wind velocity value when the wind turbine is starting to produce energy (*the cut-in wind speed* – 3 m/s on the graph) and the wind velocity value when the wind turbine is producing the nominal power (*the nominal wind speed* – 12 m/s on the graph).
The characteristics of the power coefficient C_p are presented in the figure 5, for some important types of rotors, depending on the parameter λ (the ratio between the rotor's velocity and the wind velocity).

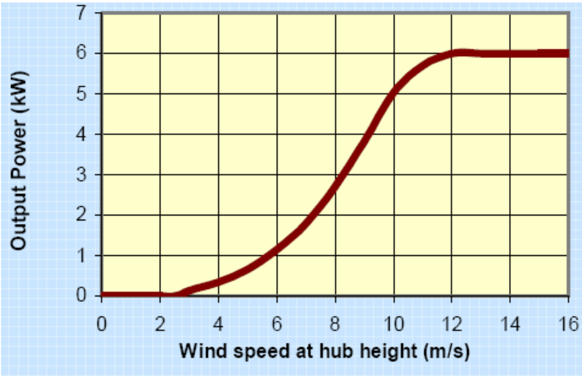

Figure 4: The power curve

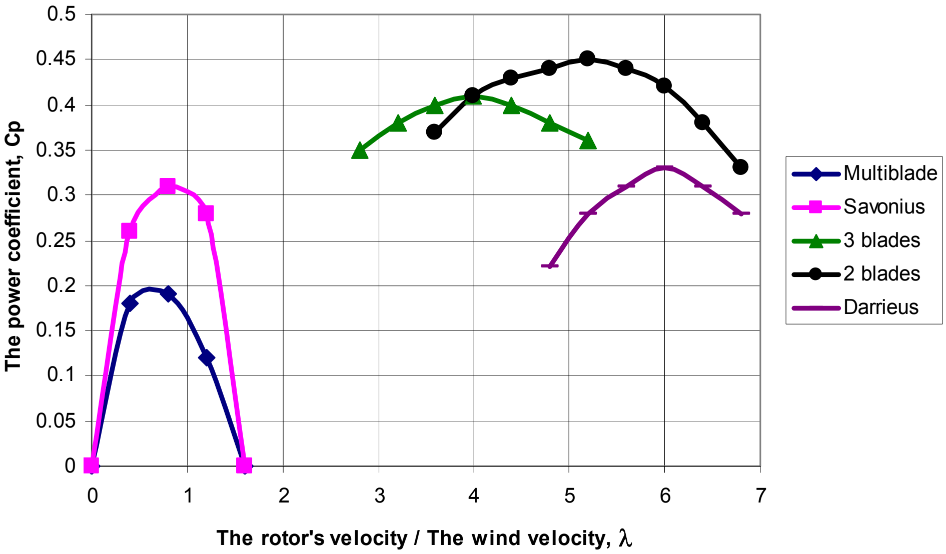

Figure 5: The power coefficient, C_p

3. Conclusions

The design process of the wind turbine is depending on the parameters: the wind data, the energy requirements, the implementation's location.

The wind data (as wind velocity and wind direction) is influencing the type of the wind turbine (rotor type – number of blades, horizontal axis, vertical axis, multirotor) and is a main parameter which is offering the class of the wind turbines (according to their power curves) which can be use for an application.

The energy requirements are offering the solution for the wind turbine, as produced power and by considering the implementation's location, the final solution is adopted.

By considering some practical examples presented in the paper, the article offers the main steps which should be considered in the design process of the wind turbine.

References

[1] Bârsan, L., Bârsan, A., Boloş, C., Lateş, M. T. Ecodesign în contextul dezvoltării durabile. Braşov, Editura Universităţii Transilvania, 2009.

[2] Bostan, I. ş.a. Sisteme de conversie a energiilor regenerabile. Editura Tehnica-Info, Chişinău, 2007.

[3] Hansen, M. O. L. Aerodynamics of Wind Turbines. 2nd Edition. Earthscan Publishing House, London, 2008.

[4] Khennas, S., Dunnett, S., Piggott, H. Small Wind Sytems for Rural Energy Services. Practical Action Publishing, India, 2008.

[5] Vişa, I., Duţă, A. Sustainable Energy. Braşov, Editura Universităţii Transilvania, 2009.