SMALL POWER EOLIAN PLANTS FOR ISOLATED CONSUMERS

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INTRODUCTION

The construction of small power eolian plants (under 20 kW) with variant destination can be useful for isolated consumers from the areas with eolian potential with annually average speed over 4 m/s.

The experience of using, all over the world, of thousands of small power wind engines show that they presents some advantages for isolated consumers:

- the using of the free eolian potential;
- accessible price;
- easy assembling and maintenance;
- they can be made with local sources and with some component from the serial production;
- adjusting systems without supplementary energy source [4, 6];
- the possibility to manufacture kits for an easier assembling on the working place.

The small wind engines are environment friendly. Manufacturing of these engines according to the industrial aesthetics law can avoid the "visual pollution" by an adequate landscape fit in.

1. REALIZED CONSTRUCTIONS FOR WINDMILLS

In the designing and the manufacturing of certain small power eolian plant for isolated consumers we started from a structural analysis of the existent eolian plants [10, 11] and we identify the following problem as important:

1.1. the way of the wind energy catching;
1.2. the utilized rotor type;
1.3. the in wind orientation of the rotor;
1.4. the rotation speed control and the protection devices;
1.5. the processing of the energy obtained from the rotor;
1.6. the storage manner for the energy.

1.1. The eolian energy catching can be made directly, through in wind placed rotors, or indirectly, through concentration devices of the wind action. These devices use for function one of the following law: the Bernoulli's principle (nozzle, Venturi tube, perpendicular on stream tube); the use of the depression from the surface of an in stream body; the use of the depression from the center of the whirls; the use of the Coandă effect etc.

The concentration of the diluted wind energy is justified from theoretic point of view but the concentrator dimensions leads to serious constructive and financial problems. So we choose the in wind placed rotor solution.

1.2. The rotor function can be based on different principles:

- the use of the shape resistance;
- the use of the impulse force;
- the use of the speed circulation around a shape;
- the use of the Coandă effect etc.

The first three principles, tacked alone or together, are used at the most type of rotors. Viable are the one with propeller type rotor with **horizontal shaft** (with 1 to 24 blades) and the one with **vertical shaft** of Darrieus type (with 2 or 3 blades) and Savonius type.

The authors choose to build three rotors with horizontal shaft, with 18 blades, solution that has a bigger starting couple than others (figure 1, table 1). Equipment $E_{0.4}$ was started up in 1981 on the testing platform of the Fluid Mechanics Department and equipments $E_{1.5}$ and E_3 was assembled and started in 1987 on a testing platform at the Black Sea coastline. All these equipments work since these times to present.

The power that can be reached from the wind with a wind engine is:

$$N = 0.000613 \cdot Av^3C_p \qquad (1)$$

where N is the power in [kW], A is the cross section of the rotor in [m^2], v is the wind velocity in [m/s] and C_p is the wind energy coefficient of utilization (power coefficient). Relation (1) is obtained for the following conditions: the air density of 0.125 kg·s^2/m^4 at the temperature of 15°C and atmospheric pressure of 760 mmHg.

With the argument Glauert-Betz [5] results the value for the ideal power coefficient

$$C_p^i = 0.593 = 16/27 .$$

For a rotor with diameter D [m] and the rotation plane placed perpendicularly on the wind direction, relation (1) becomes:

$$N = 0.000481 \cdot D^2v^3C_p \qquad (2)$$

Table 1.

Denomination of wind rotor	$E_{0.4}$	$E_{1.5}$	E_{3}
Constructive type	*Multi-blade (slow) horizontal axis*		
Nominal speed of wind v [m/s]	*8*		
Rotor			
Rotor diameter $D = 2R$ [m]	*2.6*	*3.5*	*5.2*
Nominal speed r.p.m.	*60*	*65*	*40*
Rapidity $z = \omega R/v$	*1*	*1.5*	*1.36*
Number of blades	*18*		
Profile of blade	*Arc of circle*		
Nominal power [kW]	*0.4*	*1.5*	*3*
Direction of rotation	*Right*		*Left*
Orientation in wind			
Trail surface [m^2]	*0.7*	*1.25*	*1.9*
Regulation			
Through inclination	*Off-axis rotor*		*With side plane*
Range of operations without control [m/s]	*1.5÷8*		
Range of power limitation [m/s]	*9÷14*		
Out of wind [m/s]	*Over 14*		
Produced energy	*d.c. generator - 0.4 kW*	*Mechanical energy*	
Transmission of power to the ground	*Electric current, brush collector*	*Vertical shaft, 240 r.p.m.*	*Vertical shaft, 120 r.p.m.*
Location			
Mast	*4 double cables, with anchors*	*Lattice-girder*	
Height of rotor axis [m]	*16*	*11.6*	*10*
Use of energy	*Accumulator 12V, 240Ah, 12V d.c.– 220V a.c. converter*	*Multiple use at the ground (mechanical, electric, hydraulic, thermic).*	

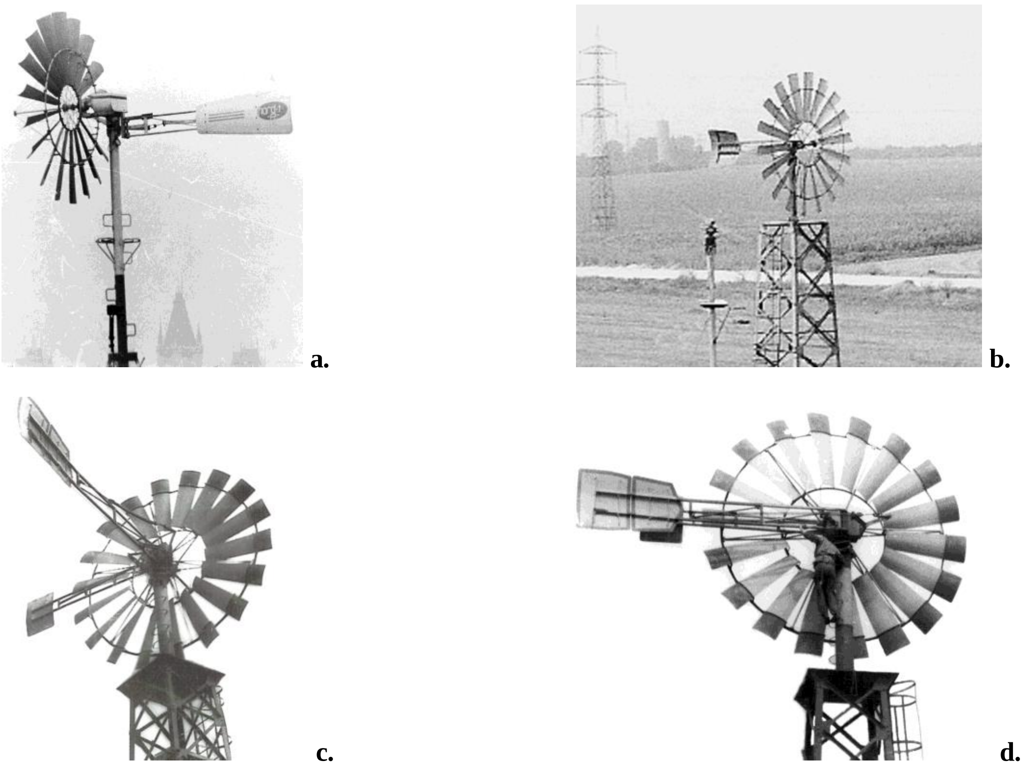

Figure 1.

The wind energy coefficient of utilization for the ideal rotor C_p^i increase with the rotor rapidity $z = u/v$ (where *u* is the circumferential speed of the rotor and *v* is the wind speed) tending to the maximal value of 0.593 for *z* = 5 [1].

For the propeller type rotor with horizontal shaft the real maximal wind energy coefficient of utilization C_p^r will be of 0.31 (at *z*=1) for the multiblade slow rotors and of 0.47 (at *z* = 5.5) for the two bladed fast rotors. The maximal cranking torque is for multiblade rotors and decrease with the number of the blades to the values that necessitate the unloaded starting of the rotor and after that the clutch engagement to the installation transmission.

Table 2.

v	2	4	6	8	9	10	20	45	60	80
v^3	8	64	216	512	729	1000	8000	91125	216000	512000
Cp_i = 0.593, A = 1 m^2, N_i [W]	2.9	23.3	78.5	186.1	265.0	363.5	2908	33125	78518	186117
Cp_r = 0.593, A = 1 m^2, N_r [W]	1.5	12.2	41.0	97.3	138.5	190.0	1520	17316	41046	97295
$E_{0.4}$, D = 2.6 m, Cp_r = 0.31, $AE_{0.4}$ = 5.3066 m^2, $N_rE_{0.4}$ [W].	8.1	64.5	217.8	516.3	735.0	1008.0	8067	91892	217817	516307
$E_{1.5}$, D = 3.5 m, Cp_r = 0.31, $AE_{1.5}$ = 9.61625 m^2, $N_rE_{1.5}$ [W].	14.6	117.0	395.0	935.6	1332.0	1827.0	14619	166520	394713	935616
E_3, D = 5.2 m, Cp_r = 0.31, AE_3 = 21.2264 m^2, N_rE_3 [W].	32.3	258.2	871.0	2065.0	2940.0	4034.0	32269	367567	871269	2065230

Table 3.

Rotor diameter ***D*** [m]		1	2	3	4	5	6	7	8	9	10	15	20
N_r [kW] Cp_r=0.31	v = 8 m/s	0.076	0.305	0.687	1.222	1.909	2.748	3.741	4.886	6.184	7.634	17.177	30.538
	v = 9 m/s	0.109	0.434	0.978	1.739	2.717	3.913	5.326	6.957	8.804	10.870	24.458	43.480
	v = 10 m/s	0.149	0.596	1.342	2.386	3.728	5.368	7.306	9.543	12.078	14.911	33.550	59.644

In table 2 we calculate the power for 1 m^2 of cross section for the ideal rotor ($C_p^i = 0.593$) and for the real one ($C_p^r = 0.31$) and also the power for the rotors $E_{0.4}$, $E_{1.5}$ and E_3 sections, with $C_p^r = 0.31$.

The analyze of the existing constructive solutions and the results of the calculus with relations (1) and (2) (tables 2 and 3) leads to some useful observation for the designing:

♦ The wind energy conversion, energy that is free, in other energy forms (mechanic, electric, hydraulic, thermic etc.) must be made with systems for that the costs provide advantageousness comparatively with the classic sources.

♦Because the air density is small, the wind energy is low at low speeds but increase with the wind speed at cube. If consider the nominal speed of 8 m/s, with $C_p^r = 0.31$, the power obtained for each square meter of cross section (table 2) is of 0.0973 kW. At 20 m/s we have 1.520 kW and at 80 m/s we have reached 97.295 kW/m^2. The powers obtained for $E_{0.4}$ at the same speeds will be of 0.516/8.067/ 516.317 kW, for $E_{1.5}$ of 0.935/14.619/ 935.616 kW and for E_3 of 2.065/32.269/ 2065.230 kW. In the strength calculation we made checking for speeds up to 20 m/s, for gusts of wind of 45 m/s (sometimes up to 60 m/s with a safety factor of 1.5, or even up to 80 m/s). If the strength calculation will be made at such extreme values of the speed and power, the installations obtained will be over measured comparatively to the one obtained with the usually values of the speed (8-14 m/s). Therefore, the installation will be dimensioned for a maximal critical speed (14 m/s for ex.) and verified for the maximum-maximorum speed with the taking into account of the hoar frost load and the earthquake load.

♦ The wind engine power increase with the square of diameter while the costs increase with the diameter at cube instead of decreasing like at others type of engines.

Therefore it is necessary to establish some optimum diameters for rotors, based on the power range and taking into consideration the local eolian potential (table 3, figure 2).

♦ In the construction of the three multiblades rotors the authors have in view the use of certain solutions technically accessible and also cheap if possible. The blades are from sheet iron, with circular arc profile, fixed on concentric circle. The whole construction can be made with local sources.

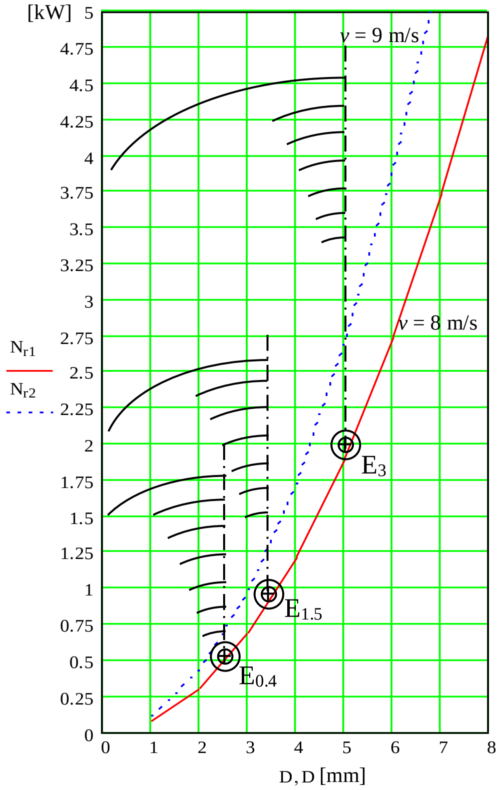

Figure 2.

♦ At all the three prototypes the rotor is placed at a certain distance face to tower for an easier access of a person in the rotor-power space for intervention.

♦ The rotors have blocking system in case of difficulty, storm or intervention.

♦ The equipment has an operating time of over 15-20 years. The authors have in view simple solutions for maintenance and repairs and the building blocks are protected to corrosion.

1.3. At the wind engines with horizontal shaft **the in wind orientation** is necessary because of the possible changes in the wind direction. The orientation was achieved with a drift. The solution has a good efficacy.

1.4. The adjusting of the rotor rotation speed is necessary for maintaining the both speed and power approximately constant at the outrunning of a certain wind speed in order to respect the requirements of the operated equipment and the power limitation from the strength conditions of the rotor (figure 3.a)

The wind speed at which the protection mechanisms begin to function is in close connection with the annually average speed of the wind [2]. For speeds *v* between 1.5 and 8 m/s no adjustment is needed. For speeds *v* between 9 and 14 m/s we have power limitations and for speeds over 14 m/s the rotor must be removed from the wind.

The nominal speed is considered of 8 m/s for the areas with annually average speed fewer than 5 m/s, of 10 m/s for speeds under 7 m/s and of 14 m/s for annually average speed over 7 m/s. The nominally wind speed tacked into consideration for all the three prototypes was of 8 m/s.

To maintain constant the rotation speed and the power we must action on the parameters from the power relation. In the particularly case of the designed installations we choose to modify the in wind area of the rotor. We realize this desideratum by surpassing the rotor. At the installations $E_{0.4}$ and $E_{1.5}$ the adjustment is made through the eccentric disposing of the rotor relating to the drift direction and the vertical shaft of the installation (figure 3.b). At the increase of the wind speed, his action on the eccentric rotor causes the surpassing. At the installation E_3 we utilize a laterally plane that create an asymmetry (figure 3.c). At the removal of the rotor from the wind, at high speeds, the laterally plane and the rotor becomes parallel with the drift (figure 1.d).

1.5. The tacking over of the energy from the rotor and his delivering to the ground it can be made through different ways (mechanic, electric, pneumatic, hydraulic, sonic). At the installation $E_{0.4}$ the rotor rotation speed is multiplied through a gear multiplier and belt pulleys with the global transmission ratio of 31.25 and directed to a d.c. electric generator.

Because of aleatory characteristic of the wind speed the windmill has a non-uniform movement of rotation and that's why the a.c. generators has a fluctuating frequency. The coupling of these generators at the electric network at the industrial frequency of 50 Hz, need very expensive systems. For small power wind engines (under 20 kW) it is not a solution.

Using of a d.c. generator of 400 W, branch type, need high rotation speeds for self-excitations. That means a high multiplication ratio from the slow windmill to the generator. The transmission of the electric current to the ground is made through brushes and collector placed between the motor head and tower.

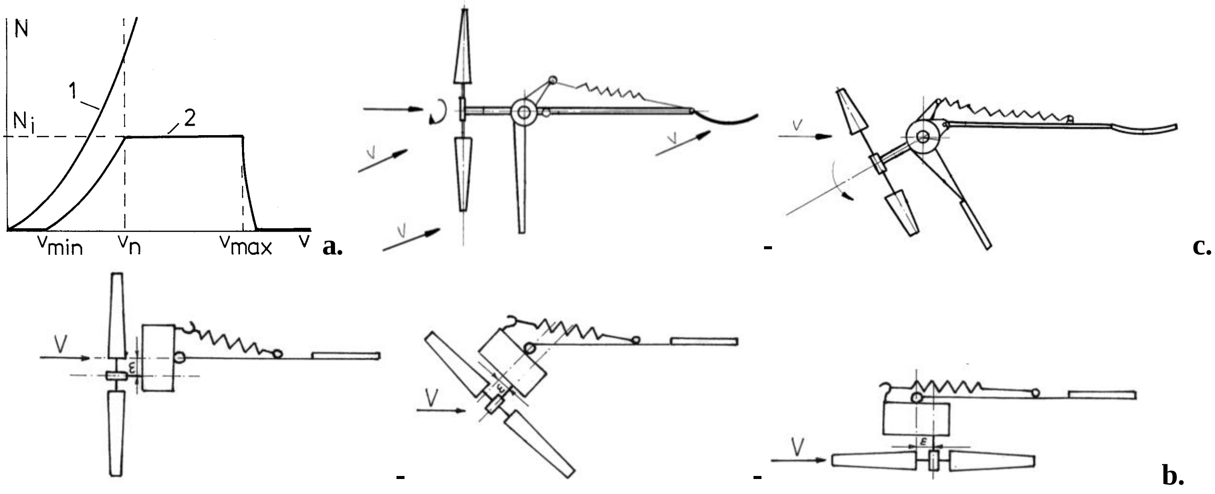

Figure 3.

The schema with d.c. generator also need a lead storage battery for the obtaining of a constant voltage as well as a current controller and a make-and-break device.

At present, d.c. motor car type generators and from railway transport are available. These types of generators are already equipped with control systems.

The transmission of the movement to the ground for the $E_{1.5}$ and E_3 installations is made through a bevel gearing and a vertical shaft. Their destinations can be very different:

- The acting of a piston pumps (there are two such pumps with dual action, designed and executed by the authors). The slow rotor having a big starting couple deliver a flow rate proportional to the rotation speed of the rotor at a constant pressure.
- The acting of a hydraulic brake for heat generation (there two such brakes of fluid flywheel clutch type, designed and executed, the secondary rotor being blocked).
- The producing of electric energy with d.c. generators.
- The acting of some household equipments.

The tower can be made in two variants: with anchor cables or self lifting type. The last variant is indicated for powers over 20 kW and tower height over 15-20 m. The tower for the installation $E_{0.4}$ has 16 m height and 4×2 anchor cables with tilting motion possibility. It is made from tubular elements and allows the mounting and the maintenance from the ground for all the suspended parts. The production and maintenance costs are accessible.

1.6. Owing to the aleatory character of the wind energy, to the small powers realized by the installations destined to the isolated consumers and to the fact that the needed energy not always correspond to the wind existence, **the storage of the energy** obtained and his delivery at request is necessary.

The stoking systems recommended for the three installations are:

- electric storage (for $E_{0.4}$) through classical lead storage battery that can provide the feeding energy only for isolated consumers and for a limited period of time. The storage battery dimensioning it is made so that the supplying of the major consumers for 24 hours did not exceed 20% of the full capacity of the battery. Like disadvantages we have the long recharging time, the big volume of the whole system, the electric complications and the high costs.
- hydraulic storage (for $E_{1.5}$ and E_3) realized by pumping of fluids (water or other) in tanks for personal use.
- thermic storage using the heat generated by hydraulic brakes (for $E_{1.5}$ and E_3) and stored through the melting of different substances with the possibility to use the back reaction.

2. CONCLUSIONS

- The wind engines designated to isolated consumers are important for the designers who know the operating principles, have an adequate equipment and a suitable eolian potential.
- The functioning of the three-presented prototypes for more than 15 years leads to useful conclusions regarding the designing, the manufacturing and the use of the small wind engines for isolated consumers.
- The approach of the wind engines problems with prudence and realism can lead to safe and relatively cheap constructions.

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