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Solutions for using renewable energy sources to produce electricity and to provide water for domestic supply and irrigation

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Abstract. Environmental pollution, greenhouse effect, intensification due the wide-ranging of organic fuel, as well as care of energy supply to the future generations caused the accelerated development of technologies oriented to the use of renewable energy sources. Some of these technologies are shown in the paper where some examples of the methods to produce electricity and to provide water for irrigations in the places where there is no access to a large electricity grid like small isolated communities, remote consumers, rural villages, inquiring centers, light houses, inaccessible farms, shelters, telecommunication stations are presented. In order to produce electricity a solution of a wind turbine with vertical axis helical rotor shape with good energetic performances is presented. Also, in the paper some considerations regarding the use of renewable energy sources are presented in order to pump water that can be used in different ways including supply water for domestic needs or for irrigation in small-scale area of lands. In this direction two solutions of using renewable energy sources with a wind turbine to pump water for houses and to pump water that is used to irrigate land of small farmers are shown.

1. Introduction

All around the world there is a number of small isolated communities, like islands and rural villages without access to a large electricity grid. The absence of an electrical network in their major area or the prohibitively high connection cost, force these remote consumers to cover their urgent electrification needs to use small diesel electric generators with all the problems of pollution of the environment and noise.

The development of renewable energy sources is a central aim of European Union energy policy reflecting the clear benefits that clean, sustainable and secure energy supplies will bring to current and future generations of Europeans, as well as other people worldwide. Clean-because they reduce the pollution that scars our cities and countryside. Sustainable –because they are renewable and do not contribute to the buildup of greenhouse gases that cause climate change. Secure-because they are sourced within Europe, not imported, and thus they reduce our dependency on events elsewhere in the world that it cannot control [1].

Because the desire was to build a wind turbine which was meant to pump water, it is necessary to know first the percentage of renewable energy sources in total consumption and the energetic potential of renewable energy sources.

Wind turbines are classified as vertical or horizontal axis machines depending on the axis of rotation of the rotor. The energy available in the wind is proportional to the cube of the wind speed: if the wind speed is doubled, the available power is eight times higher [2].

Wind turbine has many applications as:

- stock water – sheep, cattle, horses;
- domestic applications – household water for drinking, sanitation, and washing;
- irrigation – for house and vegetable gardens;
- filling dams, reservoirs, fish ponds, lakes;
- dewatering wet lands;
- water for small industry;
- waste water removal;
- sewage;
- remote locations;

The selecting of a wind turbine should be based on the next criteria: wind conditions, source of water supply, water requirements, total pumping head, and governing.

As regards the wind conditions, the right combination of wind turbine and pump is one which will work easily in light winds (about 10 km/h). This will also depend on the total pumping head [3].

The use of wind energy is an important issue for Romania to meet the target of the Renewable Energy Fact Sheet, with 24% renewable energy consumption by 2020 (figure 1), [4].

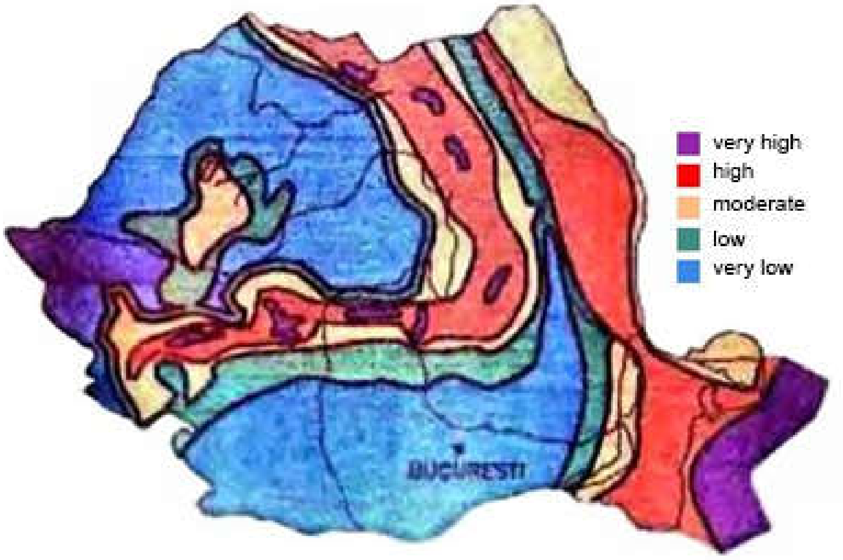

Figure 1. Chart with energetic potential wind of Romania [kWh/m^2/year].

2. Wind turbine with vertical axis helical type

For the remote locations, and when it is desired to be independent in terms of the electric energy source, a wind turbine with vertical axis helical type was designed. This type of wind turbine is easy to mount on the roof of a house, having the main advantage of not necessitating to be pointed into the wind direction with a system as other types of wind turbines. In the same time it works without any noise and the shape of the rotor make these turbines inoffensive for the birds.

The rotor of this wind turbine was made by the FINEX Company, patented in Romania, and it is with three blades with fiber glass material. The main advantages of this type of wind turbine with helical type rotor whose main rotor shaft runs to the flow streamlines, from other type of wind turbines with horizontal axis are [3, 5]:

- simplicity in construction and good strength;
- high reliability;

- smaller cost by 20 % compared to similar turbines;
- specific power bigger on the active surface;
- big torque moment at starting;
- at the wind speed bigger than 20 m/sec it is self-braking without mechanical components, due to its original shape of rotor;
- doesn't need orientation after the wind direction;
- it can work at high wind speed, such as 50 m/s;
- it is the only one wind turbine that is accepted by environmental agencies, because it doesn't kill birds;
- it doesn't make noise during its functioning;

The rotor was mathematically designed and tested in experimental conditions on the car adapted as a mobile laboratory, where the next parameters were measured:

- wind speed [m/s];
- rotational movement of rotor shaft [rpm];
- generator power [W];
- air temperature [^{0}C].

This rotor was made after long-lasting tests for the wind turbine at small power of 0.5-2 kW. For the determination of the maximum theoretical power that can be extracted from a laminar air flow, a wind turbine rotor with a horizontal axis subjected to an air flow shown in figure 2 is taken into account [5].

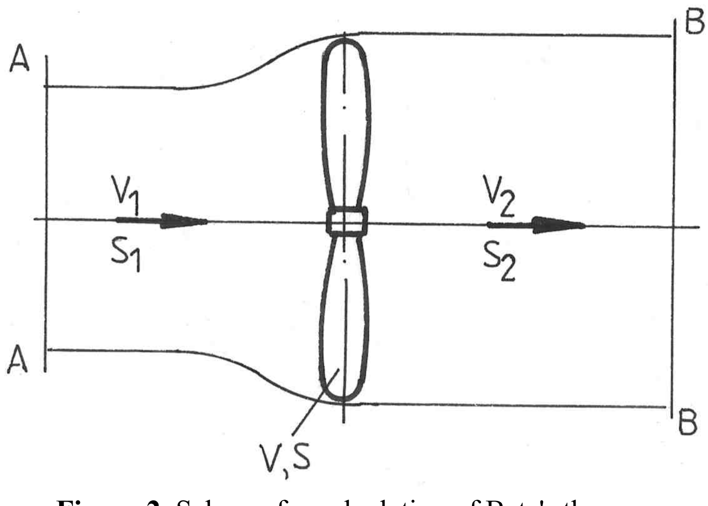

Figure 2. Scheme for calculation of Betz's theory**.**

where: v_1- air flow velocity in A-A section;
S_1 – size of A-A section;
S_2 – size of B-B section;
V_1 – air flow velocity through A-A section;
V_2 – air flow velocity through B-B section

Producing energy in rotor makes that kinetic energy of the air mass which goes out from rotor to be smaller than that that enters the rotor, thus $v_2 < v_1$. it can be considered that air is not compressible and the results are:

$$S_1V_1 = S \cdot V = S_2V_2 = Q \tag{1}$$

If the force which interacts between rotor and air flow is evaluated, it can be written:

$$F = \rho \cdot Q(V_1 - V_2) = \rho \cdot S \cdot V(V_1 - V_2) \tag{2}$$

The power absorbed by the rotor is:

$$P = F \cdot V = \rho \cdot S \cdot V^2(V_1 - V_2) \tag{3}$$

$$P = \rho \cdot S \cdot V^2(V_1 - V_2) = \frac{1}{2}\rho \cdot S \cdot V \cdot (V_1^2 - V_2^2) \tag{4}$$

From where will result:

$$V = \frac{V_1+V_2}{2} \tag{5}$$

It is possible to write *F* and $P = f(V_1, V_2)$:

$$F = \rho \cdot S\frac{(V_1+V_2)^2}{4}(V_1 - V_2) = \frac{1}{2}\rho \cdot S(V_1^2 - V_2^2) \tag{6}$$

$$P = \rho \cdot S\frac{(V_1+V_2)^2}{4}(V_1 - V_2) = \frac{1}{4}\rho \cdot S(V_1^2 - V_2^2)(V_1 + V_2) \tag{7}$$

To determine the maximum of the function related with V_2:

$$\frac{dP}{dV_2} = 0 \ \Leftrightarrow V_1^2 - 2V_1V_2 - 3V_2^2 = 0 \tag{8}$$

With the solutions:

$$V_2 = -V_1 \tag{9}$$

$$V_2 = \frac{V_1}{3} \tag{10}$$

From where the value is taken $V_2 = \frac{V_1}{3}$
So,

$$P_{max} = \frac{1}{4}\rho S\left(V_1^2 - \frac{V_1^2}{9}\right)\left(V_1 + \frac{V_1}{3}\right) = \frac{8}{27}\rho SV_1^3 \tag{11}$$

For air density $\rho = 1.25$ kg/m^3 results: $P_{max} = 0.37SV_1^3$.
The power factor of the turbine is determined by:

$$C_p = \frac{P}{\frac{1}{2}\rho SV_1^3} \tag{12}$$

The maximum power coefficient will be given by:

$$C_{pmax} = \frac{P_{max}}{\frac{1}{2}\rho SV_1^3} = \frac{\frac{8}{27}\rho SV_1^3}{\frac{1}{2}\rho SV_1^3} = \frac{16}{27} = 0{,}593 \tag{13}$$

It can be concluded that the maximum power to be obtained by means of a wind rotor in relation to the power of a free air flow passing through the same surface is approx. 0.6. This figure is called Betz's coefficient and it represents a maximum theoretical limit.

In practice, this coefficient decreases and values of good values of C_p = 0.4 are considered. An important parameter defining a wind turbine is the specific speed coefficient that varies according to the number of blades: 1 blade, λ = 9; 2 blades, λ = 6; 3 blades, λ = 5; 10 blades, λ = 3).

In the graph shown in figure 3, the variation of the power coefficient, C_p, is given according to the parameter λ, called the specific speed coefficient, where R is the radius of the rotor, ω is its angular velocity, and v is the wind speed. From this figure it can be seen that the turbine with blades has the parameter C_p, close to that of the Savonius turbine. For λ closely related values, it is noted that the turbine with blades has the higher C_p power factor, and besides this advantage, the cost price is lower compared to the Savonius type rotor due to lower quantities of materials that are part of the component.

The wind turbine, made in the experimental variant, is placed after testing at a good power coefficient C_p= 0.4 and the parameter λ has the value of 3.5 making the parameters particularly good for this new type of rotor [6].

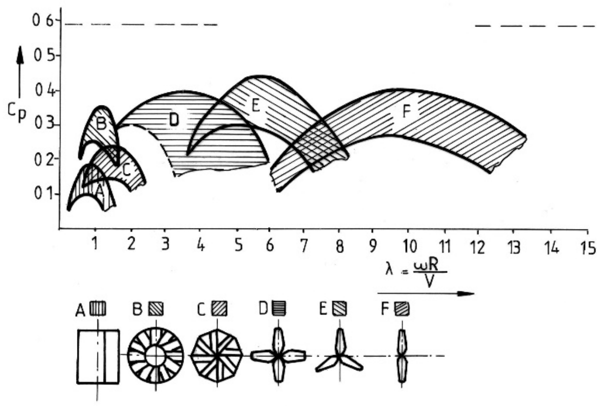

Figure 3. The variation of the power coefficient C_p according with the parameter λ.

The turbine is acting a current generator with permanent magnets (PMG) that has the characteristics shown in figure 4.

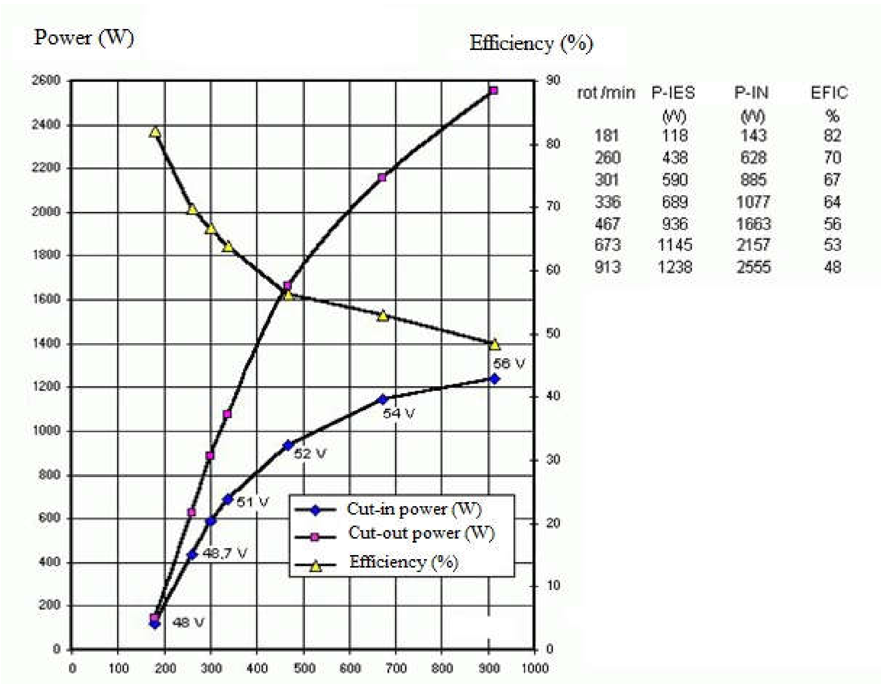

Figure 4. The characteristics of the current generator type PMG 600.

The rotor was mathematically modeled and tested in experimental conditions mounted on a car adapted as a mobile laboratory, where the next parameters were measured (figure 5), [6]:

- wind speed [m/s];
- spindle revolutions [rpm];
- power of generator [W];
- air temperature [^{0}C].

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Because the rotation of this type of rotor is maximum 120 m/min, it is necessary to use a multiplicator of rotation, which ensures an optim regime in function, for the current generator with permanent magnets. The current generated is threephasic, and it needs to use a rectifier to accurately measure the current tension at different rotations of spindle.

For the values obtained, wind speed [m/s], spindle speed [rpm] and current tension of the generator, it is possible to calculate the main parameters of the turbine. These main parameters are shown in the graph of power variation [W] according to the wind speed [m/s] (figure 6). In order to do experimental data processing the Excel Program was used.

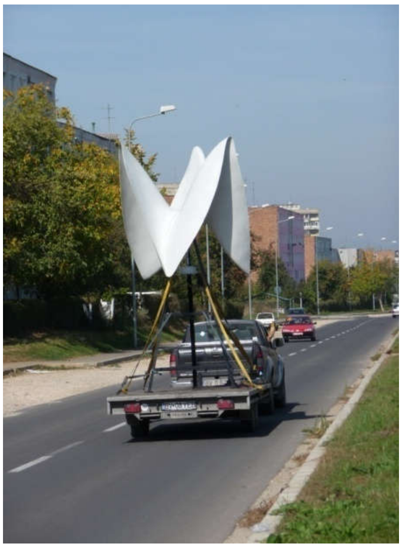

Figure 5. Wind turbine with vertical axis helical type mounted on a car during experimental tests.

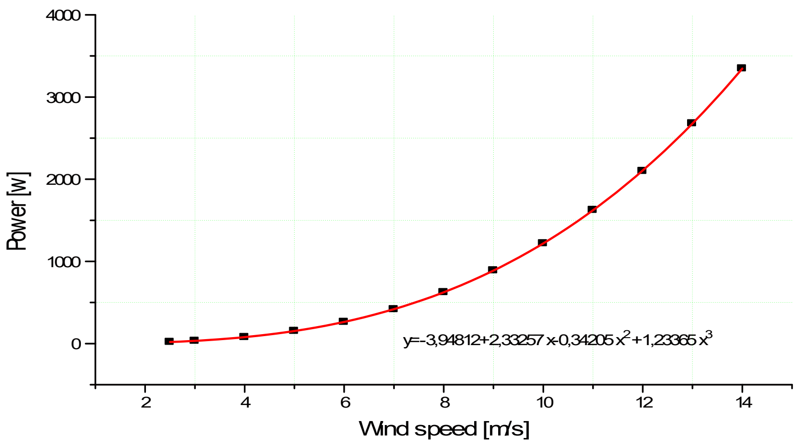

Figure 6. Graphic representation of power variation according to the wind speed.

This graph is compared with the values obtained by other companies which produce wind turbine with vertical axis and similar power.

After the experimental tests the formula of power given by this wind turbine was obtained:

$$P = 0.5 \cdot \rho \cdot C_p \cdot A \cdot \omega^3 \ \ [\text{W}] \tag{14}$$

where:

P – power obtained [W];

ρ – air density (1.225 kg/m^3);

C_p – power coefficient;

A – rotor area (4$m^{2)}$;

ω – wind speed [m/s].

The power coefficient obtained was $C_p = 0.33$.

Experimental tests of producing electricity using energy of wind with turbine vertical axis with two rotors helical type were also made. In these tests the values of electricity produced increased nearly two times comparing with the case when the turbine had one rotor (figure 7) [6].

Figure 7. The experimental tests of two rotors helical type on vertical axis wind turbine.

After many experimental tests this wind turbine was mounted in different places where the wind has a good energy during the days and it was observed how it works and the level of electric current that was produced. One of these places is shown in figure 8, where the wind turbine with vertical axis was placed in a garden.

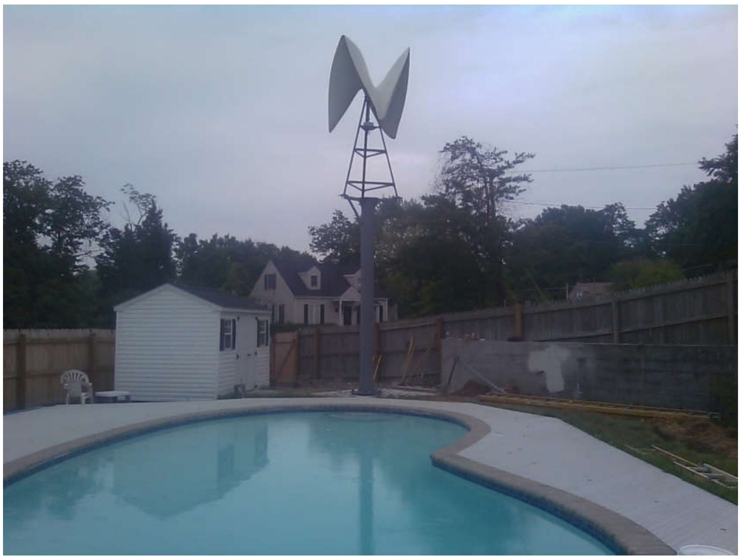

Figure 8. Wind turbine with vertical axis helical shape mounted in a garden.

3. Renewable energy sources to provide water for domestic supply

The wind is a natural resource that is available everywhere. As a general rule, the wind blows for between 8 to 10 hours per day, at a speed that is useful for the wind turbine. Wind turbine will be useful for pumping water for stock and domestic supplies in isolated rural areas. It can be an economical alternative where:

- wind conditions are reliable;
- unattended pumping is required for long periods;
- there is no other viable power source;
- the user requires environmentally clean power.

The principal advantages of using a wind turbine are outlined below:

- run unattended for long periods;
- low maintenance;

- suits isolated locations;
- no energy costs;

Some of their disadvantages are:

- high capital costs;
- intermittent pumping in very light winds;
- requires auxiliary storage;

The idea was to build a wind turbine which is used to pump water for domestic supply necessities in a holiday location where there is a number of 10 houses. The holiday place is near a river and they intend to use the water from the river for their daily needs.

In Figure 9 the principle of the idea of taking water from a river and to send it to the tank from where it can be used anytime is shown.

The main elements of the wind turbine used to extract water from the river shown in Figure 9 are [7]: 1-the water tank; 2-wind turbine body; 3-diaphragm pump; 4- pipe system; 5-the river.

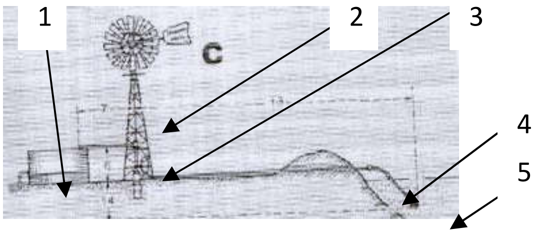

Figure 9. Principle of wind turbine to pump water.

Table 1. Determination of the necessary of water volume.

Water use	Estimated daily use (Litres)
Domestic–drinking (per person)	2
Domestic–hygiene, bathing (per person)	10
Domestic–toilet (per person)	10
Domestic-laundry (per person)	15
Domestic-household cleaning	10
Swimming pool	750
Machinery wash-down	100

To achieve the needs regarding the domestic water supply a wind turbine with horizontal axis which is presented in figure 10 was designed and realized, [7]. The main parts of the wind turbine are: 1- the rotor with blades; 2 - the tower or mast made by tubular steel with two sections of pipe coupled together; 3 -the guy wires attached to the tower in three points and with an underground concrete anchor for each set; 4 - the diaphragm pump; 5 - the concrete base.

The rotor is made by 12 blades and it has a diameter of 1.5 m. The height of the entire turbine is 6 m. The wind turbine is located at 5 m distance from the river whose water was supposed to be used for domestic needs.

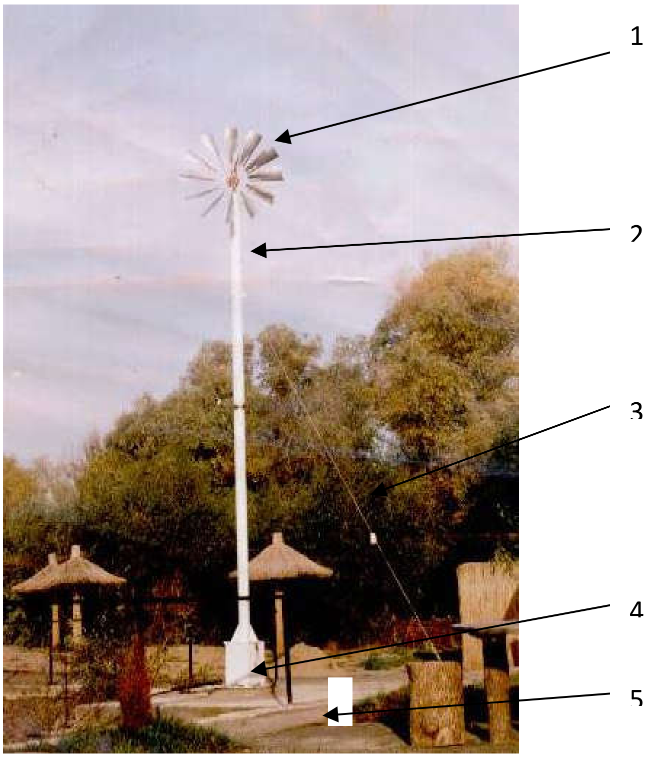

Figure 10. A wind turbine with horizontal axis to pump water.

To pump the water a diaphragm pump shown in figure 11 was chosen [7]. The pump is acted by a cable (4) that has a reciprocating motion which is received from the rotor mechanism. The rotor mechanism transforms the revolution motion into reciprocating motion through a cam. In a cam operated wind turbine, the lift of the water occurs during more than half the cycle. Using a cam that allows for three-quarters of the cycle lifting and one-quarter return, starting torque is reduced by 60 percent. The wind turbine will start in light winds, and if combined with counterbalancing, starting torque is reduced by 72 percent.

A diaphragm pump (5) is a pump that uses a combination of the reciprocating action of a membrane made by rubber and non-return check valves to pump water. When the volume of a chamber is increased – the diaphragm moving up- the pressure decreases, and fluid is drawn into the chamber. When the chamber pressure increases from decreased volume – the diaphragm moving down- the fluid previously drawn in is forced out. After that, the diaphragm is moving up again, it draws fluid into the chamber, completing the cycle.

The entire perimeter of the diaphragm is tightly held and sealed in place between the side of the displacement chamber and a flange, which is tightly bolted to the chamber. Each displacement chamber has two valves, usually spring-loaded ball valves made from the same material as the diaphragm. One of the valves admits the water being pumped to the diaphragm chamber, and the other allows the material to exit the diaphragm chamber. It is a driving mechanism that flexes the diaphragm in and out of the chamber to suck in and force out the water. The water is taken from the river through the device 7 and is sent to the water tank by the flexible pipe 3. The body of the pump 7 is connected to the tower 1 by the plate 2 by a bolt and bush-bearing which helps when the mast is erected in position.

Figure 11. Diaphragm pump used to pump water.

4. Water wheel powered by hydro resource used for irrigation

In figure 12 a constructive solution of a water mill used to take the water from a river and to send further to a reservoir is shown [7]. The main elements of this water mill are: the primary reservoir (1), the pipe (2) from where the water is conducted to the main reservoir; the rotor axis (3); the screws (4) that permit setting of the water mill in a vertical plan; the counterweight (5); the concrete pillar (6) that supports all the construction; 24 collecting tubes (7); the rotor ring (8) where are mounted the collecting tubes.

Water mill has a diameter of 4000 mm which allows lifting water from the river at a height of 3500 mm, where it is stored in a primary reservoir 1. From the primary tank (1), water is passed through the pipe 2 to the main tank located at a distance of 2 m from the concrete pillar (6). Rotor ring (8) is made of two rings of steel sheet of thickness 0.5 mm and is connected to the main shaft (3) by means of profiled spokes. On the two rings of the rotor 24 tube collectors, made by polypropylene, with a length of 500 mm and diameter of 75 mm are fixed. The impeller is submerged in the river water at a depth of 200 mm. This allows complete filling the tube collector with water from the river. Turbine construction allows adjustment of horizontal and vertical plan to a range of 150 mm which allows being adapted to specific conditions of the installation in the site near the river.

In the period between harvesting crops and starting a new season in agriculture, the turbine is decommissioned by tilting it 20 degrees. In this mode the life of the plant is extended and it reduces maintenance costs. Keeping the turbine in this inclined position is realized by a lock system [4, 5].

Turbine works without interruption throughout the period between the start of the season in farming and till harvesting period ends. Throughout this time water is stored in the main tank, and then is distributed through the pipes to areas to be irrigated. Irrigation system is different from one culture to another depending on the terrain where the turbine is installed.

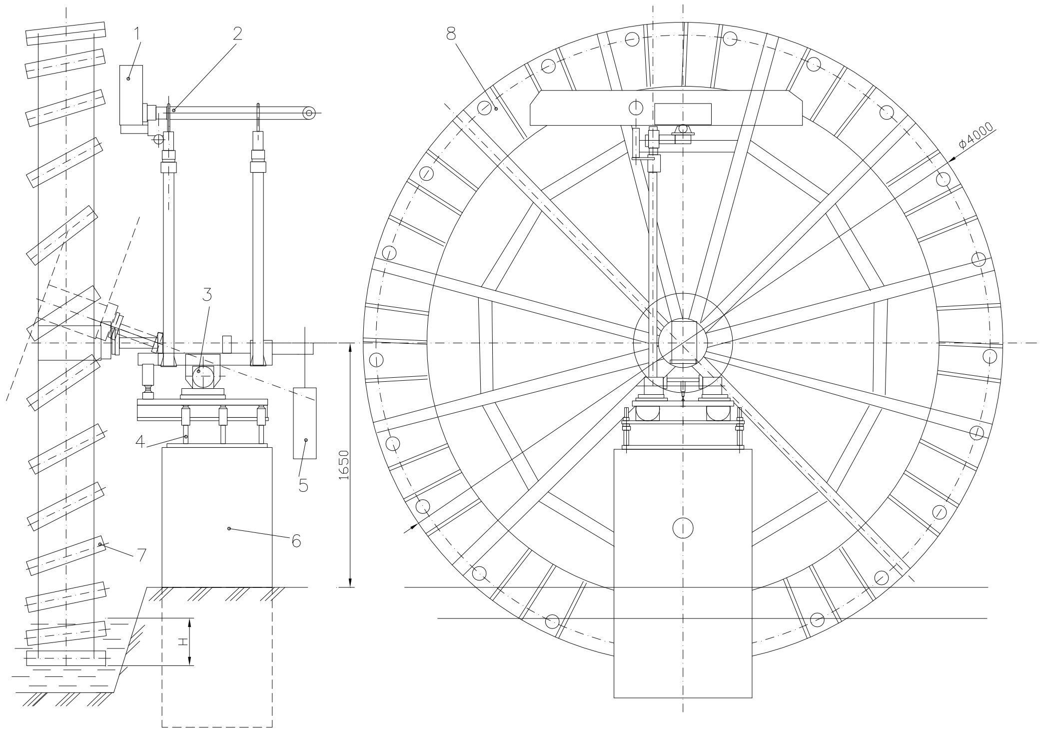

Figure 12. Schematic illustration of a water mill used for irrigation.

To calculate the turbine parameters are used figure 13. This figure shows schematically the position of the collector tube fixed on the rotor in the time when its upper end comes out from the water [7].

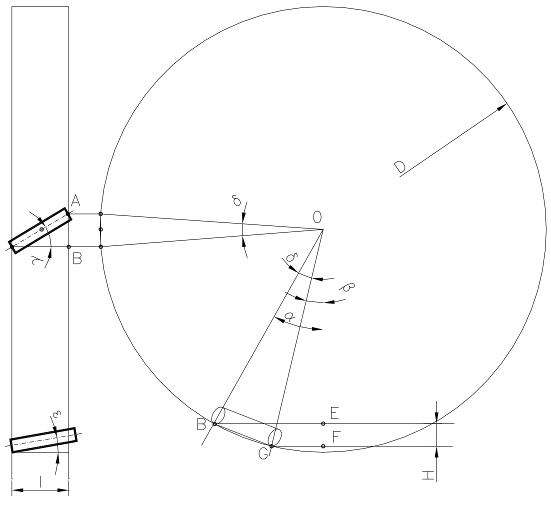

Figure 13. Sketch used to calculate the water mill parameters.

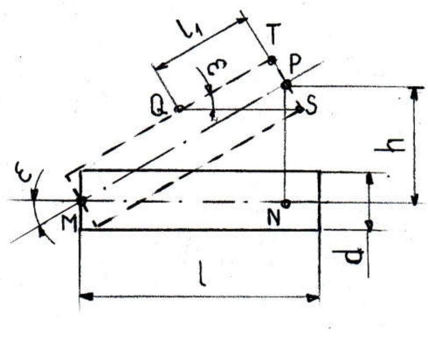

Figure 14. Calculation of the amount of water carried by the tube collector.

At this point, the collector tube is almost full with water and continues the lifting movement once the rotation of the rotor. Water collection tube is mounted on the rotor's circumference at an angle γ.

Due to tube collector mounting angle, water can never fill its entire cavity. To calculate the amount of water that is transported by one collector tube figure 14 is used [7].

After a series of calculations equation (15) is obtained which shows the amount of water that is taken from the river by one tube collector. Since the rotor has 12 tube collectors, this value must be multiplied by 12 to determine the amount of water that comes to one rotation of the rotor.

$$V_2 = \frac{\pi d^2}{4}\left(l - \frac{d\sqrt{4l^2-\{D[cos(\alpha-\delta)-1]+2H\}^2}}{2\{D[cos(\alpha-\delta)-1]+2H\}}\right) \tag{15}$$

Equation (15) gives the amount of water that is taken from the river by one tube collector. Since the rotor has 12 tube collectors, this value must be multiplied by 12 to determine the amount of water that comes from one rotation of the rotor.

Below is the calculation of water volume that is taken from the river for the next elements of the rotor:

l = 500 mm; D = 3900 mm; H = 200 mm; $\gamma = 45^0$; d = 75 mm.

Using formula (15) results:

$$V_2 = \frac{\pi\cdot 75^2}{4}\left(l - \frac{d\sqrt{4\cdot 500^2-\{3900[cos(26^0 10'-10^0 20')-1]+2\cdot 200\}^2}}{2\{D[cos(26^0 10'-10^0 20')-1]+2\cdot 200\}}\right) \approx 1{,}57\ l \tag{16}$$

So, the amount of water that will be taken from the river and transported in uppermost position during one rotation of the rotor will be: 1.57x12=18,84*l*.

An important factor for plant efficiency is the speed of the water of the river. As the speed of the water is higher, the amount of water extracted by the rotor will be greater and therefore, higher plant efficiency.

Number of revolutions of the rotor in a minute n_{min} is given by:

$$n_{min} = \frac{v_w}{\pi\cdot D} \tag{17}$$

Where v_w is the velocity of water's river, and D is the diameter of the tube collector disposed on the circumference of the rotor.

Volume of water extracted from the river in one minute V_{min} is given by:

$$V_{min} = n_{min}\cdot V_2, \tag{18}$$

where V_2 is the volume of water extracted from the river by the rotor in one rotation given by equation (15).

Relation (17) can be written:

$$V_{min} = C\cdot v_w, \tag{19}$$

where C is a coefficient given by: $C = \frac{V_2}{\pi\cdot D}$

Coefficient C was calculated for the following angles γ of mounting tube collectors on the rotor circumference, and volume of water V_2 extracted from the river water at one rotation (Table 2).

Table 2. Coefficient C depending on the angle γ and the water volume V_2.

γ	15^0	20^0	25^0	30^0	45^0	60^0
V_2	14.64	24.20	27.12	36.24	37.68	40.08
C	1.196	1.979	2.215	2.959	3.077	3.273

Using C coefficient values (table 1), the volume of water extracted from the river in one minute V_{min}, can be calculated depending on the speed of river v_w for different mounting angles γ of the collector tubes on the rotor circumference.

Having all these equations it is possible to calculate the volume of water extracted from the river one day (V_d), depending on the angle of installation of the collecting tubes on the rotor circumference (angle γ) and the speed of the river water (V_w) (figure 15).

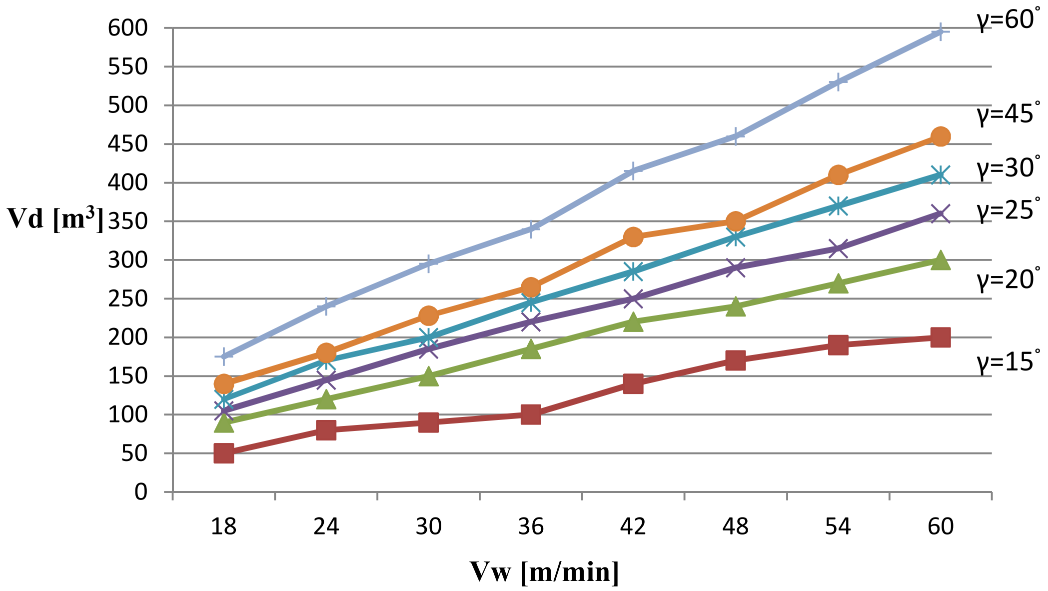

Figure 15. Volume of water extracted from the river in one day (V_d), depending on the angle of collecting tubes on the rotor circumference (angle γ) and the speed of the water' river (V_w).

In figure 16 the undershot water wheel that was made to irrigate a land of farm from a small river with the dimensions: width 2 m, depth 0.5 m and the speed of the water is 35 mm/min is presented. The rotor has a diameter of 4 m, [7].

Figure 16. Undershot water wheel used for irrigation of dry lands.

5. Conclusions

All the experiments presented in this paper are personal contribution of the authors to the field of renewable energy sources.

The main contributions consist of:

- design and testing of the wind turbine with vertical axis helical type;
- determining the power variation of wind turbine with vertical axis helical type according to the wind speed;
- the experimental tests of two rotors helical type on vertical axis wind turbine;
- the experimental tests of wind turbine with vertical axis helical shape mounted in a garden;
- the experimental tests of wind turbine to provide water for domestic supply;
- design and testing of water wheel powered by hydro resource used for irrigation by determining the volume of water extracted from the river in one day depending on the angle of collecting tubes on the rotor circumference and the speed of the water's river.

The renewable energy sources have clear benefits that distinguish them from fossil fuels. Renewable energy sources can be exploited in more ways and in more places than fossil fuels. They are environment – friendly origin, being known as "green electricity". That is way the wind energy was used to pump water in a location that is remote from electricity grid and that is unattended for long periods.

One of the advantages of using this type of irrigation system is to function as a green technology concept having no negative effect on the environment. It has a big impact on the rural economy, increasing the productivity of the cultivated fields. The development of energy systems based on water energy resources is vital to enhance the livelihood of people and it has a great potential in terms of economic impact due to its low cost, sustainability and energy renewability.

In country agriculture, water use is of great importance to obtain yields proportionate to the population. Drought is a natural very harmful factor that affects a large agricultural area from the total agricultural area of a country. Drought effect is observed mainly in the plains and hills with a moisture deficit and uneven water distribution cultivated area.

Considering the technical information from the literature in the field of renewable energy sources, the main purpose of irrigation is to supply water during the growing agricultural areas located in dry areas or in areas with unfavorable distribution of rainfall. If there are larger surface that need irrigation multiple installations mounted on the river can be used. Some other advantages of using these types of installations for the irrigation of dry areas are:

- it improves the general health of the villages;
- zero pollution;
- it operates 24 hours a day, 7 days a week without supervision;
- no fuel or electricity cost;
- low maintenance and repair cost;
- repairs are done locally;
- installation is up to 80% cheaper than other water system models;
- local manufacturing and training generates employment.

Acknowledgement

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