First published at http://www.fe.up.pt/~feliz in 20 November 2006, and registered with the Portuguese Society of Authors

Low-cost Convergent Turbine for Wind Power Usage

© J. Manuel Feliz-Teixeira

November 2006

Email: feliz@fe.up.pt
Url: http://www.fe.up.pt/~feliz

KEYWORDS: Renewable energy, wind power, "convergent" and "divergent" turbines, windmills, electrical generation, inexpensive solutions.

ABSTRACT

Here we describe the concepts related to what we consider "divergent" and "convergent" turbines and use these concepts to support the introduction of a new turbine for wind power capture. This is a low-cost turbine which can easily be build with ordinary materials, to a certain extent inspired by the old Portuguese windmill used to grind grain into flour. Mainly due to the simple construction, the low-cost of its materials and the surprising performance observed in practice, this system can be seen as an interesting alternative to the expensive wind turbines presently offered in the market. This is, however, a proposal that has not yet been verified by accurate scientific measures in order to be compared with the performances achieved by the usual turbine design. We invite the reader to contribute to such a task, should s/he find this an interesting subject. We also expect to simulate the concepts presented as soon as the time and financial support allow it.

1. Introduction

As a first remark, we would like to state that any novel ideas presented in this article are to be considered anti-patent, that is, they are offered to the public domain by its author and anyone may implement them freely without the need for any special permission, other than a symbolic contribution in order to cover the author rights. Please contact the author, in this case.

The energy contained in the blowing of the wind has been used by humankind for a long time, as we know, and sailors are perhaps those who have better experienced the power of such a source of energy. In effect, most of the geography of our Earth was "discovered" by people moving by means of wind power. Additionally, this energy was also used for pumping water and for grinding grain, for example, in systems known as windmills. Some of these practices seem to have remained stable for a long period of time, perhaps for even more than a millennium, with some of them still being used today, like the sailing vessel and some windmills in places that are still under development. At the end of the 19th century, however, a slow revolution was starting with Charles F. Brush in America and Poul la Cour in Denmark who were dedicated to developing automatically operating wind turbines for the generation of electricity (D.W.I.A., 2003). These can be considered the pioneers in using wind energy for electrical power generation. It is interesting to notice, however, in particular when we focus our attention on windmill systems, that mainly two approaches for capturing the energy from the wind are employed: in the first, there is the tendency for capturing this energy with several blades which the force of the wind drives around an "opaque" centre of rotation. This is the case of the well- known Dutch windmill, for instance, extensively used for pumping water. In the second case, there is the tendency to use sails located at a distance apart from a "transparent" centre of rotation which capture the peripheral wind force and use its superior torque for turning around a circular structure. This is the case of the ancestral Greek windmill, of which the Portuguese windmill is a particular case. Figures 1 and 2 give a better idea of these two types of methods for collecting the energy of the wind. There are also other methods that use vertical shaft turbines, like the old Chinese and Persian windmills configurations, but these systems are usually seen as being less efficient than those using the horizontal shaft scheme. An interesting overview of several wind turbine schemes can be found on the Heiner H. Dörner's webpage[1], among other Internet sites.

Fig. 1 The Dutch windmill, showing an "opaque" centre of rotation around which four blades move with the force of the wind.

Fig. 2 The ancestral Greek windmill, with a "transparent" centre of rotation where the wind can flow freely, and several sails mounted apart to capture the peripheral superior torque of the wind.

Based on these two configurations, we will soon talk about our idea of "divergent" and "convergent" turbines. For an excellent lecture concerning wind energy and electrical wind generation, the reader may find it very useful to visit to the *Danish Wind Industry Association* website[2]. Anyone interested in knowing more about modern wind energy should visit this site on the Internet.

It is also interesting to notice that the usual calculations of wind turbines are based on the aerodynamics of the wing, considering the *lift* and the *drag* effects, but here we use a simpler form for interpreting the wind flow phenomenon, trying a more holistic perspective where physics will be mixed with a certain intuition. This may therefore be considered not completely scientific in the sense of a Kantian reasoning, since it perhaps goes more in the direction of a Bergsonian[3] perception of the phenomena. In such a perspective, we try to use the knowledge of physics and engineering as tools for the intuition, that is, so that the analyst can make himself "feel" what the wind particles "feel" while traversing the turbine system. As Bergson would recognize, this is as if the analyst would have the ability of transforming himself into the wind or into the turbine. Such a perspective is different from the *empirical* approach, since *empirical* knowledge does not count with such a theoretical understanding of the laws of physics. In a way, this can at least be seen as a good exercise on three-dimensional (3D) abstraction, since there is the need for predicting the behaviour of the fluid and of the turbine system in a sort of an imaginary 3D game.

2. Divergence and convergence

In general we call a *convergent* system a system which transforms the dimensions of a certain type of flow into a more compact form, therefore reducing the space occupied by the flow and increasing its velocity or its density. On the other hand, a *divergent* system tends to expand the lateral dimensions of the flow, therefore inducing a decrease in the velocity or in the density. A typical example is the case of deflectors of electromagnetic radiation, which for light are known as optical lenses. Another simple convergent system is the funnel, for example, and a divergent system the opened doors of a stadium at the end of a match. If one thinks on some other convergent and divergent systems one may somehow intuitively associate convergence with an organized although tense movement, and divergence with a certain dispersion

[1] http://www.ifb.uni-stuttgart.de/~doerner/edesignphil.html
[2] http://www.windpower.org/en/tour/wres/index.htm

[3] Henry Bergson, a French philosopher from the beginning of the 20th century, who considered time as a history, instead of as an event or as a distance.

coming from the fact that each particle is getting freer of interactions than before. It is therefore expectable that turbulence is frequently observed in divergent systems, resulting from the natural dispersion introduced by its geometry, in particular at the system's boundary (see fig. 3). Sometimes interference phenomena are also observed in this region, if the dimensions of the system are comparable to the wavelength of the particles in motion. All this, of course, may represent a significant loss of energy, since the elements of the flow have meanwhile lost the "synchronism" they previously had within the motion.

On the other hand, in convergent systems the energy of movement tends to follow a path of concentration (fig. 3), which in the case of fluids and systems of particles results in an acceleration of the flow most of the time. There may also appear some interference between different parts of the flow, but there is no dispersion and a higher concentration of the energy is due, which therefore may easily be captured, in principle.

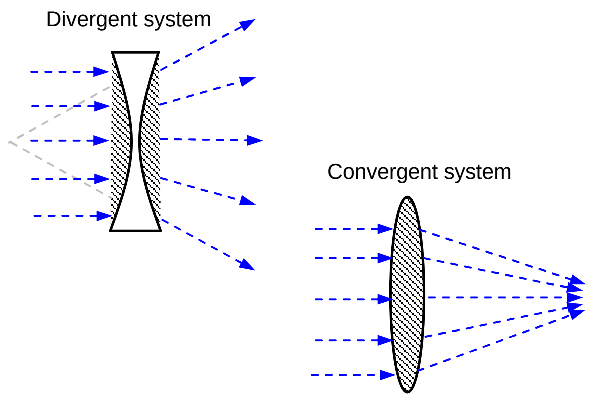

Fig. 3 The concepts of *convergence* and *divergence* as they are understood in optical systems.

3. Divergent and convergent turbines

Following the thoughts of the previous section, we may now introduce the idea of divergent and convergent turbines. With this purpose, let us imagine two circular areas of the same dimensions, each one rotating by means of three blades, for example, as shown in figure 4. In the first case (turbine A) the blades are mounted on an opaque centre of rotation and in a way that the torque is approximately constant along the blade length. In the second case (turbine B) the blades are mounted from the periphery towards the centre of rotation, which is transparent in the sense that it represents no obstacle to the flow, and the geometry of these blades is chosen in a way that the torque is made to increase towards the periphery. The inclination of the blades in respect to the plan of the turbine is important, but here we may consider it to be 45º in both cases, since we will mostly consider the drag effect of the wind at the blade surfaces. We may also suppose that both turbines run to the left, for instance.

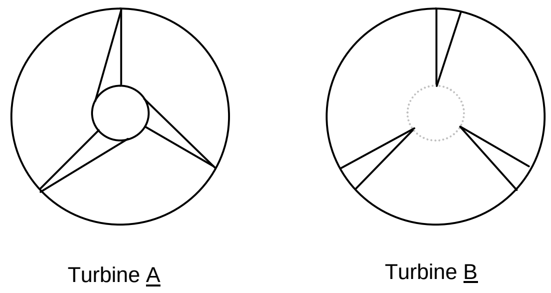

Fig. 4 Basic shapes to assist in explaining the idea of *divergent* and *convergent* turbine.

Now, if I imagine myself forming part of a huge group of particles interconnected by some elastic forces, as a first approach of the fluid, which are moving in a synchronized way in a regime of constant speed and suddenly meet one of these turbines in their way, let us see if we can imagine what will happen and how the flow will behave. Let us begin with the turbine A.

As we are now highly deformable, the first thing my group of particles will do at the moment of the first impact with the turbine is to assume the aspect of the turbine itself, as in a process of getting formed by a mould. After that, the form of my group of particles will be distorted principally due to concurrent forces of pressure, drag, elasticity and centrifugation. The first of these forces results from the sudden obstruction to those particles moving near the centre of the turbine, since this is "opaque", compared with the almost free movement of those which are traveling in the periphery. The drag force is mainly coming from the drag impulse imposed by the blade in its movement. The elastic force results from the reaction of the particles to these movements as an elastic coerent medium. The centrifugation is naturally produced by the inertia of the fluid while "refusing" to rotate.

Thus, if we imagine being the particles moving in this complex process, some of us are forced to compress and then to slip at the blades, due to the velocity with which the turbine impacts on us. At that moment, we realise that the turbine starts to rotate to the left and we feel compelled to do the same during the time we need to traverse the turbine depth, being under the drag force effect. Different directions of drag in the different blades and the natural elastic forces ensuring the medium continuity introduce a rotation in us all, from which we therefore feel a centrifugal force moving us in the direction of the peripheral part of the turbine. So, we are compelled to rotate with the turbine at the same time we move apart from the centre, pushed away by the higher central pressure where many particles first tend to gather on the first impact. Once we reach the peripheral lower pressure, we will feel again somehow free of the stress introduced by the turbine, and in certain cases we will disperse in the air. This behaviour is schematicaly represented in figure 5.

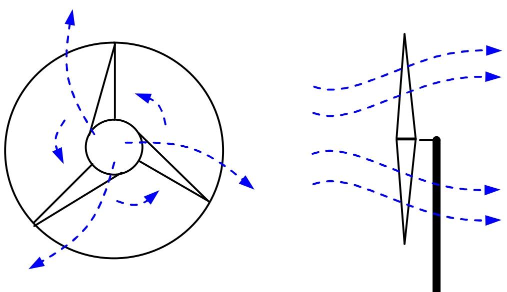

Fig. 5 Expected lines of force induced in the flow in a *divergent* turbine running to the left. Frontal and lateral views.

Let us now imagine the same situation, but with the turbine B. Once again, in the moment of the first impact with the turbine the group of particles tends to assume the form of the turbine itself, which is now less complex than in the previous case, since there is no central obstruction. Then, it will be also distorted by the influence of forces of pressure, drag, elasticity and centrifugation. In this case, however, the pressure forces result from the obstruction made by the blades to those particles moving near the periphery of the turbine, since this turbine tends to be "opaque" in this zone, compared with the almost free movement of those which travel along the central aperture. The drag force is again coming from the drag imposed by the blades, the elastic force from the coercion of the fluid, and the centrifugation from the rotational inertia. Thus, when the impact of the blade hit us, particles moving near the periphery, many of us are forced to compress and then to slip along the blades, making the turbine turn, and then we slip either in the direction of the periphery, if the drag impulse plus the centrifuge force is superior to the vacuum force coming from the centre, or in the direction of the centre if this vacuum force is stronger (fig. 6). We realise, however, that the turbine is rotating to the left probably not only due to the first impact on the blades, but also due to our forced slip through these while being sucked to the central vacuum, which at high speeds may start to resemble a little tornado.

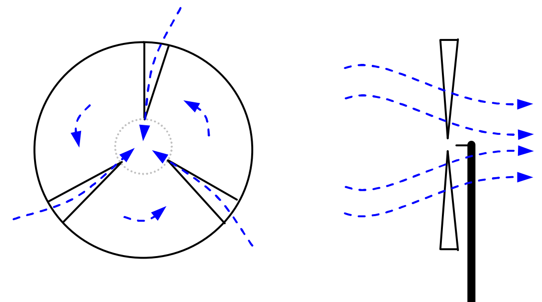

Fig. 6 Expected lines of force for the *convergent* turbine.

After this simple trip with the particles, we start to believe that convergent turbines can even be more efficient than divergent ones, as well as the possibility that we can expect less turbulence of them, higher resistance to fatigue, easy to build, much easier to start running, probably less noisy too, and being much less expensive. In order to reduce tip effects at high speeds, as well as keeping the noise generated by the turbine low, the blades in the periphery of the convergent system may be kept parallel to the turbine movement, reducing friction with the air.

4. A curiosity about the *Betz limit*

As a curious detail, we would like to recall that the so called *Betz limit* was computed on considering the behaviour of a *divergent* turbine system, and not the dynamics of a *convergent* one, and for a constant fluid pressure along the plan of the turbine. For good mathematical detail concerning fluid flow in turbines, please see (Corten, 2001; Gorban et al., 2001), for example. So, when from the Betz approach we conclude that

59% will be the maximum achievable efficiency for any sort of wind turbine, we may, perhaps, be too severe. Anyhow, it is not our intent to confront such a mathematical analysis in the present article, since at the moment we are more interested in reasoning from a particle-like perspective, which we expect will be useful in our future commitment to a microscopic simulation analysis.

5. The perfect convergent turbine?

From the last discussion, we may expect, once again by means of intuition, that a good design for a convergent turbine may be of a conical shape, since that way more fluid will be forced into the direction of the central transparent spot, where the pressure is lower due to the vacuum induced by the free wind movement in that zone, and by rotation. Figure 7 aims to represent such a layout.

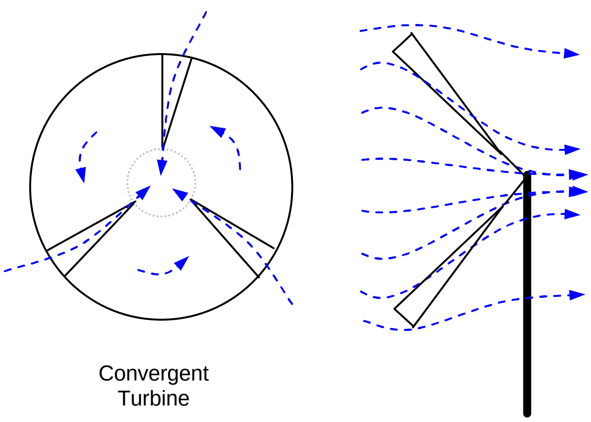

Fig. 7 A *convergent* turbine with the shape of a funnel.

In a turbine of this kind, wind would in effect tend to slip down the blades to the centre, where it would also rotate driven by the movement of the blades. Such a design would also help to minimize the amount of fluid that coud simply pass around the border of the system. We would even expect, perhaps, the central pressure to become lower than the atmosferic pressure at high rotational speeds. All this would, in principle, optimise the amount of wind power captured by the system.

Evident problems arising from such a design are, in our point of view, the complexity of the process to build the turbine and the dificulty to install it in the wind tower, since its blades are inclinated and the structure is unbalanced in terms of weight distribution. Such an assimetrical structure would also require very special care for it not to become highly unstable with wind turbulence, for example.

6. An easy-to-build convergent system

We will finally present in this section a very simple *convergent* turbine, which anyone can build even at home using the cheapest materials and the simplest tools. The rotor dimensions may be chosen in accordance with the particular energy requirements, and no special concerns are due to turbines of different dimensions, other than the usual cautions about the resistance of the materials employed, since the wind power increases with the square of the *turbine radius* and with the cubic law of the *wind speed*:

$$P(Watt) \propto r^2 v^3 \qquad (1)$$

To help the reader get an idea of the amount of wind power entering a wind turbine, here we show some simple expressions:

$\rho = 1{,}2$ Kg/m^3 – density of the air
$E = ½\, m\, v^2$ – wind kinetic energy
$S = \pi \,.\, r^2$ – Area of the rotor (turbine)
$P = 1{,}9\, r^2\, v^3$ – Wind power received (Watt)

For a turbine (rotor) radius of 10 meters, these equations lead to the following data (notice that the power of a wind system is usually given for a wind speed of around 40 Km/h):

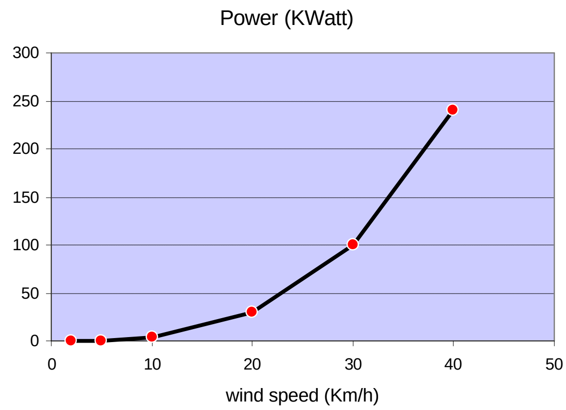

Fig. 8 Power received by a turbine of 10 m radius.

This means that more care must be taken when testing or installing turbines of increasing dimensions, and always avoid handling them on windy days.

We may now proceed with our convergent turbine construction. For that, one can simply get a rod of wood or a metal tube in which four holes have to be made, as depicted in figure 9. Notice that these holes make two sets of parallel lines differing by a rotation of 90º.

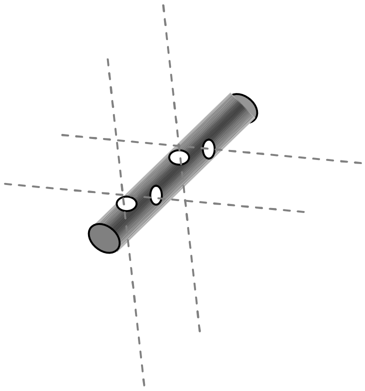

Fig. 9 The base support for the *convergent* turbine.

Now, simply insert along these holes, four other sticks, of wood or aluminium tube, thinner and longer, which will define the turbine's diameter. The structure must look like the one depicted in the next figure (fig. 10).

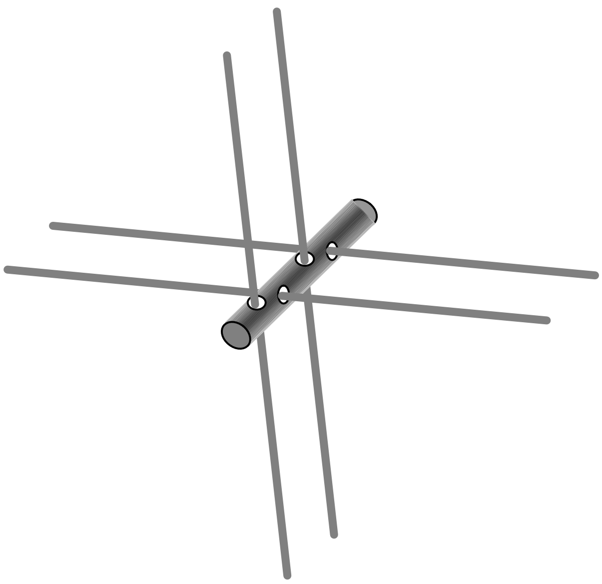

Fig. 10 Inserting the supports for the blades.

This is the structure of the most basic convergent turbine, two steps from being ready to use. We would like to remind that it is extremely important that these rods will be well positioned around the centre, so that the rotor will be maintained in a good equilibrium. This, of course, will have influence on the minimal wind speed at which the system begins to turn. These long rods giving the base for the future blades may be of any material that is light and resistant enough to support the wind power captured by each blade. Many common materials will work for low speed winds, but the challenges are much higher at high wind speed regimes, as previously observed.

The next step is to use a wire to give the structure good rigidity, which can be done by simply rolling it around the tips of each parallel rod in order to connect them to each other, and then to its perpendicular neighbours, pulling it slightly to give the system a certain tension. The rigidity of the structure will come from this tension. The system will then look like what is shown in the next figure (fig. 11).

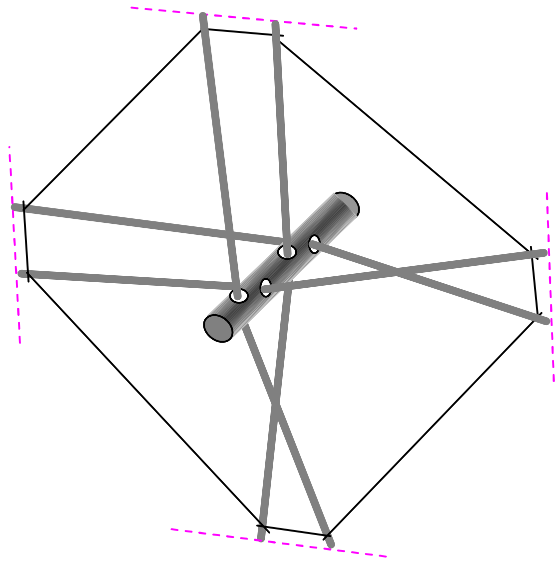

Fig. 11 Preparing the blades' support and giving rigidity to the turbine's structure.

Notice that the tips of the rotor are now made almost parallel to the rotation plan, and this will reduce the friction with the air in the peripheral region. Notice also that if one uses an "elastic" wire in this type of construction, it is possible to build a system in which the blade area is automatically reduced as the wind speed increases, while at the same time the rigidity of the structure tends to get higher. This could turn out to be useful for designing turbines with a strong resistance to wind storms and with a controlled rotational speed. The maximum natural area of each blade may of course be computed as the *rotor radius* times the *distance between parallel holes*, but the maximum useful area can roughly be estimated as being half of this, taking into account that the wind faces almost no area at the central region, due to the structure design. One may also take the option of letting the blade start only some distance apart from the centre, as is commonly observed in the so-called Wind Rose American style windmills, since the torque in such a region is small and the wind will easily traverse the turbine. A complete view of this first convergent turbine is presented in the next figure (fig. 12).

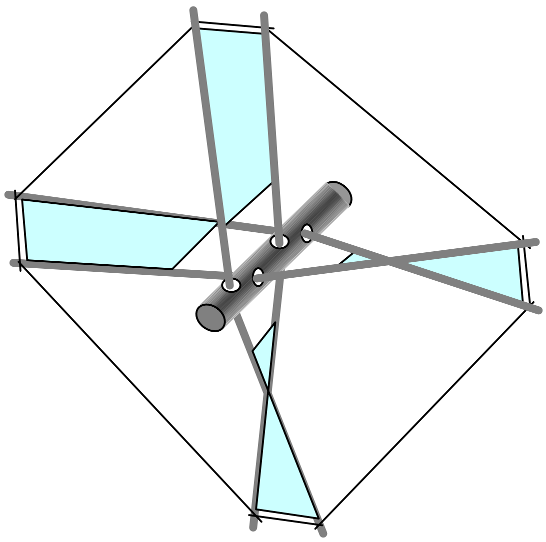

Fig. 12 A simple convergent turbine with four blades.

Notice that since the system was given enough rigidity, one could then fill the space reserved for the blades with any light material. This can be done with four pieces of cloth taken from an old camping tent, for example, which then are mounted tightened between the arms of the blades. An easy, nice and faster approach is to make the blades with several pieces of transparent TESA® adhesive tape, glued along both sides of the blade. This tape is resistant enough for testing the turbine performance. Thus, being already in the possession of the materials needed, mounting one of these turbines hardly would take more than 15 minutes!

Another interesting feature observed in these turbines is the rigidity of its tips, since these are continuously under the tension maintained by the wire; unlike what usually happens in most divergent turbines, where blade tips easily vibrate and obviously create great instability in the entire wind machine structure. Notice also that a structure of this kind can be made very light, if the technology of materials is employed in its construction, for instance, using reinforced fibreglass or carbon fibre.

7. The eight blades version

We may now expand the idea for any number of blades, as long it is a multiple of four. In this section, we show an example of how to append extra four blades to our turbine, by adding four more holes in the base rod with an inclination of 45º in respect to the previous ones. The next figure (fig. 13) helps to visualize the frame resulting from this.

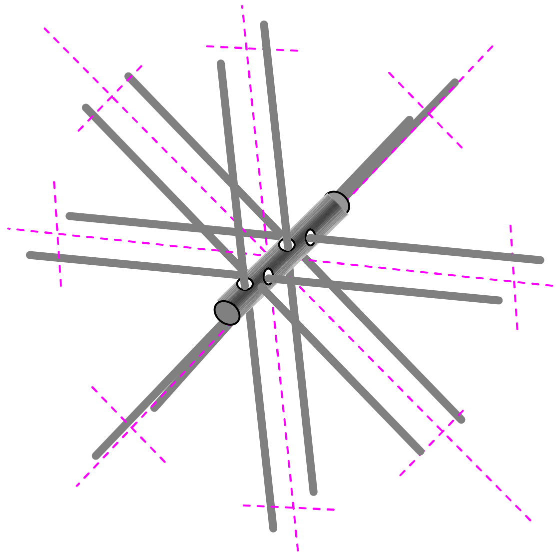

Fig. 13 The eight blades basic structure.

Finally, figure 14 shows the complete turbine with eight blades ready to operate. Such a rotor will obviously run easily than the previous one, since it is able to capture a superior torque from the wind.

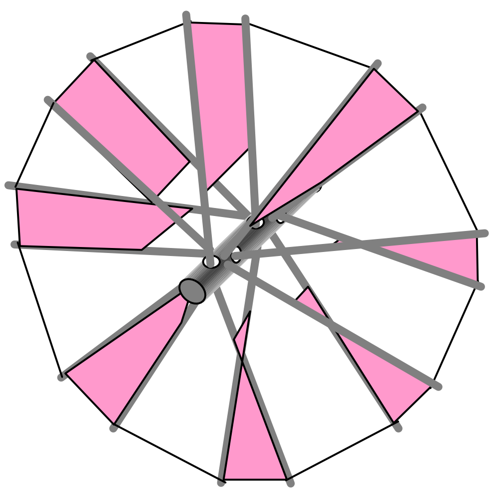

Fig. 14 The complete eight blades wind turbine.

8. Comparing with the Portuguese windmill

The beautiful windmill depicted in figure 15 is the typical Portuguese windmill. It may be found mainly in the south of the country. For a long time these systems were systematically used to grind grain for the population. Such a system of sails is also simple to manage, helping the miller in his control of the machine, since he can adapt the sails configuration to the actual wind speed by changing the area exposed to the wind.

Fig. 15 The typical Portuguese windmill.

As we can see by the arrangement of sails, this mill uses a convergent turbine concept to capture the power of the wind. The sails are, nevertheless, mounted on the structure of wooden rods in a way slightly different from what we propose. In effect, there is a large area of exposure in each sail, and that is expected to reduce the efficiency of the system. From the figure, one can see that the wind seems to stagnate when it is captured by those sails, instead of rapidly traversing the turbine. This, of course, is expected to create useless pressure on the mill house instead of contributing to the efficiency of the machine.

On the other hand, the configuration we propose does not allow this to happen, since instead of contributing to the stagnation of the wind, it forces it to slip along the blades. Consequently, it also increases the transparency of the overall turbine, which is known as a good practise for wind power generation systems. In rotors of high diameter and substantial number of blades, the transparency can also be increased by reducing the distance between the parallel holes in the base rod which supports the structure, at the same time reducing the drag but also the friction with the air at high speeds.

9. The observed performance

As we pointed out at the beginning of the article, there has not yet been an experimental measure of the performance of this convergent turbine, in order to compare it with the divergent ones offered in the market. We have, however, built a rotor based on these ideas one meter in diameter (fig. 16) with which we have observed a very good response in a wide range of wind conditions. In effect, this turbine showed to work steadily with wind speeds in the order of 3 or 4 kilometres per hour, and maintained a good shape and rigidity while running much faster during a little windstorm. The impression is that this is very efficient design, and, what is also impressive, that it is extremely silent, since no sound was ever coming out from it.

Fig. 16 A model of a 1 m diameter convergent turbine built of wood sticks and blades made of TESA® adhesive tape.

10. Other convergent designs

The idea of a convergent turbine can lead us to imagine other types of structures to capture the power of the wind. The one presented here was simple, resistant, and much less expensive than any of the wind turbines offered in the market. In fact, it was built with materials bought at an AKI storehouse. Anyhow, there is another design deserving attention, mainly due to the ability to automatically adapt the area of exposition of its blades do the wind speed. We are in particular talking about the system shown in figure 17:

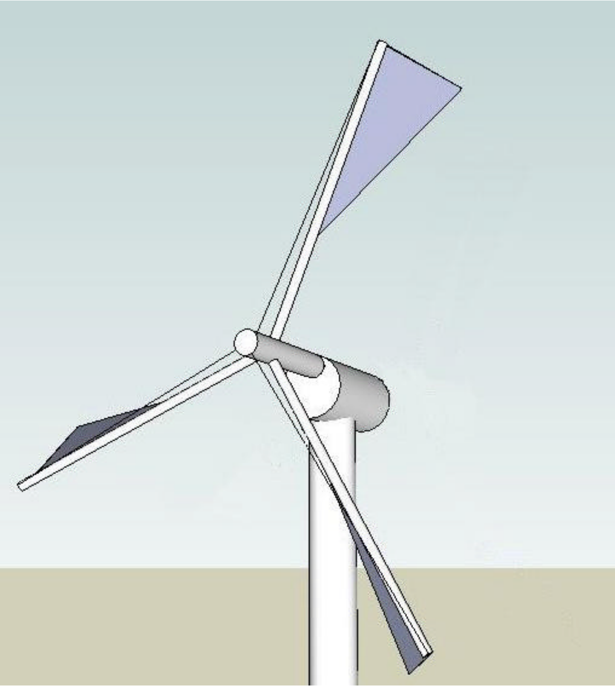

Fig. 17 Another convergent turbine with blades that automatically adapt to the wind speed.

This system uses blades in the form of triangles mounted on the respective rods in a way that they can follow the wind, as flags do. When the intensity of the wind is very high, they will assume the direction parallel to the wind flow and therefore minimize the overall wind impact in the turbine system. This may be extremely useful to achieve a good behaviour in the case of storms. On the other hand, when the wind speed is low, the blades will naturally assume an inclination of 45º, for example, by means of some kind of restoring force produced by a spring or any other simple mechanism.

11. Conclusions

As a result of the ideas exposed in this article, we may conclude that anyone can afford a *convergent* turbine for capturing the power of wind, since the materials needed to construct it are in effect inexpensive and their assemblage relatively simple. Compared with the prices asked on Internet sites, for example, which still make most of the wind systems unavailable to the population, these new turbines could represent a good solution to anyone interested in making use of the advantages of renewable energies. At the same time, although there has not yet been an experimental confirmation concerning the real efficiency of the *convergent* systems presented in this article, we expect them to be perhaps more efficient than the normal ones, since the process of capturing the wind power is slightly different from that used in the familiar *divergent* turbines. This fact also makes us wonder if the *Betz limit* of 59% maximum efficiency could be somehow debatable, in the case of a *convergent* system.

Finally, we welcome any contributions to the testing, developing, spreading or implementation of these ideas, which we would applaud with pleasure since it would mean a turn to handling the energetic resources of our planet more reasonably.

Author Biography:

J. Manuel Feliz-Teixeira graduated in Physics in the Faculty of Sciences of University of Porto, Portugal, and received an MSc and PhD from the Faculty of Engineering of the same university. His work has been related to various matters, from optical communications, solar energy and seismology to, more recently, the simulation of complex systems in management science, like warehouse and supply chain. His PhD thesis is on “Flexible Supply Chain Simulation”.

Corten, G. P. (2001). *Novel Views on the Extraction of Energy from Wind.* Paper presented at the EWEC 2001, Copenhagen.

D.W.I.A. (2003). *A Wind Energy Pioneer: Charles F. Brush*. Danish Wind Industry Association (online). from http://www.windpower.org/en/pictures/brush.htm

Gorban, A. N., Gorlov, A. M., et al. (2001). Limits of the Turbine Efficiency for Free Fluid Flow. *Transactions of the ASME, 123*, 312-317.