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Bicycle Wheel: A Surprising Wind Turbine

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ABSTRACT

This is the third in a series of articles about the concept of *convergence* in turbines (Feliz-Teixeira, 2006b), in particular in those used for wind power capture. Herein we present a discussion and some conclusions about the design of the bicycle wheel converted into an easy-to-assemble *convergent* wind turbine. The results observed in practice have been so promising that we suggest that this could be an excellent design for a wind turbine. We also expect once more to promote renewable energies so that they definitely become a strong alternative to generate electrical power. A short video of a small bicycle wheel running with wind can be seen at http://www.fe.up.pt/~feliz.

1. Introduction[1]

Actual wind systems are of diverse kinds, but most of those dedicated to generate electrical power are of the *divergent* type. As alleged in Feliz-Teixeira (2006b), these systems tend to enlarge the flow of the wind, therefore introducing not only a reduction in the wind speed but also a certain dispersion at the system’s boundaries. Due to the tendency for moving the wind flow from the central region to the peripheral zones, and also due to the blades’ design and the expensive technology used, these systems are suspected to be less efficient and much more expensive than certain easy-to-build *convergent* ones. On the contrary, *convergent* turbines seem to concentrate the flow instead of dispersing it, therefore avoiding some of the effects that contribute to reducing the efficiency of the system. These systems have a transparent central spot where the wind can pass freely, and that is believed to create a low pressure responsible for sucking the peripheral wind to this central zone. This is also believed to contribute to a higher efficiency than expected in the usual turbines.

In the last two articles, discussions have been carried on regarding the design of some *convergent* systems, for single and double turbines (Feliz-Teixeira, 2006a), and the advantages and challenges that they imply. But, in neither case was the issue of accumulating the wind energy addressed, as the problem of finding a more efficient response to the wind flow was also not addressed, since standard turbines start to run only around 8 *Km/h*, and therefore a substantial amount of energy is simply lost on days of low wind. It is, somehow, intriguing for most people that huge machines installed along certain mountains spend most of their time stopped. We obviously understand that the power contained in low winds is very small, but if we calculate the energy lost on some of those days or even weeks it is our belief that this energy is also of value. A simple calculation shows, for example, that a single day of a stopped 8 metres radius turbine (with 30% of efficiency) while the wind continuously blows at 5 *Km/h* (=1,4 *m/s*) would represent less 2,4 KWh of energy injected into the public network: 300 Watt x (30%) = 100 Watt during 24 hours = 2,4 KWh. That is, less 48 lamps of 100 Watt operating in the illumination of the streets, almost the illumination of a small village. That is, less 96 laptop computers

[1] 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.

operating during a day of work, in a medium size enterprise. If one thinks of 100 stopped turbines, then we think of 100 villages without public lighting or 100 medium size enterprises with their laptops off, for instance. We have considered a single day. It is not rare, however, to see those turbines stopped for a week, or even more.

In this article we will not only present a way of converting the bicycle wheel design into an efficient *convergent* wind turbine, but also discuss the idea of accumulating the wind energy in a mechanical form, in the wheel itself, and what such a move would imply in terms of efficiency in the overall process of energy production. Some systems based on the bicycle wheel design are also offered as interesting ways of collecting the energy from the wind.

2. Bicycle wheel, the perfect design?

Apart from all the fascination drawn by wheels, which have since for ever attracted the attention of a large number of the curious, inventors, mysticists and scientists, it is in fact a sort of magic to appreciate a bicycle wheel running "alone" by means of the wind. Frequently, as we have good knowledge of the weight and the dimensions of such an element, we find ourselves asking the question: how is that possible, to run so fast with almost no wind? The answer lies in two aspects: the *convergent* design which lets the turbine start running at low wind speeds; and the ability of accumulating energy in a mechanical form, in the wheel itself. We will firstly talk about the first aspect.

Any attentive observation of the structure of a bicycle wheel will bring light to our spirits: in effect, the steel wires connecting the metalic ring to the central axis of rotation are mounted in a way that resemble the *convergent* turbine design. In the centre, these tense wires are inserted almost parallel to the direction of the wind flow (perpendicular to the plan of the wheel), while they gently turn around as they approach the periphery, where they finally become practically perpendicular to the wind flow (see Fig. 1). This is practically the same design as the one proposed in the previous two articles concerning this subject. This is, therefore, a very nice coincidence, which have brought lots of joy to our experiments. So, to convert this system into a turbine one only needs to construct the blades, that is, to tightly wrap some TESA® adhesive tape, a surprising resistant and extremely light material, around the appropriate wires:

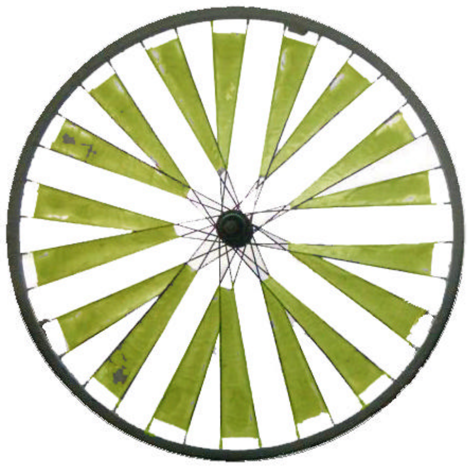

Fig. 1 Bicycle wheel converted into a *convergent* turbine.

Figure 1 shows a real turbine made with this simple technique. Notice the obvious transparency of the central spot, and the area of exposure of the blades increasing towards the periphery, in order to take the advantage of a superior torque. The wind is thought to slide down the blades in the direction of the central transparent spot due to the low pressure produced in this zone. The radius of a normal bicycle wheel is around 0,27 metres, and so one expects such a system to be exposed to around 1,9 x 0,073 x 2,744 = 0,4 Watt (5 Km/h) and 1,9 x 0,073 x 1000 = 139 Watt (35 Km/h). Thus, commercially this would easily be considered a system of near 100 Watts, that is, enough to feed two laptops.

Considering P_0 the power spent on the forces of friction affecting the overall structure, including the air and even the inertia of a possible generator, one can say that the wheel will start to turn when the overall torque per unit of time (P_w) induced in its blades surpasses P_0 , that is:

$P_w > P_0$ => wheel starts to turn

For a certain P_0, this of course will mostly depend on the blade design and on the radius of the wheel. So, in principle it will not be difficult to build one of these turbines to turn with a very low wind, since the process of construction allows it to be extremely light and the blade design captures the superior torque near the system boundaries. The rate by which the wheel approaches the final speed

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will obviously depend on the difference between P_w and P_0, since this is the power transferred into movement: (P_w –P_0). For this to be acheived in practice, the wheel must be perfectly calibrated, of course.

The metalic ring around the blades will increase the overall weight of the turbine, and therefore it will also contribute to the increase of P_0, but even so, it does not interfere too much with the system's ability to start rotating, any more than slowing a bit the process. On the other hand, this ring will be a good accumulator of rotational energy, as we will see soon. We may for now consider that the change in *angular speed* (w) induced by the wind *force* (F_w) in the turbine comes from the simple fact that *torque* (t) is what changes *angular momentum* (L):

$$t = dL / dt = I\, dw / dt \qquad (1)$$

where I is the *moment of inertia* of the turbine, which is dependent on the design and on the mass. From this we can write:

$$dw = (t / I)\, dt \qquad (2)$$

Now, since it holds:

$t_w = F_w \times b =$ wind force x distance of action = <u>wind torque</u>
$t_0 = F_0 \times e =$ resistive forces x distance of action = <u>anti torque</u>

We easily deduce that the new angular speed (w) induced by these two torque contributions at the instant of time $t+dt$ is:

$$w(t+dt) = w(t) + (F_w\, b / I)\, dt - (F_0\, e / I)\, dt \qquad (3)$$

Notice that the factor (F_0 e) is used here as a simplistic approximation for the resistive forces involved, and must be considered null when the turbine is not rotating ($w = 0$). Otherwise, the turbine would start to move in the opposite direction if stopped. The overall expression shows, however, that for a certain level of torque, a turbine with higher *moment of inertia* will tend to respond slower. A mass located far from the centre increases the moment of inertia, for example, but the system will always start to rotate as long as it holds $t_w > t_0$. Notice also that even if the two forces F_w and F_0 would be comparable, the fact is that usually one has $b >> e$, since most of the resistive forces concentrate near the centre, and therefore the contribution of the wind force for the rotation is more superior than the contributions of the resistive forces for the "anti-rotation". So, the *convergent* design is also an important factor for minimizing the effect of resistive forces, since it tends to capture the wind torque far from the centre (b large).

3. A mechanical accumulator of energy

Accumulating the energy from a renewable source with the uncertainty of the wind or of the solar radiation is usually a challenge, and thus good management of the energy inventory is essential. Usually, large wind systems are prepared to inject the generated electrical power directly into the public network, but smaller systems are frequently connected to banks of batteries where the energy is accumulated before usage, in order to prevent shortages and ensure a steady output. The battery, however, acts as a capacitor, and therefore also as a *low-pass* filter for the electrical signal produced by the generator, as shown in figure 2:

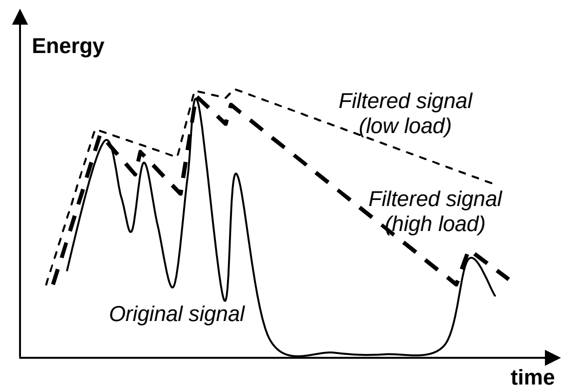

Fig. 2 The effect of a capacitor in an electrical signal.

Notice that in principle the battery works as a capacitor and so the output level is more stable than the original signal. Such stability depends, however, on the *load* the system is supporting in a given moment. With no external load or at low level loads the stability is high, of course, but it tends to deteriorate for higher rates of consumption of energy (=high loads). The only way of avoiding such a problem is either capturing more energy or consuming less energy, obviously.

But we may now recall that the relation between

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angular speeed (w) and *angular momentum* (L) is:

$$L = I\,w \qquad (4)$$

So, looking with attention to equation 3 and multiplying its two members by the *moment of inertia* (I) leads us to the following equation for the increment of *angular momentum*:

$$L\,(t+dt) = I\,w(t) + F_w\,b\,dt - F_0\,e\,dt \qquad (5)$$

As we know, *angular momentum* is conserved in the absence of external torque acting in the system, and this equation can therefore also be seen as an accumulator, in which the term $(F_w\ b - F_0\ e)$ contributes to the increase in accumulated energy, and ($F_0\ e$) represents its natural decline due to the overall resistive forces, including the generator's resistance. The energy accumulated is of course proportional to $Iw(t)$, meaning that wheels with a higher moment of inertia will accumulate more energy, and, once the situation $b >> e$ is maintained, the wheel will easily be found running "alone" even after the wind has vanished. That is due to the energy in the mean time accumulated in the form of *angular momentum*. With a certain humor, we may proudly say that this is a wind turbine which can even run without wind.

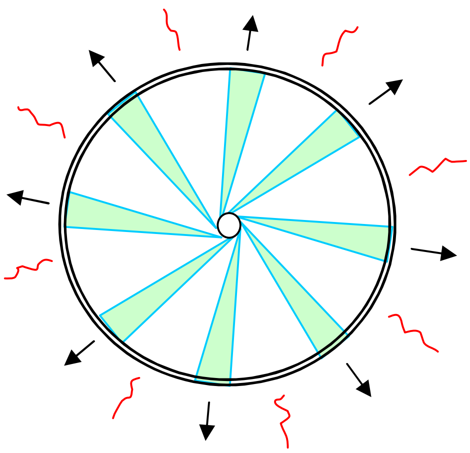

Fig. 3 The energy accumulated in the form of tension due to the centrifugal forces.

In the absence of the wind force, the small torque from resistive forces is what will try to stop the wheel. The energy is, in effect, for a while kept prisoner of a sort of virtual gravitational field parallel to the plan of the wheel, which is created by centrifugal forces. Thus, a larger ring's mass implies that the system "sees" the resistive forces less, and so it approaches the ideal situation, which, of course, would imply the continuous motion. Notice, however, that the accumulation of energy by this method is limited to the resistance of the materials employed. Beyond that, the wheel would simply disintegrate. Figure 4 shows how one of these wind turbines could look when mounted on an American mill structure.

Fig. 4 Bicycle wheel turbine mounted on a typical American mill structure. With 2 m of radius, this would receive 8 KWatt of wind power at 10 m/s wind speed.

4. Angular speed

The previous discussion was mainly about the sensibility of the bicycle wheel related to turning, therefore we talked of the *rate of change* of angular speed. Even if some conclusions could be achieved, nothing was deduced about the *angular speed* itself, under a certain wind regime. Instead of the angular momentum conservation law, we will now make use of the law of conservation of energy. In this case, we may state it by saying that the *total torque* equals the change in *kinetic energy*:

$$t_w - t_0 = \tfrac{1}{2}\,I\,w^2 \qquad (6)$$

From where one gets, during a time Dt:

$$(P_w - P_0)\,Dt = \tfrac{1}{2}\,I\,w^2 \qquad (7)$$

And finally:

$$w = [\,2\,(\,P_w - P_0\,)\,Dt\,/\,I\,]^{1/2} \qquad (8)$$

So, if the wind blows in a continuous regimen with power P_w , and if $P_0 = ½ P_w$ meaning the efficiency of the system is 50%, then, for a bicycle wheel of 2 m radius, mass of 5 Kg, and a wind power of 8 KWatt, the *angular speed* of the wheel will increase with the time by means of the relation (notice that $I = m r^2$ is the moment of inertia of a ring):

$$w = [\,2 \times 0{,}5 \times 8000 \times Dt / (5 \times 4)]^{½} = 20{,}0 \times Dt^{½}$$

And, for instance, 9 seconds after starting we would have:

$w = 20{,}0 \times 3 = 60{,}0$ rad/s
$f = w / (2\pi) = 9{,}55$ Hz = 573 rpm

The generator would therefore be producing 4KWatt at 573 rpm. The next graph shows how the *angular speed* (rpm) would tend to increase with time, if no increase of the resistive forces with angular speed would be considered.

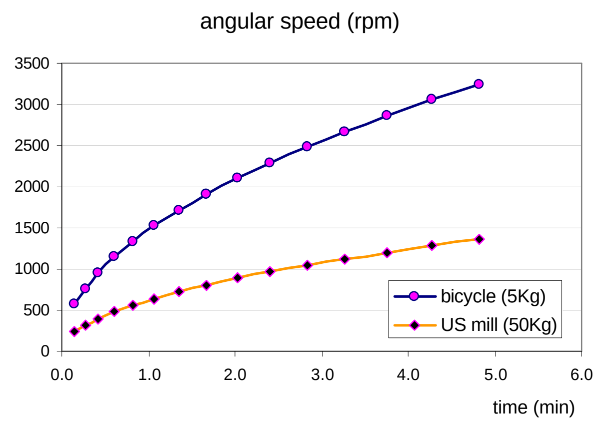

Fig. 5 Ideal angular speed responses for a bicycle wheel of 5Kg, 2 m radius, and an equivalent American windmill of 50Kg, when receiving a constant power of 8 KWatt, with efficiency of 50%.

Obviously, a windmill would perform better if of the same weight, but in effect the weight of an American windmill of 2 metres radius is not 5 Kg. It can be around 10 times that (50 kg), at least, if we make an estimation with an average density of 5000 kg/m^3 for the metalic material used in its blades. This obviously dictates an advantage for the bicycle wheel. We must be aware, however, that the previous graph does not take into account the increase of the resistive forces with the increase of rotational speed, due to drag effects and also due to the increase in air friction at tip speeds approaching the speed of the propagation of sound (*match-I*). At these speeds, air becomes incompressible, and so it acts as if approaching the solid state, therefore introducing a high resistance against the movement. In the case of the previous turbine, *match-I* would be reached at around 1600 rmp. At this speed, the turbine tips would be moving with a velocity of 340 m/s = 1224 Km/h, much faster than a commercial airplane! Thus, what is usually acceptable is that the system will not surpass a tip speed of around 100 m/s, which, in this case, corresponds to:

$v = \omega r = 2\pi f \times 2 = 100$ m/s
$f = 100/(4\pi) = 7{,}96$ Hz = 478 rpm

We may therefore conclude that we can build a bicycle wheel turbine much lighter than an American windmill, yet with an interesting moment of inertia giving it the capacity for accumulating energy. The advantages are mainly in the increase of rotational speed, and the ability of helping to accumulate energy, and therefore it may be used for electrical generation too. Figure 6 shows the common American windmill, used for water pumping, but certainly not for generating electrical energy due to its low rotational speed.

Fig. 6 A typical American windmill style turbine, installed somewhere in China.

5. Some images and some comments

Here we will consider some other aspects related to these convergent turbines, mainly involving the design, ways of implementation and curiousities.

We may start by stating that, in our point of view, the American wind mill turbine suffers from two small problems: excessive weight due to the large quantity of metal used in its blades, and a subtle problem of design, which does not let the turbine take advantage of a truly *convergent* system. A good observer will detect such a design failure while inspecting figure 7:

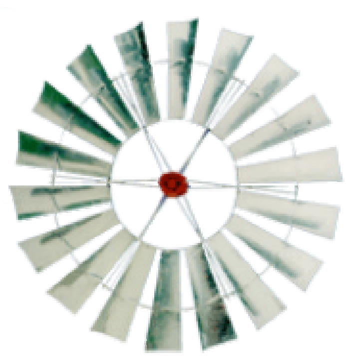

Fig. 7 The American windmill turbine, slightly different from the proposed convergent design.

Another image we show here (Fig. 8) is of a normal bicycle wheel transformed into a turbine and simply mounted to a tree, which rotates with extremely low winds. People may try to make this experiment and notice that sometimes the wheel is running so much that it seems almost impossible, or like something magical.

Fig. 8 A bicycle wheel fixed to a tree runs with extremely low wind speeds.

The next image (Fig. 9) is a montage with which we expect to help the reader to imagine how a small-medium generator installed in a little cottage could look. Notice that a turbine constructed based on a bicycle wheel structure can be made very light and is very easy to install. This will also make the support structure much simpler. Besides, the outside aluminium (or other light material) ring may be thought of as a protection against hazards. If there is an accident, the results will probably be less significant, at least compared with the hazards due to a normal turbine with its strong and solid blades.

Fig. 9 A probable view of a wind system, mounted to supply electricity to a small house.

Another simple way of capturing the wind for generating electricity is the scheme shown in figure 10. The advantage of this is that the structure can be made of standard bicycle wheels, which are easy to obtain. Notice, however, that the resistive forces are now acting also at significant distances from the axis of rotation, meaning that the system is in principle less efficient. This may of course be improved. Notice also that another way to connect the wheels is using little skate wheels between the bicycle ones, so that the turbines would rotate all to the same side. This scheme could even be mounted at the top of certain buildings, or on a farm in the form of an extensive wall which naturally captures the wind energy.

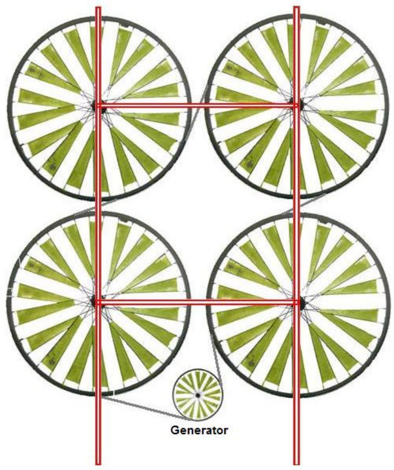

Fig. 10 Another scheme using normal bicycle wheels for producing electricity.

In figure 11, one shows two possible quasi-static systems based on *convergent* turbines, which would simply adapt their positions by means of a computer controlled base structure.

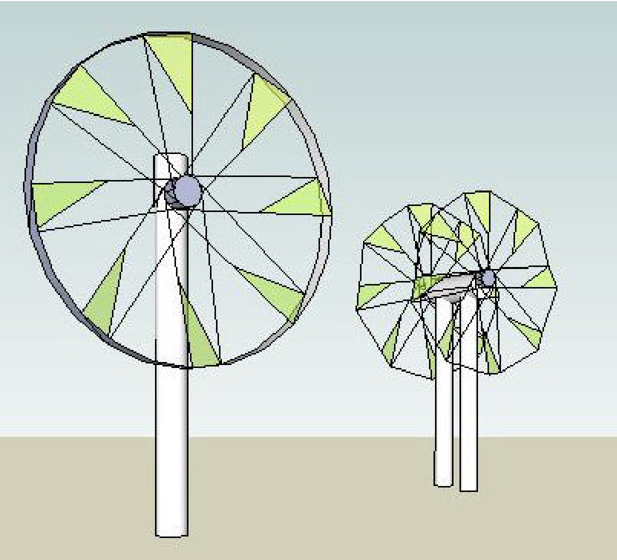

Fig. 11 Examples of two quasi-static *convergent* systems, with single and double turbines.

Finally, in figure 12 several types of double wind convergent systems are shown, some of which make use of the previous idea of a ring for accumulating energy. In effect, a variety of these systems can be installed for producing electrical energy.

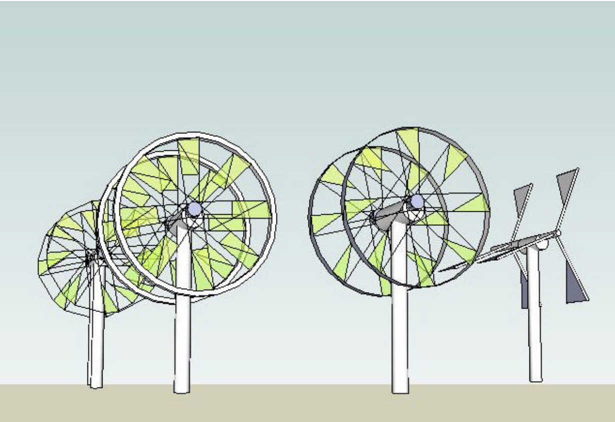

Fig. 12 Several types of wind systems taking advantages of rings and of double convergent turbines.

6. Conclusions

After having built and appreciated several wind turbines made from standard bicycle wheels, we believe that this is a good and simple design that can also be used in larger wind turbines, even in those dedicated to generating electrical power. The low weight of the turbine achieved with such a method will lead the system to be able to rotate at significant speeds, and the ring around it will mainly contribute to the accumulation of the energy not directly transformed by the generator into electrical power. So, we not only believe that this design is interesting for constructing efficient systems, but also that such systems will not be as demanding in terms of battery stability as the present ones. Besides, we consider the design quite beautiful and easy to adapt to several different circumstances.

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”.

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