Another Take on Domestic Wind Turbines - Can you print your own and the venturii paradox?

Ideal

It would be convenient if there was a domestic generator that could produce 100 to 500W consistently that:

- Didn't occupy too much space.
- Worked all year round
- Was not noisy
- Was no threat to wildlife.

Types of wind turbines

Classically wind turbines divide into 2 types:

- Horizontal Axis Wind Turbines (HAWT) and
- Vertical Axis Wind Turbines (VAWT)

HAWTs are more efficient if the wind is flow is in one direction and not turbulent, these conditions typically exist at sea and at rural sites. They do not normally exist in urban areas. Most wind farms are comprised of a number of HAWTs, which are now very large. Small HAWTs are available, but these aren't widely deployed because:

- At typical urban wind speeds below 5 m/s their output is very small.
- They don't deal well with turbulent conditions around housing.
- All except the smallest turbines require planning permission.
- The turbine should be mounted on a pole/tower at least 10m above ground.
- They can be noisy.

VAWTs are less efficient because at any time only half the blade is travelling in the direction of the wind, but they are more capable of dealing with turbulence. Commonly advertised VAWTs do not have a good reputation.

Earlier investigations

In my earlier unpublished paper on Wind turbines (/var/share/bigdisk/ACT/BuiltEnvironment/Urban Wind Energy_v0.2.docx) I talked about some domestic possibles: Flower Turbines, Vortex Bladeless, Alpha 311, Qr6. All of these except Vortex Bladeless are VAWTs.

Of these Flower Turbines and Alpha 311 seem to still be viable enterprises. Flower turbines has a retail price list in $ - quite expensive, quite a few tests have been published now, it is notable that gradually the quoted outputs have dropped, and are now probably realistic.

Relationship between power output and wind speed

At higher wind speeds with ideal conditions (laminar flow), power output is proportional to the cube of wind speed.
The generator and mechanics of the wind turbine have a resistance to turning, which means that no power is generated below the starting wind speed.
The power generated is also proportional to the swept area of the turbine blades.

The power in the wind is:
$P = 0.5\ \rho\ A\ V^3$ Watts, where ρ is air density (in kg/m3),V is the wind speed (in meters per second).
At 101.325 kPa (abs) and 20 °C (68 °F), air has a density of **approximately 1.204 kg/m3**

For a HAWT in laminar flow:
The best overall formula for the power derived from a wind turbine (in Watts) is
$P = 0.5\ Cp\ \rho\ \pi\ R^2\ V^3$, where Cp is the coefficient of performance (efficiency factor, in percent), R is the blade length (in meters). Location matters most.

More generally for other turbines:
$P = 0.5\ C_p\ \rho\ A\ V^3$, where A is the swept area of the turbine.

In turbulent air the situation is more complex and worse.

Example

Suppose I wanted to generate 100W from a 5m/s wind (a bit higher than average urban wind speeds), what is the swept area assuming Cp = 0.2 ?

Rearrange the formula for power to give area:

$A = P/(0.5C_p\rho\ A\ V^3$

Substituting
$A = 100 / (0.5 \times 0.2 \times 1.204 \times 125) = 6.64\ m^2$

If the wind speed were to increase to 6m/s then the area required would drop to $3.85m^2$

The theoretical maximum for Cp is 59.3% known as Betz limit.
Most HAWT have an Cp between 30% and 40%

Planning permission is not required if the swept area of the blade is less than $3.8m^2$. Note that this is the blade not the collector.

I found an interesting paper which gives a design procedure for simple VAWT this suggests that a Cp as high as 0.45 can be achieved with the right design, and that this performance can be achieved at quite low wind speeds.

Recent designs

Some more recent designs try to collect wind from any direction, speed it up and redirect it to an enclosed turbine. Suppose that the wind speed is doubled, then theoretically the power generated is 8 times as much, and the energy is 4 times as much. Some also improve the starting speed by using low resistance bearings (for example magnetic levitation) and low resistance generators. This type of turbine has potential to be applied in urban environments and seems to overcome the inherent disadvantages of VAWTs.

In the 18th Century Erasmus Darwin (Charles Darwin'w grandfather) invented a wind turbine which was an box with flaps on all sides, so that on the windward side the flaps would open and on the leeward side the flaps would close. This traps the wind, if the top is closed and there is a fan at the bottom, the wind if directed to the fan and so the fan should turn.

There are some examples that have been produced:

- Ventum Dynamics have a working example on Skegness pier.
- Invelox, tries to accelerate wind with a funnel that feeds a venturi with a small turbine in it. It is described in this critical video - the stupidity of Sheerwind Invelox (22 mins), the issue is that the design claims to increase the kinetic energy of wind passing through it - not possible!
- Robert Murrray-Smith Youtube videos.

Robert Murray-Smith's videos are interesting because his prototypes are open source, and so could be replicated by anyone. Could we set up a DIY project based on his prototypes? Links to various videos are below.
The best of these comprises:

- Fins to redirect the wind downwards.
- Cone to act as a venturi to increase wind speed
- Generator consists of a disk with magnets mounted round the perimeter. Blades on the disk are turned by the wind.
- Static self-wound coils, with rectification.
  Need to link to important videos.

His later designs are 3D printed, which takes a long time (think weeks) for a relatively small prototype, this could be worked round by:

- Injection molding - mass produced plastic.
- Producing part of it in marine ply formed to a suitable shape.
- Producing something in fibreglass.

Issues:

- Whilst speeding up wind may seem to increase power, a passive design cannot create energy, and will inevitably loose some. So the most energy that could be derived is from the raw wind speed and the area of the intake presented to the wind
- A design which directs wind downwards requires a force to do this, which must have a reaction, which will probably lift the device … this may be ok for a hand held design, but will be troublesome for a larger design. Where a design with the fan at the top will tend to be pushed into the ground.(as in the ventum design).

Performance cannot be better than an HAWT whose swept area is the same as the intake area, but it could be better than a VAWT because energy can be derived from all the intake area, rather than only half or the swept area. This design is also non-directional, and could have a lower starting speed than an HAWT..

The Venturii Paradox

This seems to contradict the conservation of energy principle, where is the catch?

For a venturii, where a fluid passes from a large diameter pipe to a smaller diameter pipe the quantity of fluid passing through both pipes in a given time is the same.

E.g.
$Q = A_p V_p = A_v V_v$

From which
$V_v = A_p V_p / A_v$ ….. (1)

The power in the venturii is given by:
$P_v = 0.5\rho\, A_v\, V_v^3$ ….. (2)
Also
$P_p = 0.5\rho\, A_p\, V_p^3$ ….. (3)

Substitute (1) into (2) gives
$P_v = 0.5\rho\, A_v\, (A_p V_p / A_v)^3$
$P_v = 0.5\rho\, A_p^3 V_p^3 / A_v^2 = (0.5\rho\, A_p V_p^3) A_p^2 / A_v^2$
Substitute P_p for $(0.5\rho\, A_p V_p^3)$
Then
$P_v = P_p A_p^2 / A_v^2$
As $A_p > A_v$ then $P_v > P_p$
But we know that this can't happen, or do we?

A similar argument applies to kinetic energy in the system, which appears to show that the kinetic energy at the venturii is greater than at the intake. I must be missing something because energy is conserved (for this kind of system energy - mass conversion doesn't apply)

I am looking for an answer to this:
- A sound physical explanation expressed mathematically.
- A convincing practical demonstration.

Robert Murray-Smith Videos

Catalog - a catalog of all his videos
1997 - Darwin wind turbine on Skegness Pier
5 minute video visits the Ventum turbine on Skegness pier, including:
- Omni-directional wind capture system with HAWT on its side at the top
- Darwin's wind capture device - Tower of flaps direct the wind over the turbine proper.
- Ventum turbine is a nested tower of funnels, getting closer together as they get nearer to the turbine.

1966 - A system of Generation - folding HAWT
50 Minutes video goes through the theory and practice of building a generation system including:

- Serpentine Coil
- Generator using nydemium magnets
- Planetary gearing system
- Folding HAWT made from drainage pipe.
- Most parts are 3D printed and available open source.

1989 - The Ultimate wind turbine - Darwin and Pelton
Idea of Pelton turbine.
1920 - The Mathematics of Wind Turbines
1921 - Super efficient turbine - a betz beater?
1903 - How effective is a wind turbine - A DIY way of measuring
1901 - New wind turbine design for camper vans, boats and roof ridges
1892 - Revisiting the flat turbine
Shows a flat turbine and generator combined showing:

- Generation at the rim
- Magnetic levitation
- Feathers to reduce resistance

1880 - Modelling of the Darwin Waters turbine
1857 - How to make super strong 3D printed parts
1833 - Is 3D printing for you?
1815 - 3D Printer models the easy way - CAD without tears
How to use TinkerCAD - free to use web based CAD.
3D prints using PLA filament can be recycled. (cost of recycling equipment circa $500).