The Darrieus rotor, a vertical axis wind turbine (VAWT) with only a few advantages and many disadvantages

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Contains page

1 Introduction

This report is about a translation into English of my report KD 20 (ref. 1) written in 1997.

The Darrieus rotor is a vertical axis wind turbine (VAWT) provided with two or more blades having an aerodynamic airfoil. The blades are normally bent into a chain line and are connected to the hub at the upper and lower side. However, also Darrieus rotors with straight blades (H-Darrieus) have been developed which therefore have large hubs provided with spokes. The energy is taken from the wind by a component of the lift force L working in the direction of rotation. The same principle is used for a horizontal axis wind turbine (HAWT).

There are also VAWT's for which the power is gained by the difference in drag D of the blade moving in the direction of the wind and the blade moving against the wind. A cup anemometer, used for measuring wind speeds, is an example of such a rotor. There are also VAWT's, like the Savonius rotor, which are working on a combination of lift and drag.

One of the advantages of using the lift principle is that much higher power coefficients C_p can be realised than for windmills using the drag principle. Another advantage is that the tip speed ratio λ, can be much higher resulting in a much higher rpm for the same rotor diameter and in using much lesser material.

Although the Darrieus rotor is working according to the lift principle, the maximum C_p is a lot lower than for a well designed HAWT. The reason is that the blade of a Darrieus rotor has an acceptable angle of attack α, only during two parts of a revolution. Therefore the average drag over a whole revolution is rather large.

In the past period in several countries research for Darrieus rotors is performed. In The Netherlands it has been done by for instance Fokker for a design with 5.3 m rotor diameter. However, nowhere the Darrieus rotor breaks through and is produced in large quantities. I think this is, although the Darrieus rotor has some advantages, because it has many disadvantages. Because of the disadvantages the Darrieus rotor is losing the battle with the HAWT, except for some very special situations.

In the next chapter the advantages and disadvantages of the Darrieus rotor are given.

2 Advantages and disadvantages

Advantages of Darrieus rotors

1. The rotor shaft is vertical. Therefore it is possible to place the load, like a generator or a centrifugal pump at ground level. As the generator housing is not rotating, the cable to the load is not twisted and no brushes are required for large twisting angles.
2. The rotor can take wind from every direction.
3. The visual acceptation for placing of the windmill on a building might be larger than for an horizontal axis windmill.

Disadvantages of Darrieus rotors

1. The angle of attack α varies strongly and therefore the lift, the drag and the C_d/C_l ratio varies strongly too. During the parts of the revolution where the blade moves about parallel to the wind there is only drag and the distribution to the torque is negative. Therefore the maximum power coefficient C_p is about 0.35 for big rotors (but only 0.2 - 0.3 for small rotors).
2. Because the blade load is fluctuating strongly, this results, especially for a two bladed rotor, in strong fluctuating loads on the tower and the foundation.
3. The starting torque coefficient is zero and at low tip speed ratios it is even negative. Therefore a special motor is required to start the rotor.

4 The design tip speed ratio λ_d may not be taken lower than about 4 because lower values of λ_d result in stalling of the blade as the blade moves about square to the wind. The design tip speed ration λ_d may not be taken higher than about 7 because higher values of λ_d result in too high C_d/C_l values to realise an acceptable C_p.

5 It is difficult to protect the rotor against high wind speeds. Turning the rotor out of the wind is not possible. Pitch control is only possible for Darrieus rotors with straight blades but pitch control requires a complex construction with many turning points. Systems with air brakes appear not to work in practice. Braking the vertical shaft mechanically is the only possibility, but this is not really fail safe because the rotor will turn unloaded if the brake fails for some reason.

6 A very large bending moment is created in the rotor shaft, if it is not supported at the top. Support at the top requires a large, wide guiding.

7 For a traditional Darrieus with blades bent into a chain line, the upper and lower parts of the blade don't contribute to the torque or even heave a negative torque because the local radius and therefore the tip speed ratio is too small.

8 For a Darrieus rotor with straight blades (H-Darrieus), the blade is loaded very strongly by bending because of the centrifugal force in the blade. A H-Darrieus requires long spokes to connect the blades to the hub and to minimise drag, these spokes should have an aerodynamic airfoil.

9 The pipe which is placed in between the upper and the lower side of the rotor creates, especially for large diameters, a turbulent wake which has an unfavourable influence on the aerodynamics of the blade as it passes this wake.

10 Because the blade has a positive angle of attack α at the front side of the rotor and a negative angle α at the back side, one has to use symmetrical airfoils like the NACA 0015. These airfoils have lower maximum lift coefficients if they are compared to asymmetrical airfoils of the same thickness. To realise a certain lift one must therefore use a larger chord.

11 Because the blade angle β is 0°, large angles of attack α are created if the blade moves about square to the wind. For a tip speed ratio of 4, this angle is about 10°. The angle at which a symmetrical airfoil stalls depends on the relative airfoil thickness and on the Reynolds value. The airfoil NACA 0015 (with a thickness of 0.15 % of the chord) already stalls at 11° at $Re = 1.66 * 10^5$. Therefore on needs thick airfoils at low Reynolds values which occur at low chords and low wind speeds. However thick airfoils have higher minimum C_d/C_l values than thin airfoils and this has an unfavourable influence on the C_p value. Because of this effect, Darrieus rotors have only an acceptable C_p at low wind speeds if they are rather big.

12 At the same tip speed ratio and the same swept area, the required amount of material for a Darrieus rotor is very much larger than for an horizontal axis windmill and the shape of the $C_q = \lambda$ curve is much more unfavourable.

13 There is no simple aerodynamic theory available to design a Darrieus rotor. The available theories are very complicated. For a HAWT the required aerodynamic theory is rather simple. It is given in my report KD 35 (ref. 2).

3 Retrospect

Because of many disadvantages and only some advantages it will be clear why the Darrieus rotor has lost the battle with the HAWT. However, people remain fascinated by the Darrieus design and try to develop it over and over again but in almost all occasions after some years they stop the development because they can't solve all the problems or because they went bankrupt. I have spent some time in developing a Darrieus rotor myself and it is possible to find solutions for some of the disadvantages but in most cases new disadvantages are created.

As an example I mention the starting problem. It is possible to make a Darrieus rotor self starting by introducing a cyclic variation of the blade angle. However, this requires a rather complex mechanism with many turning points and the advantage that it is not necessary to turn the rotor in the wind, is lost.

The advantage of the vertical shaft is only realy relevant for the direct drive of a centrifugal pump because for such use, the transmission from a horizontal axis to the vertical axis of the pump is omitted. May be it is possible to start the rotor by a rope which is wound around the pump axis or by using a small Savonius rotor. However, as a Savonious rotor has an optimal tip speed ratio of about 1, it must be small to match with the C_q-λ curve of the Darrieus rotor. Therefore the supplied starting torque will be small and a rather high wind speed will be required to start the Darrieus rotor.

So for myself I have decided not to spend any time in this kind of windmills. Translation of report KD 20 into English is the last thing that I have done with respect to Darrieus rotors. I believe that any activity in this field will appear to be a waste of time and therefore I will answer no questions about this report.

4 References

1 Kragten A. Ideeën over de Darrieus-rotor: een vertikale-as windmolen werkend volgens het liftprincipe, July 1997, report KD 20, enginering office Kragten Design, Populierenlaan 51, 5492 SG, Sint-Oedenrode, The Netherlands.

2 Kragten A. Rotor design and matching for horizontal axis wind turbines, free public report KD 35, January 1999, latest review November 2015, engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode, The Netherlands.