Are three blades really better than two?

4 August 2011 by David Milborrow

Noisy neighbours...two blade rotors spin faster

In the intervening years, advances in materials and in our understanding of the loads on wind turbines has brought about dramatic reductions in blade weights, which influence the weight of the rotor hub, nacelle bedplate and the tower itself.

This has resulted in a preference for the three-blade design, but has also led to a few common queries or even misconceptions about wind turbine rotor designs.

Thirty years ago, the combined weight of the two blades (91 metre diameter) of the US government's 2.25MW MOD 2 turbine was 50 tonnes.

Today, the three blades (116 metre diameter) of the 5MW Areva Wind M5000 turbine tip the scales at just one tonne more.

Below, we look at some of the key differences and address a number of standard queries.

More blades are more powerful

It seems logical to assume that putting more than three blades on a wind turbine rotor will enable more power to be extracted, but this is not the case.

Adding more blades puts more resistance in the path of the airflow and, as the air is not constrained and forced to pass through the rotor, more bypasses the rotor disc.

Rotor efficiency does increase very slightly if four blades are used, rather than three, but the rotor weight would increase and the rotational speed at which peak power would be delivered would drop.

That, in turn, would increase the rotor torque — necessitating a thicker shaft — and the slower speed would mean a more expensive gearbox, as the gear ratio would increase.

Slow-turning multiblade machines are better suited to applications such as water pumping than to electricity generation.

Why three blades?

Although many early machines had two blades, the three-blade concept gradually became dominant during the late 1980s.

One key disadvantage of two-blade machines is that yawing operations — when the nacelle and rotor turn around a vertical axis — need to take place slowly to limit fluctuating dynamic loads during the operation.

When the blades are vertical the forces required to yaw the rotor are low, but when the blades are horizontal the forces are much higher.

The cyclic forces impose significant stresses on several parts of the structure and these forces are much lower when a three-blade machine is yawed, as the asymmetric forces encountered as the rotor rotates are much less.

Another reasons why two blades fell out of favour is the fact that they are slightly less efficient than three-blade machines and need to rotate faster to realise peak efficiency.

This is a disadvantage for onshore machines as noise increases rapidly with tip speed.

Two blades are lighter than three, so they may be of interest again for offshore use

The notion that the increased activity in offshore wind might encourage renewed development of two-blade machines has been circulating for about ten years but has not yet generated much commercial hardware.

However, it is true that lower weight is a particular advantage offshore and ease of handling and assembly is another important factor.

Also, increased noise is considered to be less important in the offshore setting. Nordic Windpower manufactures a 59-metre diameter, 1MW turbine for onshore use but does not appear to be targeting the offshore market. 2-B Energy is aiming at the offshore market, with a 130-metre diameter, 6MW turbine, due to be installed this year or early next year.

Two-blade machines are two-thirds the weight of three-blade machines

Not necessarily. This may be another reason why there seems to be little enthusiasm for them. Theoretical considerations suggest that two-blade machines may only be about 13% lighter, but there is not enough data to substantiate this.

The figures that are available appear to indicate that two-blade machines are actually heavier, but most of the two-blade data comes from early machines and advances in materials science and in our understanding of wind turbine loads has led to a gradual reduction in blade weights.

Rotor speeds have been constrained to limit noise, leading to loss of efficiency

This may be partially true, inasmuch as it may be a contributory factor to the low enthusiasm for two-blade machines.

Two-blade machines reach their peak efficiency at a tip speed to wind speed ratio of about nine; the equivalent ratio for three-blade machines is just under eight, see the graph, right.

The loss of efficiency either side of the peak, however, is small.

Now that variable-speed machines are becoming common, a three-blade machine can maintain peak efficiency up to a wind speed of, say, ten metres per second (m/s), corresponding to a tip speed of 80m/s.

A two-blade machine would generate higher noise levels if it maintained its desirable tip speed to wind speed ratio, as this would correspond to 90m/s at a wind speed of 10m/s.

There is little evidence that three-blade machines have been constrained in speed to reduce their efficiency.

Tip speeds of most three-blade machines range between 60 and 80m/s. That ensures high energy yields and noise within acceptable limits.

Blades have reached the limit of their aerodynamic performance

Almost, but not quite, is the answer. There are three factors that influence the overall efficiency of turbine rotors.

The passage of the air through the rotor generates "swirl" which, as its name implies, means that the air stream acquires rotation.

Loss of efficiency through swirl cannot be avoided, as it is an inevitable aerodynamic phenomenon.

The loss is highest at low tip speed to wind speed ratios, and declines with higher values.

Tip losses are also highest at low tip speed to wind speed ratios, and then decline.

They are lower with three-blade machines. These losses are controllable to a limited extent and that is why some manufacturers are experimenting with special tip shapes.

Drag losses, on the other hand, increase with tip speed to wind speed ratio as the relative velocity of the air over the blades increases.

They can also be controlled to a certain extent, which is why research is in progress on developing special aerfoils with low drag.

The trend towards ever-larger machines also works in favour of reducing drag losses as the higher the span and tip speed, the lower the drag.

The graph above shows how these losses vary with tip speed to wind speed ratio, for a three-blade rotor.

The losses are shown as a fraction of the power in the airstream.

The power coefficient, or Betz limit — the theoretical maximum value of this fraction that can be converted into power from the rotor — is 0.593.

When all the losses together are subtracted from 0.593, we derive the maximum amount of power that can realistically be extracted.

In the case of three-blade machines the fraction is about 0.51 (51% efficiency); for two-blade machines it is 0.49 (49% efficiency).

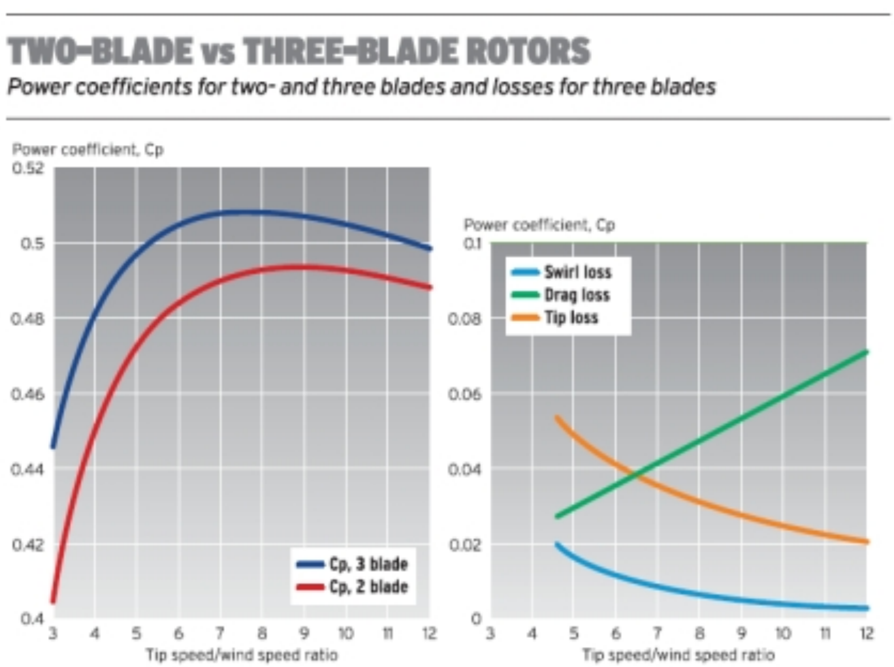
Blades will continue to get lighter (at any given size)

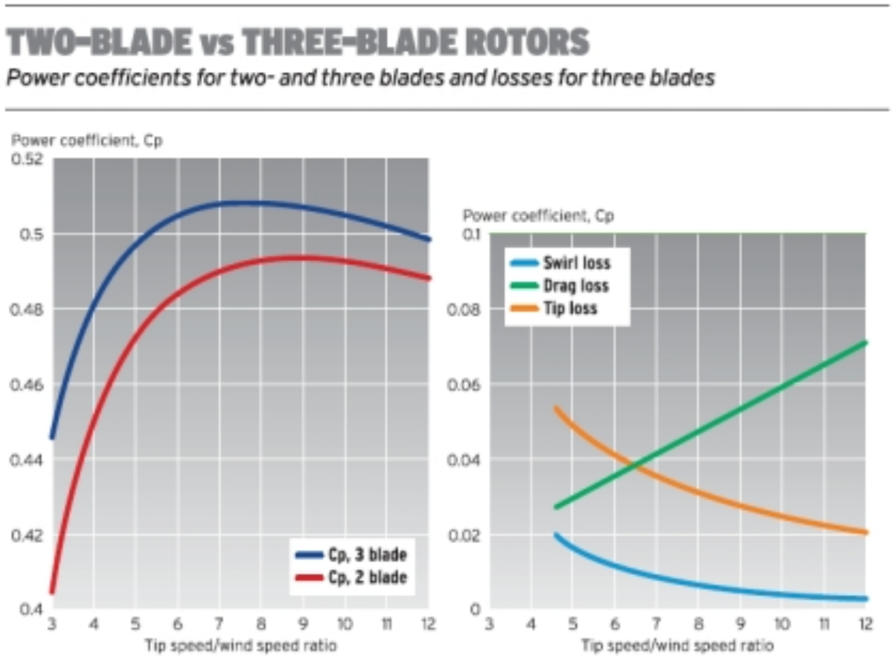
Possibly, but not necessarily.

The reason for this note of caution is that blades are now being designed for offshore sites with high wind speeds, and blade weight is a function of wind speed.

Increasing the design wind speed from 8m/s (a typical onshore value) to 10m/s pushes up the weight by 35% or more, depending on the design criteria.

On the other hand, the use of strong, lightweight materials, such as carbon fibre-reinforced plastics brings down the weight. The better the strength to weight ratio, the lower the blade weight.





Related Articles

[The ongoing effort to globalise standards]
[New player tackles radar problem]
[Squaring the circle of life]
[Reaching a joint decision]
[Introducing the biggest test rig in the world]
[How to plan proactive blade maintenance]
[Global guide to rotor blade manufacturers]

Have you registered with us yet?

Register now to enjoy more articles
and free email bulletins.

Sign up now

Already registered?

Sign in