Controlling the Green Giants

**Adam Stock writes about the influence of control engineering on wind turbines and how the size limit for these machines may be reached for an unexpected reason.**

Wind turbines have seen a massive increase in their size over the past thirty years, from approximately 15m diameter, 50kW machines turbines in 1980 to the ‘green giants’ seen today that have a huge 124m diameter and have a rated power of 5000kW.

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|  | Why have turbines become so large?  The first and most obvious answer is that the larger a turbine is the more power it will produce. However, why have one 80m diameter turbine and not two 40m diameter machines? This is because the amount of energy contained within the wind is proportional to the square of the turbine diameter. Hence, a turbine 80m in diameter is two times bigger than a 40m diameter machine but produces 22 times the power, or twice the power of two 40m diameter machines. |

Turbines are continuing to grow; machines with diameters in excess of 150 metres are already under construction. The National Renewable Energy Centre (Narec) based near Newcastle upon Tyne are developing a facility to test blades up to 100 metres long which would create turbines with a diameter of over 200m.

Why not before?

The link between the size of a turbine and the amount of energy it can capture has been known for many years and comes from basic physics; so why is it only now that wind turbines are becoming so huge? There are three main factors that have enabled this growth:

* New Materials
* Moving Offshore
* Control Engineering

New Materials

Since electricity producing wind turbines were first developed, our knowledge of materials engineering has greatly improved. Very early machines were made with steel or aluminium blades; however the high density of these materials has led to them being replaced over time with blades made from advanced composite materials which may weigh up to four times less than a steel equivalent. Current wind turbine blades are made predominantly from glass fibre composites but the emergence of new techniques to layer carbon-glass fibre composites and carbon fibre composites may see this change over the next few years.

Moving Offshore

Whilst onshore wind turbines continue to be built, they have inherent difficulties that limit size, which can be avoided by moving offshore. Most complaints about onshore wind turbines concern either the noise created or the visual impact of the turbine. Both of these factors become harder to minimise as turbine size increases. As offshore turbines are often out of both sight and earshot of the population, offshore locations allow turbines to be made with less emphasis on these factors.

Control Engineering

Control engineering for wind turbines involves altering the variable aspects of the machine (usually the generator firing angle or the rotor blade angle) in order to control the overall behaviour. In the early days of wind turbine control this was often done solely to maximise the energy captured by the machine. As turbine size increased however, more responsibility was placed upon the control system to ensure that the machine did not become overloaded.

Nowadays turbines have become larger and the materials required to facilitate this increase in size have become more flexible. Together, these factors make the new wind turbines more prone to fatigue stresses from the cyclic loading induced by the rotor as it turns. It is these fatigue loads that cause the majority of failures in modern wind turbines which in turn lead to repairs, extra maintenance or the destruction of the turbine. It has therefore become a major part of controller design to limit these loads. Software has been developed that can create accurate models of wind turbines so new control techniques to tackle this problem can be tried without risking an actual turbine.

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| Research recently completed at Strathclyde University has developed a new control technique that can reduce the cyclic loading on the tower of the wind turbine, causing a lifetime load reduction of over 10%. Additional work (also at Strathclyde University) has shown that allowing each blade to be individually controlled can lead to a reduction in the loads on the blades[1].  As machines increase in size, the ability of control engineers to decrease the loads on the structures becomes more and more important. However, there is a problem on the horizon. | What is Fatigue?  Fatigue is a process whereby small loads (below the yield strength of the material) cause very minor damage to components. This effect is cumulative and eventually the damage builds up to the extent that the component fails. If the force is higher, then less repetitions of the force are required to break the component. It has become a major requirement of the design of the wind turbine controller to keep these loads low in an effort to maximise the life time of the components. |

Work conducted by Professor Bill Leithead at Strathclyde University alongside Sergio Dominguez, now working for MLS in Glasgow, has shown that there may be a limit to what controllers can achieve[2]. Their work has shown that there is a complex relationship between the natural frequency of the rotor blades and the bandwidth of the controller. When controlling a wind turbine, it is necessary to be able to minimise any loading that has a frequency within the usual ‘target bandwidth’ of a wind turbine controller. However as the rotor blades increase in size and change material to allow them to cope with this increase in size, the natural frequency of the blade changes as well. This change in natural frequency is capable of imposing a maximum achievable bandwidth on the controller that may well be less than the bandwidth required to control the turbine satisfactorily. This limit is a mechanical property and so no matter how clever the control engineer is, they will not be able to increase the bandwidth using the current control techniques.

This in turn will have to lead to a change as to when designers start to consider the control system. Current practice involves designing the turbine and the control system somewhat separately, with little thought required as to how the mechanical design of the machine may affect the control system. As the mechanical design may cause the large wind turbines to be uncontrollable, the control design in the future will clearly have to be done concurrently with the mechanical design with an integrated design approach. However, even this approach may reach a limit for turbine size.

There may be other ways to combat the size restriction. One method would be to radically overhaul the way in which wind turbines are controlled, perhaps through new actuators (mechanical devices) or through novel and completely different controller programming. The problem with this method is that new techniques would have to be developed which would take a very long time, with no guarantee that they will not encounter their own restrictions on turbine size. A second method is to radically alter the design of the wind turbine, maybe using vertical axis machines or possibly kite based wind power generation systems. Although both vertical axis machines and kite-based machines have been developed in the past, the success of the horizontal axis design led to very little funding for alternative methods and so the scientific and engineering knowledge of these machines is some way behind. This method would therefore also take a great many years and again there are no guarantees of success.

Without the necessary control to reduce the fatigue loads on the turbine, the turbine becomes impossible to build. It is therefore imperative that as designers look to increase the size of their turbines, that no matter what they do to overcome the current problems, they do not forget the complex role of control engineering in allowing these green giants to stay standing.

[1] W.E. Leithead and V. Neilson, “A novel approach to structural load control using Intelligent Actuators,” 2009 17th Mediterranean Conference on Control and Automation.

[2] W.E. Leithead and S. Dominguez, “Size Related Performance Limitations on Wind Turbine Control Performance,” 2006, *International Control Conference 2006*,.