Review of Combined preliminary-detailed design of wind turbines

Summary

The system wide optimization of wind turbines represents a step change in the level of sophistication in system optimization, moving beyond the previous generation where the aerodynamics were optimized first and the structure and manufacturing were left to be optimized within the constraints produced by the aerodynamic and production requirements. The ability to optimize structural and manufacturing in conjunction with aerodynamic performance has led to the current generation of turbines with larger rotors and aerodynamic performance sometimes off optimum to allow for more efficient structural designs. This paper takes that current practice and expands the envelope to consider tower design, height, and diameter in the optimization loop. Although it claims to be the first, it is at the leading edge of an emerging area of work in which there have already been forays into these combinations of design variables (e.g., Ning, A.; Dykes, K. (2014), see below). This work arguably brings this work to a significantly higher level of fidelity in the modeling of individual subsystems within the turbine system. It is expected that future work in this areas will continue beyond the individual turbine design and into the realm of full wind plant optimization were each turbine is allowed to optimally fit its particular location and operating constraints.

This paper is silent in the area of how the drive train component sizing if affected by design elements other than rotor torque and rotor weight. Since the design standards make no such connection, it is understandable that this optimization illustration does not attempt to create and then implement linkages to imbalanced rotor loads, but it would supply another restraining factor to the growth to much larger rotors. This is also an area of potential future work, as is a connection to mechanical subsystem reliability. Both of these are significant additions to this work and their absence does not diminish the accomplishment at all.

The demonstration of this new optimization capability and the ensuing benefits is the main outcome of this work, but it supplies many other useful results that might be highlighted in the article. First, the optimized version of the baseline machines provides something of an improved baseline in each case. The closer a baseline design is to the global optimum for the embedded technology, the more useful it becomes as a measure against with new approaches and technologies can be measured. These altered configurations could be considered as the baseline, Rev. 2. There have been a number of studies proposing technology innovations where the use of a suboptimal baseline makes the change to new technology almost guaranteed to produce an improved outcome. The publication of improved optimal baselines would be a great benefit if used in these studies.

Second, the work has explored the design space at two interesting turbine sized and has exercised design constraints that differ at each size. These design constraints themselves are very interesting outcomes of the study and a more explicitly display of them would be very useful. While those active in commercial design may know what drives design, many researchers are not knowledgeable, and publish results assuming great impact when in fact the studied impact is not design driving at all. This paper could provide guidance in this area to a great many researchers.

The study also examines the use of Lower Induction (LI) designs to reduce structural loads on the rotor and find that there is little to gain in the land-based turbine, but the 10MW offshore machine could benefit by also growing the rotor and increasing swept area. The LI is achieved with a pitch offset. It would be interesting to know how a change in pitch (twist) schedule along the blade to reduce induction in a more tailored way might enhance the outcome of that option. Perhaps some discussion of the point could be included by the authors.

The authors do an excellent job of providing context and conditions that help the readers with their expectations of how generally useful this particular study should be. They note limitations that might be imposed by logistics, and the scattered definition of design load cases and storm loads might otherwise drive a specific design. This is a very readable and informative article. However, there could be a more direct statement of the importance of the cost models in driving the optimization result, as well as the analysis capabilities, which are the main contribution the authors have brought to this area. Cost models and assumed step changes in cost elements at points where manufacturing or transportation constraints come into play should be highlighted to a greater extent than currently stated. Overall, this is an excellent study.

Ning, A.; Dykes, K. (2014). “Understanding the Benefits and Limitations of Increasing Maximum Rotor Tip Speed for Utility-Scale Wind Turbines,” Article No. 012087. *Journal of Physics: Conference Series.* Vol. 524(1), 2014; 10 pp.; NREL Report No. JA-5000-61729.)

Issues for Consideration – Mandatory changes

1. Revise the statements the statements that this is the first time optimization has included tower and rotor size to be more consistent with the current literature (e.g., see above)
2. I don’t recall seeing a mention of any speed constraint on the rotor. Was there a tip speed constraint and how was it determined?
3. Discuss the issue of rotor non-torque loads and how they were or were not included in the costing of the drive train components. It is assumed the drive train was designed for the steady loads, but it just needs to be made clear.
4. In two places the term “under-designed” is used. It appears to mean under sized, but it is not clear. A more clear term should be used.
5. Plots such as Figure 6 showing blade design parameters should be labeled as “Blade span” instead of “Blade Length”
6. Plots such as Figure 5 showing tower parameters should have the independent variable of height on the x-axis and the dependent variables (such as thickness and diameter) on the y-axis to be consistent with the blade results.

Issues for Consideration – Optional changes

1. The practice of using software language statements (subroutine names) in the equations documenting the optimization process seems to be growing, especially in this area of system optimization. While it may provide better understanding to the practitioners of this area of

expertise, it is not as clear to those (like this reviewer) who are outside the area. Consider revising the equations to use more traditional mathematical symbols and descriptors.

2. On page 5, the first paragraph, there is a statement that no dependence of H is assumed for the 50 year storm wind speed. That sound ominous and could use more explanation.
3. Better define the term “un-exceedable loads”.
4. Discuss the option to introduce the LI designs through a distributed change in blade pitch (twist) rather than through a single offset.
5. On page 7 it would be useful to describe each IEC DLC briefly rather than just referring to each number.
6. Also on p. 7, explain how close the “close to be active” the frequency constraints are.
7. The design driving load cases that provided active constraints are very nicely listed and discussed. Consider creating a table that summarizes them for each design size. These are very interesting results.