WASATCH WIND
Tower Systems and Wind Development

Wasatch Wind, Inc
357 W. 910 So. STE. A
Heber City, UT 84032

Phone: 435-657-2550
Fax: 435-657-0095
www.wasatchwind.com

A New Tower Technology for Reducing Cost of Energy

A Space Frame™ tower in combination with a strut type damping system offers the potential to reduce tower costs and transportation barriers.

This article first appeared in North American Wind Power, 4th quarter 2005 and has been updated to reflect the companies new name

BY TRACY LIVINGSTON AND THOMAS CONROY

The need to reduce cost of energy (COE) is the overarching factor influencing technology advancement of wind turbines today: Advances in drive trains, blade efficiencies, and control systems are slowing while up-scaling of capacity and hub height is continuing.

Low wind speed enablers such as larger blades are also progressing. The combination of taller turbines and low wind speed blades is particularly beneficial to reducing COE. However, the weight, cost, and size limitations imposed by tubular steel towers is the primary impediment to further progress.

Transport barriers

Larger wind turbines are more cost efficient, and mean fewer roads, foundations, transformers, electrical collection, maintenance, etc. With no apparent technological limit to size, commercial installation of 5 MW machines is imminent and design feasibility studies are on-going for 10 MW machines.

However, larger turbines are focused on off-shore projects. Water transport of large items is relatively straightforward, while land based projects are reaching transportation limits. The problem is most acute for towers.

Transport expense is rising faster than the benefits of increasing size, creating a drag on wind farm economics. Even for the1.5 MW size, tower transport costs can easily exceed $80,000 for readily deployable sites. Unfortunately, land-based machines, especially when using the larger, low wind speed blades are limited to1.5 to 2.0 MW turbine sizes, even though the larger nacelles are more economical.

Low wind speed technologies

Lower wind speed technologies are also important for wind generation development. Because most of the high wind speed sites (Class 5 and 6) are being aggressively developed, the less windy class 3 and 4 sites will become the predominantly available resource in the future.

According to NREL, since these low speed sites comprise over 10 times the land area of the high wind sites, suppliers will need to implement low wind speed technology solutions in order to maintain a rapid pace of wind power expansion.

NREL has suggested two areas of focus; larger, more efficient blades, and more economical, easily transportable, taller towers to access superior winds at greater heights. These two areas are important for low-wind-site development because of exponential

Wasatch Wind, Inc
357 W. 910 So. STE. A
Heber City, UT 84032

Phone: 435-657-2550
Fax: 435-657-0095
www.wasatchwind.com

effects. Power increases with the square of blade length and with the square of the wind speed.

To illustrate how these factors can influence a project, we analyzed the power output of a 1.5 MW turbine, using a 77m rotor diameter on a 65m tower, located at a class 3 site (6.75 m/s average annual wind speed). The site exhibited an annual wind shear of .18 from 60 to 100m height, which is a common shear value across many areas of the U.S. Great Plains.

We then compared the output using the same turbine but with an 82m rotor on a 100m tower. The capacity factor increased 25%: 11% due to the larger rotor, and 13% due to more constant and higher wind speed on the higher tower. The decision then becomes a financial one: Are the blade and tower component amortized cost increases lower than the revenue derived from the increased power output?

At least for blade size, the market has responded quickly with a resounding yes. With the implementation of blade advancements, suppliers have kept weight increases manageable and transport and manufacturing costs reasonable.

Five years ago, 1.5 to 1.8 MW machines using 70m maximum rotor sizes were common, while today these same capacities are using rotors up to 90 meters on less windy sites. However, beyond this size, an economic limit is imposed by the increased costs of a heavier, more rigid tower required to withstand rapidly increasing tower torque. The load is caused by increased oscillations of the larger parked or idled rotor exposed to extreme wind gusts.

Taller towers also increase power output. Recent surveys across the U.S. Midwest indicate that wind shear is substantially greater than earlier studies have indicated. Greater shear means increased wind speed with height.

The use of taller towers, however, smacks head-on into the issue of transportability. Wind Tower Systems has completed extensive analysis of tower weights and cost per unit of height. The weight and cost of conventional tubular towers increases exponentially with height.

IEC Class 2, 65m tall towers, normalized to a fixed rotor area, weigh approximately 40 lbs per square meter of rotor area. At 80m, the weight jumps to 54 lbs, and at 100m increases to 73 lbs, reflecting an increase to the 1.4 power. If a proportional height to weight relationship where possible, a 100m tower would weigh 62 lbs yielding a 15% weight reduction and broadly justifying tall towers

Detailed cost analysis reveals that if a proportional tower cost increase with height where possible (assuming that the transport problem where solved) then taller towers would lower COE even in common wind shear conditions of .14. Presently, only extreme wind shears found in less than 10% of sites can economically justify the cost increase of taller tubular towers.

Other tower limitations

The weight of a tubular steel tower increases rapidly with height because of natural frequency harmonics. If the tower base moment (thrust load times the taller turbine height) during power generation were the only design issue, then tower weight would increase proportionally with height.

However, towers become dynamically softer with height. Softer towers have lower natural frequencies, which tend to converge with the frequencies generated by extreme

Wasatch Wind, Inc
357 W. 910 So. STE. A
Heber City, UT 84032

Phone: 435-657-2550
Fax: 435-657-0095
www.wasatchwind.com

wind events when the blades are feathered. To compensate, designers must increase tower stiffness in order to increase the towers natural frequencies. They do so by increasing wall thickness. The additional wall thickness prevents converging natural frequencies from creating a runaway destructive condition in an extreme wind (the Tacoma Bay Bridge of the 1930's was an example of this problem). The increased material usage creates heavy towers.

To summarize, breakthrough improvements are needed for towers to cease being a limiting factor to improved wind economics and site selection. The desired characteristics are: a tower with linear weight increase with height, zero weight change for larger blades of a fixed turbine capacity, a reduced baseline weight to overcome transport capacity limits, and modularity for on-site assembly and easy deployment. If these goals are achieved, the towers would; 1) contribute to lowering baseline COE for all heights, 2) enable larger land based capacities, and 3) enable low wind speed sites using larger blades and taller towers.

Conventional solutions

In the 1980's lattice towers, with their lighter weight and onsite assembly, were thought to be a solution to the tower transport and cost problems. The sub-megawatt 30m to 60m towers solved the harmonics problem by adding stiffness through a large (4x-6x) increase in base diameters. Resonance conditions could then be tailored without significant weight additions. However, scaling lattice towers to greater heights and larger rotors has proved to have significant limitations: tower base diameters became large, unwieldy, and unsightly.

Further issues of bolt loosening and slop, fretting, time consuming assembly, worsening height/weight ratios, and avian perching caused lattice towers to all-but disappear as industry offerings.

Recently, the industry has tried modifications to the popular steel tubular tower. To solve the size bottleneck, on-site assembly using site-poured concrete lower sections mated with steel upper sections is being tested.

Development is occurring on a process to fabricate (roll and weld) steel tower sections on-site. Another approach offers a segmented steel tower using tube tower sections sliced lengthwise and stacked for transport, and then bolted together on site.

Each of these solutions only partially solves the transport problem, and all add cost and weight to an already excessively heavy and expensive tower.

Space Frames™ - a new design

In 2002, Wind Tower Systems, LLC a division of Wasatch Wind, Inc. embarked on a DOE funded project to develop a radically different tower structure to solve the inherent problems of tubular steel towers. The goal was to design and certify an 80meter tower for 1.5 to 3 MW turbines, with subsequent development to 100m height. If the tower design was successful, 3 to 5 MW machines on land, as well as lower wind speed turbines using larger rotor to capacity ratios could become practical.

The company conceived an approach based on a "Space Frame™", which is defined as "a particular kind of tube frame that consists exclusively of relatively short, small-diameter tubes. The tubes are connected together in a configuration that loads them primarily in tension and compression."

Wasatch Wind, Inc
357 W. 910 So. STE. A
Heber City, UT 84032

Phone: 435-657-2550
Fax: 435-657-0095
www.wasatchwind.com

Space Frames™ are common in architecture, aircraft, and spacecraft applications. Utilizing steel tubular struts joined with expanding pins to eliminate slop, the Space Frame™ had the potential to be easily assembled on-site and light-weight like a lattice tower.

The extremely-large base diameters required for lattice towers where considered unacceptable. In response, a design goal was set for an overall diameter similar to tubular towers. A reasonable base diameter would also enable the application of non-structural cladding to achieve the aesthetics of tubular towers.

Damped struts reduce loads

Within the design parameters tower harmonics remained a problem. Since diameter could not be increased to obtain stiffness, and heavier members were not desirable, an alternative solution was needed. Damped strut members emerged as the optimal solution to reduce tower harmonic loads.

Several hundred design iterations revealed that the proper selection of the damping elements would reduce dynamic loads to be equivalent-to, and in some cases less-than, the tower top loads of a tubular tower.

Maximum dynamic loads occur primarily during parked-rotor extreme wind events, when broad-band wind gusts overexcite the tower like a bouncing spring. A Space Frame's™ natural frequency is low and the wind gusts can become coherent with tower natural frequency.

Unlike the weight stiffening methods of a tube tower, the Space Frame™ was designed such that a few of the steel diagonal struts could be swapped out with a new technology; a stiff energy absorbing strut. Highly effective at suppressing the tower dynamic loads, the damped strut did not add appreciable weight to the baseline design.

Wind Tower Systems has completed modeling of a commercially available 1.5 MW turbine with multiple rotors to fully validate the Space Frame™ design. The design has been modeled at IEC Class 1 and 2 wind conditions, and at both 80m and 100m heights. The tower included 12 repeating bays of steel struts. Each bay is composed of five vertical load bearing members and diagonal braces. To establish a baseline design, one bay of steel diagonals was replaced with 5 damped struts.

More dampers, less weight

The increased dynamic loads of taller towers or larger blades during extreme wind events are reduced by using additional dampers. Additional analysis has shown that with sufficient damping, dynamic loads are reduced to non-load limiting levels and static loads (thrust) then predominate. Thus operational thrust loads become the limiting design driver.

When sufficient damping levels are reached, the tower weight scales proportionally with height. With further adjustments to damping, tower weight is reasonably independent of blade swept area. Some configurations of taller towers, greater rotor sizes, and increased winds, required multiple bays of damped struts.

In all configurations, the steel member sizes and geometry remained unchanged in the un-damped bays. The possibility of creating one basic, lightweight tower design for many rotor sizes and heights is likely. The original design-parameters for the new Space Frame™ tower were met for all models.

Wasatch Wind, Inc
357 W. 910 So. STE. A
Heber City, UT 84032

Phone: 435-657-2550
Fax: 435-657-0095
www.wasatchwind.com

- Tower weight scales linearly with height.
- Tower weight is unchanged with larger blade diameters for a fixed capacity.
- Baseline tower weight is 35% to 60% less than tubular towers.
- Modularity of a strut-based design overcomes transport problems.

The result of the combined “Space Frame™” tower innovations is reduced COE for wind farm owners, and an increase in available wind sites. The Space Frame™ tower lowers COE through lower baseline weights, provides a constant weight with rotor size increase, and a linear cost scaling with height.

Modular strut-based construction of the Space Frame™ tower solves transportation limits and opens the opportunity for even larger, land based turbines. Work is continuing in establishing manufacturing relationships and commercialization strategies with wind turbine manufacturers for adoption in next generation products.

Tracy Livingston is the founder and chief executive officer of Utah based Wasatch Wind a wind farm devopment company and it’s subsidiary Wind Tower Systems, LLC., which provides tower solutions and related engineering design and certification services to wind turbine manufacturers and developers through licensing and manufacturing arrangements. He can be reached at tlivingston@wasatchwind.com . Tom Conroy, President at the Company, is responsible for managing operations, and can be reached at tconroy@wasatchwind.com