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

An Analysis of MW-Class Wind Turbines Compared to Tilt-Up Turbines for Hurricane-Prone Areas

J. Tracy Livingston
CEO
Wasatch Wind, Inc

ABSTRACT

Wasatch Wind has married the transportable Space Frame Tower and Hi-Jack self-erection system with a hurricane resistant MW class commercial turbine for deployment in remote locations to provide the lowest cost/Mwh. The low cost deployment characteristics of the Hi-Jack System for crane-less maintenance and repair make large turbines feasible in remote locations for the first time. MW-class turbines provide significantly improved energy extraction efficiencies over smaller tilt-up turbines. Taller towers to 100m offer access to substantially greater winds at greater heights. The subject turbine incorporates free yaw to withstand 60 m/s peak wind gusts for resistance to Category 3 hurricanes.

Problem Statement

A dual challenge exists in many remote locals such as islands and other tropical regions. Because wind speeds on average tend to be low (below 6.5 m/s), blade swept area must be larger in order to extract more wind energy during the more prevalent lower wind speed times.   Almost all MW-size low wind speed turbines are designed for IEC Class 2 wind regimes.   Class 2 rated turbines are typically not capable of withstanding the peak gusts of hurricanes and typhoons. Exacerbating the problem is the need for taller 80m to 100m towers in order to realize gains in energy extraction of 40% to 50% (over tilt-up turbines) and increase capacity factors to make projects economic in low yield locations. Class 1 turbines capable of withstanding hurricanes are available, but these machines have smaller blade swept areas and thus lower energy yields making them generally unsuitable for many island projects.

Are shorter tilt-up turbines the solution?

Some islands have considered 100 kw or smaller tilt-up turbines as a way to mitigate hurricane risk. By lowering the turbine prior to these events, the turbine is more likely to survive.

However, tilt-down turbines have three deficits that make for difficult economics:

- The efficiency of the machine is lower than MW class turbines. The ability to extract wind energy is a function of blade efficiency. The larger class turbines with their more efficient blades can extract 42% of the energy in the wind at optimum wind speeds, while the smaller turbines are lucky to exceed 35%. Therefore capacity factors for equal hub height wind speeds are reduced by 16% or more.
- In order to be able to tilt down, the tower must be short. The typical hub height of tilt down turbines is 20m. Using simple wind shear calculations, the wind speed at 20m is much lower than at the 80 m height for MW turbines. Typical available wind energy is 40% to 50% greater at 80m than at 20m height.

- Small turbines do not benefit from economies of scale. Larger turbines are less expensive on an installed cost/MW basis simply because of size. On a per MW basis, generators, blades, towers, and project fixed costs are lower when the unit is 10x larger. Even if a small wind farm had the same annual energy output of a larger-turbine size project, the number of foundations, power lines, roads, etc is an order of magnitude greater on an output-amortized basis. . As will be shown below, the installed MW capacity of a small project must be much larger in order to equal the annual Mwh output of the large turbines.

Economic Comparisons

On most wind farms, wind speed increases with hub height. The rate of increase is a function of the roughness of the terrain. The greater the roughness, the more the wind is slowed due to surface friction. The following table describes the landscape types in the right column as commonly occurring at wind farms with the exception of “water surface” usually found only in off-shore locations. The energy gain realized by raising the hub height of the turbine from 20m for the tilt-up towers to 80m for the 1000 kw machine is significant. Since the power output is approximately equal to the square of the wind speed, small increases in wind speed result in large power gains. We selected the third row as the most common landscape for wind farms. The energy gain by raising the turbine to 80m is 46%.

Roughness Length m*	Wind Speed Increase from 20m to 80m	Wind Speeds at 80m	Energy Increase 20m to 80m	1000 kw Turbine Capacity Factor at 80m	100 kw Turbine Project Capacity Increase for Equivalent Energy Yield	Landscape Type
0.0002	12%	5.60	35%	18.8%	158%	Water surface
0.0024	15%	5.77	39%	20.2%	170%	Completely open terrain with a smooth surface, e.g.concrete runways in airports, mowed grass, etc.
0.03	**21%**	**6.07**	**46%**	**22.6%**	**190%**	**Open agricultural area without fences and hedgerows and very scattered buildings. Only softly rounded hills**
0.055	24%	6.18	48%	23.5%	197%	Agricultural land with some houses and 8 metre tall sheltering hedgerows with a distance of approx. 1250 metres
0.1	26%	6.31	51%	24.5%	206%	Agricultural land with some houses and 8 metre tall sheltering hedgerows with a distance of approx. 500 metres
0.2	30%	6.51	55%	26.1%	219%	Agricultural land with many houses, shrubs and plants, or 8 metre tall sheltering hedgerows with a distance of approx. 250 metres
0.4	35%	6.77	60%	28.2%	237%	Villages, small towns, agricultural land with many or tall sheltering hedgerows, forests and very rough and uneven terrain

Assumptions:	
20 m height reference wind speed (m/s)	5
100 kw turbine capacity factor (20m hub hgt)	11.9%
100 kw turbine efficiency vs 1000 kw	85%
1000 kw turbine hub height (m)	80
*www.windpower.org/en/stat/unitsw.htm#roughness	

Table 1: Wind Speed Increase from 20m to 80m as a function of surface roughness

The capacity factor (the average annual output divided by maximum possible output) for a wind turbine was then calculated both for the 20m, 100kw turbine as well as the 80m, 1000 kw machine. Assuming an annual average wind speed at 20m of 5 m/s and a Raleigh distribution of wind speeds, the capacity factor of the 1000 kw machine at 80m is 22.6% versus 11.9% for the 100kw machine at 20m. Therefore, many prospective wind farms do not get built on the islands due to this misperception of low energy yield, yet a viable project is literally right overhead. At 80m the energy yield is 1.9 x greater. A capacity factor goal for an island utility depends on the power rates, but typically projects with greater than 20% can be viable. Even in islands reaching the threshold of higher energy yields with tilt-up turbines, the MW class turbine is economically superior.

Larger turbines in mainland industrialized countries are being installed today for less then $1700 per kw of nameplate capacity. In those same areas the 100 kw machines can be installed for approximately $2500 per kw. However, on the islands, if crawler cranes are used to install large turbines and are redeployed for maintenance and repair, then project costs can easily exceed the costs for tilt-up turbines that are less encumbered by remoteness and road infrastructure. Combined with the need for using high wind speed turbines to withstand hurricanes and the lower energy yield from smaller swept area, the typical large wind turbine is not economic on the islands. Yet in many cases, the tilt-up turbines are too short and too inefficient to be enabled either.

To change the existing island wind paradigm, Wasatch Wind has introduced a system to install MW turbines at 80 to 100m with a new type of transportable tower. The Space Frame Tower is an open tubular framework covered in an architectural fabric skin. Contrasted to heavy tubular towers with severe cost and transport issues, this lighter weight, container-shippable tower is assembled on site. Due to the lighter weight of the tower, a new crane-less installation is enabled called the Hi-Jack System. The self-climbing Hi-Jack™ system is particularly beneficial to remote sites by substantially lowering the cost of mobilization and transport. Not only does the Hi-Jack™ system solve the costly crawler crane methods on the islands, but it can also be rapidly redeployed for heavy maintenance replacements and repairs. An extensive cost analysis for remote sites was undertaken to determine the installed costs of projects in remote locales. In every case, project costs were below $2000 per kw even at smaller 3 turbine projects. Thus, MW+ island projects can now provide electricity at costs far below tilt-up turbines.

The following table takes the capacity factors previously determined for the two different height turbines and calculates the annual output per kw of capacity. Since the larger turbine has greater energy yield it will produce more kwh per unit of capacity. Dividing this yield into the project cost per kw then compares directly the cost to produce a unit of energy. The capital cost per kwh of the tilt-up project is seen to be more than 2.3 times more expensive than for the taller MW-class turbine project as illustrated in the last column below.

	Turbine Capacity Factor	Project Cost per kw of Capacity	Annual kwh of Output per kw of Capacity	Project Cost per annual kwh of Output
1000 kw turbine	22.6%	$ 1,950	1,980	0.98
100 kw turbine	11.9%	$ 2,500	1,042	2.40

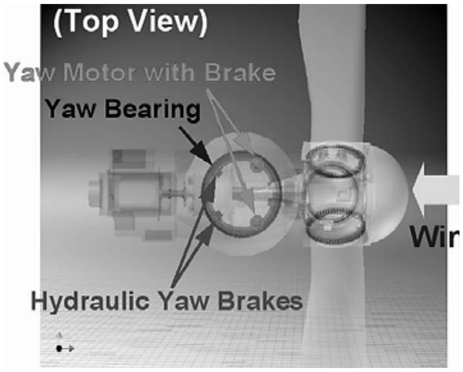
Table 2: Annual energy cost comparisons

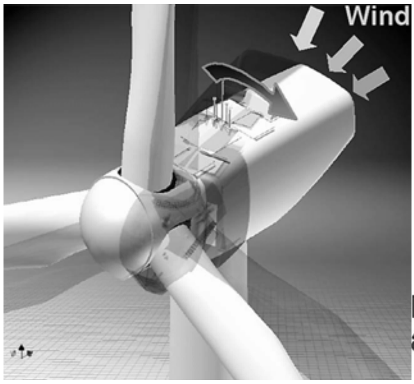
The Free Yaw System[1]: Solving the Hurricane Problem

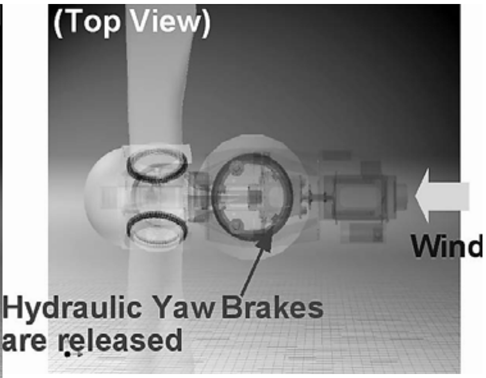
Wind power generating equipment is designed to absorb loads under varying conditions during normal operation and extreme wind conditions. Because of the exposure to these extreme wind conditions they are an important factor in designing the size and strength of the blade and tower. For typical turbines in extreme winds, the system stops generating and actively yaws to position the blades upwind and feathered in order to reduce system loads. However, backup power systems are designed for short durations and are not sustainable during hurricanes. Thus, with the wind direction changing as the hurricane passes through and backup power systems depleted, the blade sweep plane does not remain facing the wind and the system experiences excessive loads. Typical Class 2 low wind speed turbines are not capable of handling this condition.

The turbine used with the Wasatch Wind Tower System includes a free yaw system to reduce turbine loads allowing the Class 2 turbine to sustain peak hurricane gusts. Power failure is taken into account in addition to the extreme wind condition in order to ensure safety. The turbine is designed to free yaw downwind without active yaw power with the blades feathered.

Yaw references the direction the wind turbine faces, and free yaw refers to allowing the wind turbine to rotate freely during extreme wind events resulting in the turbine facing downwind. Facing downwind during extreme wind events significantly reduces the load on turbine and tower, as opposed to facing upwind like all other vertical axis turbines. During operation the wind turbine turns to face upwind by using a yaw motor and hydraulic yaw brake at the time of normal power generation. In times of strong winds, however, the hydraulic yaw brake is released, allowing the wind turbine to shift to the downwind direction based on the principle of the wind vane. During this shift from upwind to downwind orientation the brake installed on the yaw motor is applied with appropriate frictional force to prevent generation of excessive swinging in the wind turbine. Once the turbine is downwind, loss of primary or backup power does not effect the Free Yaw operation.







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[1] Free yaw information courtesy of technical literature from turbine supplier partner. Contact Wasatch Wind for details.

Furthermore, since the yaw movement of the wind turbine is not constrained, even if an excessive load acts on one of the three blades due to spatial turbulence of wind, the wind turbine carries out yaw movement due to the load difference between this blade and the other two. This motion results in the absorption of the large temporary load. With the Free-Yaw System, the load acting on the blade in times of strong winds is reduced by 25% and tower load by 30%. These load reductions enable the turbine to withstand peak hurricane gusts of over 60m/s.