Cost Benefit Analysis and Argument in Favor of Replacement of Mechanical Turbine Control Wind Sensors

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Lufft

Introduction

This analysis will address the costs and benefits of replacing mechanical wind sensors with ultrasonic wind sensors (both devices are also known as anemometers) for Operations & Maintenance (O&M) service providers to utility-scale wind energy projects. Costs and benefits will include both financial and risk considerations over the typical lifespan of a wind farm.

Anemometers are vital components of utility-scale wind turbines. These wind sensors measure wind speed and direction at the site of a given turbine, which determines the performance of the turbine's output. A standard wind turbine power curve shows power output (kW) at a range of wind speeds (m/s). Turbines operate in a relatively narrow range of wind speeds, cutting in at around 3 m/s and cutting out at around 25 m/s. The turbine blades will not efficiently turn below the cut-in speed, and wind speeds above the cut-out speed may cause damage to the turbine blades or other components. The anemometer is the sensor that measures wind speed, points the blades into the wind to optimize power output, and signals the turbine to operate or feather its blades.

Mechanical sensors used to measure wind speed can be described as having three hemispheric cups attached to arms on a vertical axis turn in the wind at a speed proportional to wind speed. Wind direction is measured by another type of mechanical sensor a vane anemometer that combines a small horizontally oriented propeller and tail to turn the axis perpendicular to the wind direction and the propeller blades transmit wind direction to the turbine. These two types comprise of moving parts such as ball bearings that are subject to damage at high wind speeds, icing incidents, and typical mechanical ageing due to wear and tear found operating under various weather conditions.

In the market today, companies are transitioning to ultrasonic anemometers. These sensors contain no moving parts and are entirely electric, which reduces the probability of failure with other benefits for O&M providers. Ultrasonic anemometers without hydraulic or mechanical parts are not prone to rust, scale, or other buildup that may impede proper operation. Some ultrasonic sensors are also equipped with heating components that control the internal temperature in icing events, which may occur at hub height. It is imperative that the sensors are kept at a temperature that allows it to operate accurately and maximizes power output of the turbine. Furthermore, ultrasonic anemometers may have both digital or analog outputs directly from the sensor, which can provide direct communication with the turbine's Programmable Logic Controller (PLC), that monitors and operates each turbine's electromechanical processes. This direct communication is important for minimizing power loss, reducing replacement costs, identifying turbine maintenance needs, reducing dead band, and help in reducing the writing of code for performing vector averaging by the OEMs or O&Ms.

This analysis will examine all of the relevant costs incurred by O&M service providers using four different anemometer options: ultrasonic, mechanical without heating capability, mechanical with heating capability, and mechanical with communication protocol. Results will be presented in terms of comparative costs of each type of anemometer over a 20-year period, which is the approximate lifespan of a wind turbine on the market today. These costs will be demonstrated on a per-turbine basis, as well as for a 100-turbine wind farm, representing current wind farms ranging from 150-300 megawatts in capacity.

Methodologies

Cost figures and other industry metrics used in this study have been gathered from various sources that include O&M industry expert interviews (n=4), online industry reports, and publicly available data. The data provided is not product- or model-specific, but rather provides an overview of the four reviewed varieties of anemometer.

Key assumptions made based on these sources that construct the analysis include the following:

- Data is given in rates per wind farm, assumed to be about 100 turbines (150-300 MW). Some data may be normalized to this standard.
- Mechanical anemometers fail at a rate of 40% each year, excluding icing events.
- Anemometers without temperature control/heating capacity have an additional failure rate of 5% each year; this figure is derived from industry O&M experts reporting approximately 5 incidents per year for which mechanical anemometers need to be replaced due to freezing temperatures causing failure of the sensor (5 incidents per 100 turbines = 0.05 or 5%).
- Experts also report that an unscheduled sensor replacement notification requires "2 to 3 weeks" of turbine downtime with corresponding power production loss required to order, receive and replace the sensor. As a conservative estimate, this analysis calculates costs based on 14 days of lost power production per replacement.

- The hourly wage of a wind turbine technician is $23.46/hour[1]
- It requires approximately 5 hours of work by a wind technician to replace a sensor
- The loss of power from a typical wind turbine undergoing maintenance costs about $40/hour (1.6MW turbine at $0.10/kWh)
- An ultrasonic anemometer has a typical lifespan of 5 years

These assumptions contribute to the costs and benefits calculated for each type of sensor. For each anemometer, a number of variables are accounted for in a five-year time period, which are linearly extrapolated to a 20-year period, the typical lifespan of a turbine on the current market. These include the following:

- Purchase and shipping costs
- Maintenance/installation labor costs
- Turbine downtime losses of power production
- Signal conditioning
- Additional wiring

Additional non-monetary costs for consideration include risks of sending a maintenance worker to hub height with each repair/installation, additional trips to and from (often-remote) wind farm sites, additional time needed to identify specific maintenance needs due to lack of communication protocol, and others. Therefore, this cost-benefit analysis is a conservative estimate of the corresponding costs and benefits of each anemometer type.

The results in the following section use the above variables and assumptions to examine the costs for a single turbine in a 5-year period, for a granular marginal analysis. The results will also be linearly extrapolated to demonstrate cost-savings to an O&M service provider in a realistic scenario of a 100-turbine wind farm (150-300 MW) over a 20-year timeframe, which as stated before, represents the standard lifespan of turbines currently available on the market.

[1] http://www.bls.gov/ooh/installation-maintenance-and-repair/wind-turbine-technicians.htm

Results

By capturing the 5 year costs of four different types of wind sensors, the comparison of the long-term costs of each anemometer type demonstrates that while mechanical anemometers may have a lower upfront investment cost, the additional costs of replacement, lost production, additional wiring requirements, need for signal conditioning, and other maintenance costs over the analysis period exceed the initial cost investment of the ultrasonic anemometer.

The graph below compares the 5 year costs of 1) mechanical non-heated sensor, 2) mechanical heated sensor, 3) mechanical with communication protocol, and 4) ultrasonic anemometer. Based on the assumptions outlined in the Methodologies section of this analysis, lifetime costs of an ultrasonic anemometer are significantly lower than the other three mechanical anemometer options available on the market today for Operations & Maintenance service providers in the utility-scale wind industry.

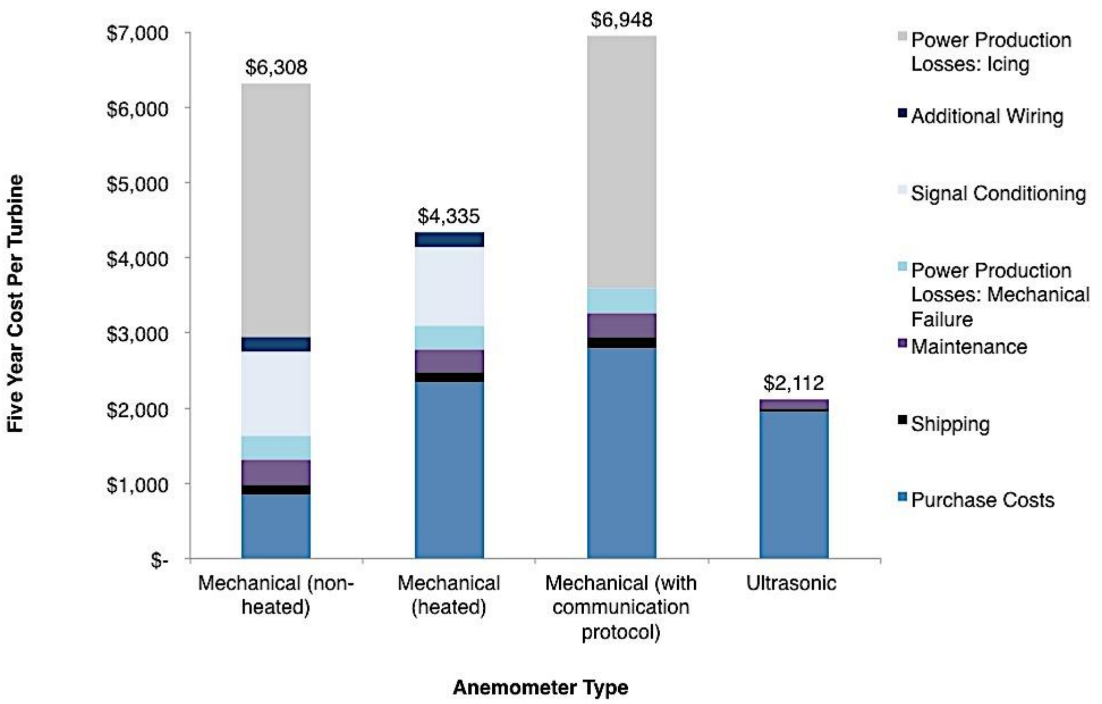

Figure 1. Five Year Anemometer Costs Per Turbine. Compares individual costs over a 5-year period (a conservative estimate of the lifespan of an ultrasonic anemometer) based on variables identified by O&M service providers as complete wind sensor costs beyond the initial purchase price.

As illustrated in Figure 1, ultrasonic anemometers cost $2,112 over a 5-year period, which includes a single instance of purchase and installation (~$2000) with minimal lifespan costs. The heated mechanical sensor costs only about $900 upfront, but given the 40% annual failure rate probability, replacement sensors will be purchased, which requires shipping, installation, lost power production time, and signal conditioning for each replacement in a 5-year period, resulting in about double the cost in that period. The two non-heated mechanical sensor options considered in this study have costs over three times that of ultrasonic anemometers, with the lost power production accounting for a sizeable amount of costs incurred.
One can agree that a broken, damaged, or icy wind sensor results in lost power production. Icy weather conditions cause wind sensor failure in anemometers with mechanical moving parts, resulting in wind turbines not being able to be operated because the wind sensor is used for measuring the wind speed, indicating if it is safe to generate electricity according to the turbine model's power curve. The financial viability of wind power is based on robust estimates of power production at a (usually) established unit price, foregone revenue from power generation is accounted for as a cost corresponding to non-heated anemometers that have a probability of failure of 5% due to icing incidents (in addition to the 40% failure rate of mechanical anemometers due to moving parts). This cost can account for over half of the total costs of a mechanical non-heated sensor over a 5-year period. A basic mechanical anemometer has a 5-year cost of about $6,308, with the lost power production costs due to icing incidents accounting for $3,360 per year, which is about 53% of total costs in this period. Conversely, an ultrasonic anemometer, which includes heating capabilities and which also does not have moving parts to be impacted or broken in extreme temperatures, incurs no lost power production costs.

Currently, one of the barriers to higher market penetration of ultrasonic anemometers in the wind sensor market is upfront cost. While mechanical wind sensors like cup and vane sensors can cost as little as $300 to purchase, ultrasonic anemometers are sold for six to seven times more. While this significant cost difference may discourage service providers from replacing less sophisticated sensors with ultrasonic sensors, long-term costs should be considered when comparing wind sensor options. Many O&M providers should consider the costs of replacement, lost power production, and the other variables previously mentioned to make a true cost comparison. The future costs should be contextualized beyond the initial purchase costs in a longer time frame. The ultrasonic anemometer has a long lifespan (minimum of five years) with greatly reduced costs beyond initial purchase price. The chart below demonstrates the accumulating costs across a five-year period of an inexpensive mechanical sensor compared to an ultrasonic sensor.

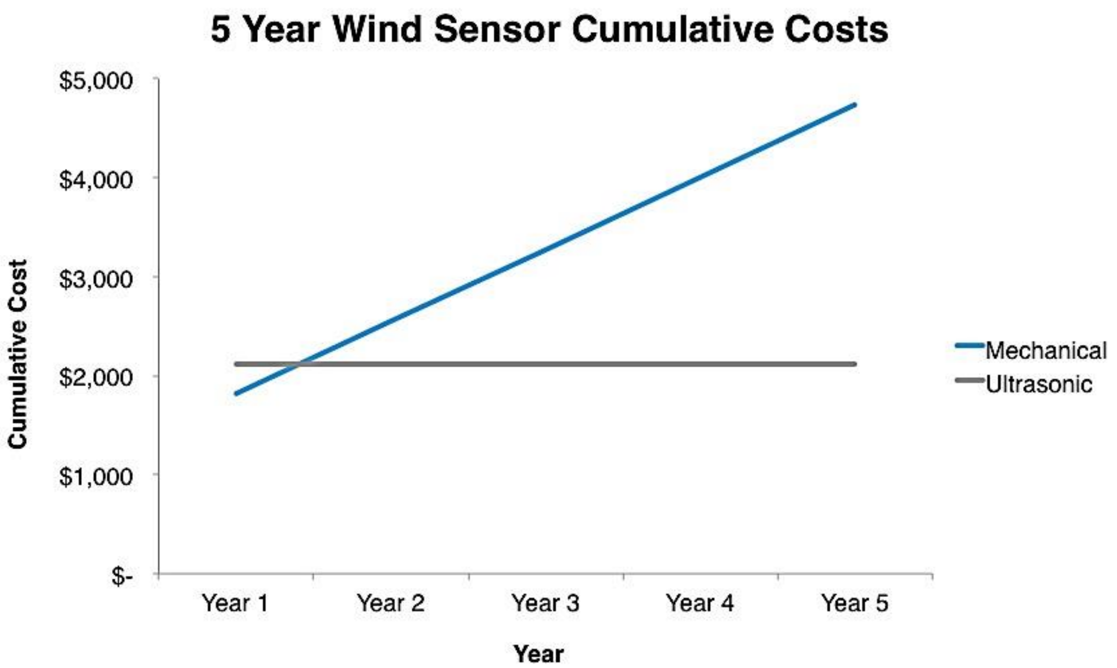

Figure 2. Five Year Wind Sensor Cumulative Costs. Accumulation of related costs across a five-year period of mechanical versus ultrasonic wind sensors. High maintenance and lost power production costs over that period demonstrates that mechanical sensors cost customers substantially more over a longer term.

This cost comparison indicates that avoidance of future costs by purchasing an ultrasonic anemometer instead of a mechanical anemometer will create per-sensor cost savings beginning in year 2. In year 1, the customer will incur a higher cost by purchasing an ultrasonic anemometer, which has an upfront cost of up to seven times that of a mechanical sensor. However, due to the avoided burden of costs such as annual replacement, lost power production, and other factors, the cumulative costs of the mechanical sensor surpass those of the ultrasonic sensor before the end of year 2. The breakeven point, as illustrated in Figure 2, is captured in the first year of replacement.

Conclusions

The purpose of this analysis is to examine the costs and benefits of ultrasonic and mechanical wind sensors to O&M service providers. While the baseline of this analysis has been shown on a 5-year time-scale to compare apples-to-apples, being that ultrasonic anemometers do not fail at the same rate of mechanical anemometers. By examining the costs and benefits across a 20-year period, the cost differences between ultrasonic and mechanical wind sensors are dramatic. Further, O&M providers are responsible for maintaining entire wind farms rather than individual turbines, the results have been expanded to reflect the cost savings for an O&M provider contracted to service a 100-turbine wind farm for 20 years. A 100-turbine wind farm with 1.5-3 MW turbines represents an example of a 150-300 MW farm, which is typical for the market today.

Anemometer Type	Five Year Costs	Twenty Year Costs	Lifetime Costs compared to Purchasing Ultrasonic
Ultrasonic	$211,230	$844,920	$ - -
Mechanical (Non-heated)	$630,844	$2,523,376	$1,678,456
Mechanical (heated)	$433,498	$1,733,992	$889,072
Mechanical (w/ communication protocol)	$694,844	$2,779,376	$1,934,456

Table 1. Comparison of costs of four different types of anemometers. Five-year and twenty-year costs are considered for each type of sensor. The twenty-year costs of each type of mechanical sensor is compared to the twenty-year cost of the ultrasonic anemometer to reflect the additional lifetime costs of purchasing mechanical sensors as compared to ultrasonic sensors.

Table 1, details the summarized costs of the four types of sensors for a 100-turbine wind farm. The column labeled “Five Year Costs” totals all of the cost variables for 100 turbines over the 5-year period that is the basis for this analysis. The column labeled “Twenty Year Costs” multiplies those costs by four to represent the total costs of the example wind farm over the course of its expected lifespan. Finally, the column labeled “Lifetime Costs compared to Purchasing Ultrasonic” represents the lifetime cost difference between the mechanical types of anemometers and the ultrasonic anemometer. As Table 1 shows, the lifespan costs of all of the mechanical anemometer types examined are more expensive over 20 years than the ultrasonic sensor. Therefore, selecting an ultrasonic anemometer instead of any of the listed mechanical anemometer types will result in cost savings.

Even purchasing the least expensive mechanical sensor over the lifespan of a wind farm will cost O&M service providers about $889,000 more than purchasing ultrasonic sensors over 20 years. By selecting an ultrasonic sensor rather than a mechanical sensor, service providers can save up to $1.9 million over the course of servicing a single 100-turbine wind farm.

This analysis “Cost Benefit Analysis and Argument in Favor of Replacement of Mechanical Turbine Control Wind Sensors” was written by Erin Williamson on behalf of Lufft USA, Inc. All analysis is original research based on industry expert interviews (n=4), publicly available information, and industry reports. The assumptions provided are a complete explanation of all uncertainties, and results represent a conservative estimate of cost savings from purchasing ultrasonic anemometers.

For questions or comments regarding this white paper “Cost Benefit Analysis and Argument in Favor of Replacement of Mechanical Turbine Control Wind Sensors” please contact Lufft USA, Inc.

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