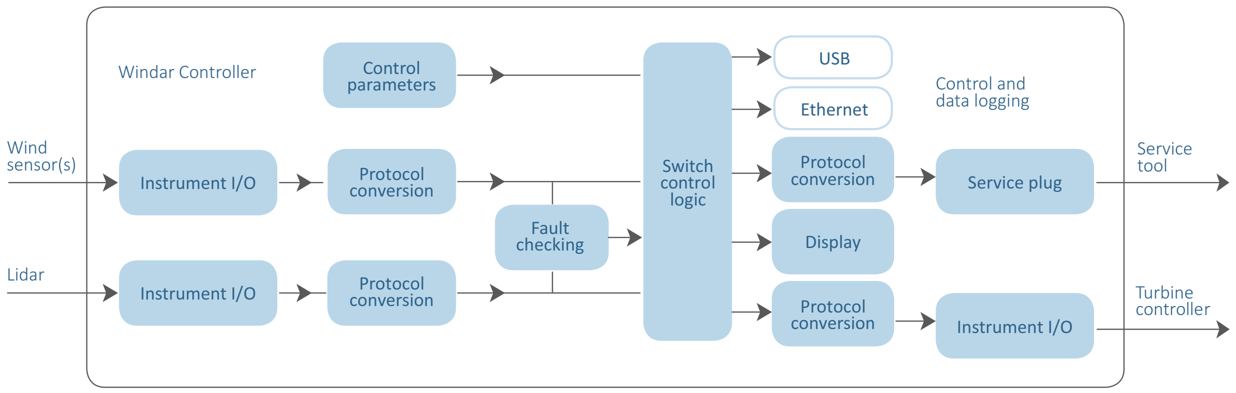


Figure 1

"The mentioned example is one of the more extreme cases we have seen, which we use to illustrate how much yaw-correction matters in relation to AEP increases. On a general level, we usually see yaw misalignment of about 5 degrees and AEP gains of about 2%," says Thomas Dyhr, Technical Project Director at Windar Photonics.

THE WINDTIMIZER™ AND LEGACY ANEMOMETRY

As LiDAR sensors measure air born particles, any LiDAR sensor will experience periods where back scattered signals cannot be detected by the WindEYE™ sensor. By default the WindTIMIZER™ will transmit the wind direction data received from the WindEYE™ sensor to the wind turbine control system. However, during periods where no data is available from the WindEYE™ sensor, the WindTIMIZER™ will automatically transmit the wind data from an existing wind sensor, such as a anemometer, which continues to provide wind data to the wind turbine control system.

INTEGRATION AND SIGNAL CONVERSION

The WindTIMIZER™ receives signals from both the legacy wind-sensors and the LiDAR system, converts the signal from the LiDAR system to the protocol of the legacy wind-sensor signals, and sends the signal of the LiDAR system into the wind turbine controller, as long as the LiDAR system signal is available. This makes the LiDAR instrument "appear" as the legacy anemometry to the wind turbine control

system, which makes it possible to integrate the LiDAR without any changes to the wind turbine control system.Furthermore, the WindTIMIZER™ will compare the converted measurements from both the LiDAR system and the legacy anemometry to check for any faults. In case the LiDAR system gets an unusable datum (e.g. if a blade passes in front of one of the LiDAR's beams), then the WindTIMIZER™ will be able to use the datum from the legacy sensor instead. A diagram showing the software system of the WindTIMIZER™ and the conversion process can be seen in figure 1.

- The WindTIMIZER™ will convert the signals from the LiDAR to the format of the legacy anemometry.
- Using the same format makes the LiDAR "appear" as the legacy anemometry; no need for adjusting the wind turbine controller
- The WindTIMIZER™ checks the signals for faults; in case of faults the WindTIMIZER™ will use the signal from the legacy anemometry

SAFETY CHAIN

Maintaining the wind turbine safety chain is of the greatest importance, hence it is imperative that any technical or meteorological problems involving the LiDAR system and the WindTIMIZER™ does not jeopardize the safety chain. In case of a force majeure emergency, like a lightning strike that harms the WindTIMIZER™, a failsafe switch will still transmit the legacy anemometry signal to the controller.

THE FUTURE OF YAW MISALIGNMENT CORRECTION

To further reap the potential AEP gain from proper yaw alignment than has already been done by the static correction method, the industry will have to explore new methods and technology. Through control integration and dynamic yaw correction, the WindTIMIZER™ and WindEYE™ solves the problems inherent to the static yaw correction method, providing cost-efficient increases to both revenue and asset longevity. ■

Not measuring correctly can be a costly affair

WINDAR PHOTONICS

Dynamic yaw misalignment correction by Windar Photonics

The Danish company Windar Photonics, who recently was listed on AIM London Stock Exchange, has developed a fully integrated dynamic yaw misalignment correction system.

THE PROBLEMS WITH THE STATIC YAW CORRECTION METHOD

It is fairly well known that a significant part of the currently running wind turbines have yaw misalignment greater than 5 to 10 degrees, which results in a continual loss of AEP. Other manufacturers of Lidars and measurement technology have tried to remedy this situation by offering a static realignment of the turbine to correct the yaw misalignment, usually done by applying an offset to the turbine controller or the legacy anemometry. The off-set factor is derived from the data collected through a measurement campaign of variable length involving Lidar or sonar technology. This method has been proved to work and will result in an average increase of AEP. However, there are three issues with this method:

1. Both the correction off-set and the projected hypothetical AEP increase are based on past measurement results, collected over a finite period of time. As it stands, there is currently no conclusive evidence as for how long the projected increase in AEP is valid from these measurement results, as the past measurement results does not necessarily correlate accurately with the actual and future meteorological conditions at the wind turbine site. As such, the correction and hence the hypothetical AEP increase could be valid for only a week, a month, or maybe only a few days, but nobody knows for sure.

Wind speed interval [m/s]	Observed misalignment		Misalignment after correction	
	Mean	Absolute	Mean	Absolute
[4 - 5]	3.67	7.78	-1.08	4.09
[5 - 6]	4.85	6.33	-0.16	3.40
[6 - 7]	4.04	6.04	-0.58	3.13
[7 - 8]	4.07	6.10	-0.50	3.29
[8 - 9]	4.58	6.09	-0.40	3.11
[9 - 10]	6.67	5.49	1.07	2.86
[10 - 11]	7.56	5.47	1.37	2.53
[11 - 12]	8.35	5.46	1.74	2.58
[12 - 13]	6.85	4.81	0.92	2.42
[13 - 14]	5.57	3.80	0.01	2.00
All	4.96	6.15	-0.17	3.23

Measurement results for each wind bin

2. The measurement period involved in the static correction method, as mentioned above, is based on a finite period of time, oftentimes only 1 to 3 weeks. It is by no means guaranteed that this is adequate and will include the necessary data for all wind bins, or even include enough data in general, to calculate a representative average for the correction of the turbine.

3. The average yaw correction degree calculated from the measurement results is applied to all the wind bins, even though the wind industry is well aware this is a methodological fallacy.

THE PRACTICAL IMPLICATIONS OF THE STATIC METHOD

On a practical level, the static yaw correction method involves deploying the remote sensing equipment at the relevant wind turbine, then conducting the measurement campaign for a length of time, and lastly moving the remote sensing equipment to the next wind turbine in need of correction. This procedure is a practical necessity due to the costly nature of the remote sensing equipment. Additionally, further resources has to be spend on both the installation and deinstallation of the sensing equipment. Furthermore, the maintenance of the sensing equipment will have to be carried out by the manufacturers where the equipment will be unavailable to the owner. Alternatively, other companies have chosen to provide the correction as a service, which negates most of the above-mentioned problems; on the downside, the same companies will generally charge the client according to the calculated increase in AEP, which in the end might be more costly for the client than simply owning the system.

THE WINDAR PHOTONICS SOLUTION

As a solution to the above issues, Windar Photonics has developed a dynamic yaw misalignment solution that ensures a continuous improvement to the AEP through its continuous measurements - hour by hour and year by year. Taking account of the different degrees of yaw misalignment for each wind bin, the system is not only able to more accurately correct the yaw misalignment, but also to minimize potentially damaging loads affecting the turbine - while at the same time being cost-efficient enough to own and install on every turbine.

“Right from the beginning, it has been the intention to develop a product that will provide our customers with a reliable return of investment and ensure an appreciable stream of revenue many years in the future,” explains Thomas Dyhr, Technical Project Director at Windar Photonics.

DYNAMIC YAW MISALIGNMENT CORRECTION

The problems inherent to static yaw misalignment correction can be alleviated by ensuring that the turbine is corrected according to actual and continuous measurements – in other words, dynamic correction. The Windar Photonics LiDAR optimization solution, in contrast to the prevalent industry standards, is able to dynamically correct the yaw misalignment of the turbine by utilizing the continuous measurements from the LiDAR sensor.

By utilizing a dynamic mode of yaw-alignment correction, the turbine is continuously corrected according to the actual meteorological conditions and not just the offset from a given measurement campaign.

CONTROL INTEGRATION WITH THE WINDTIMIZER™ FOR DYNAMIC YAW MISALIGNMENT CORRECTION

To facilitate a dynamic and continuous yaw misalignment correction, it is required that the Windar Photonics LiDAR optimization solution is integrated with the wind turbine controller. The WindTIMIZER™ is Windar Photonics’ elegant solution to facilitate the integration between the LiDAR system and the wind turbine controller, where the WindTIMIZER™ functions as a mediator between the controller and the LiDAR system without the necessity of actually altering anything in the wind turbine controller at all. The WindTIMIZER™ likewise receives data from the legacy anemometry to further enhance the reliability and ensure the safety chain of the wind turbine is untouched.

Static vs. Dynamic

STATIC

- › Based on a calculated mean
- › No integration w. turbine controller
- › Requires constant calibration
- › Ongoing costs for re-calibration
- › More stoppage days for calibration
- › Lesser degree of AEP increase

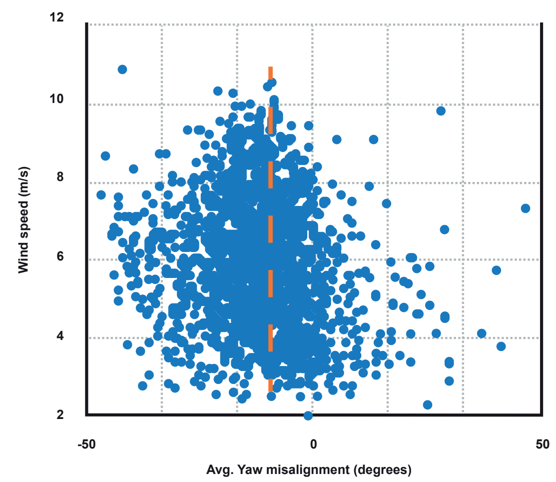
VS.

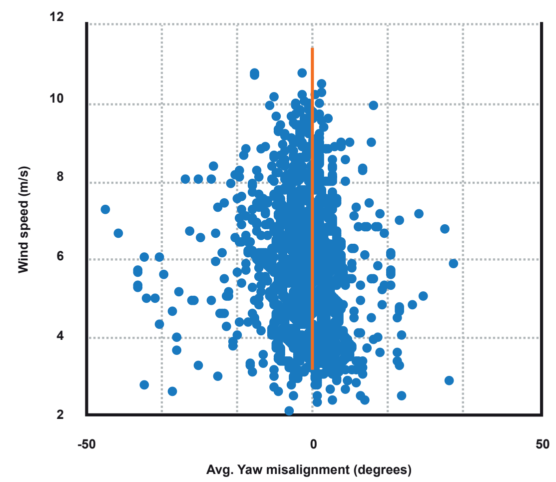
DYNAMIC

- › Based on continuous measurements
- › Integration w. turbine controller
- › No manual calibration required
- › Only requires normal maintenance
- › Fewer stoppage days
- › Greater degree of AEP increase

EFFECTS AND RESULTS

The very tangible effects of dynamically correcting yaw misalignment is a turbine that always has the optimal yaw-position and hence produces more energy and is less subject to damaging loads. Below you will find two diagrams showing a turbine before and after the application of dynamic yaw-correction:





The plot diagram displays the measurement results from one of the most recent installations of the Windar Photonics optimization system. These results are from the preliminary measurement campaign, where the yaw misalignment is measured before it is corrected. Our measurements showed that the turbine had a mean misalignment of 11.26 deg., which can be translated into a theoretical AEP increase of 4.1% when the turbine is being corrected for yaw-misalignment.