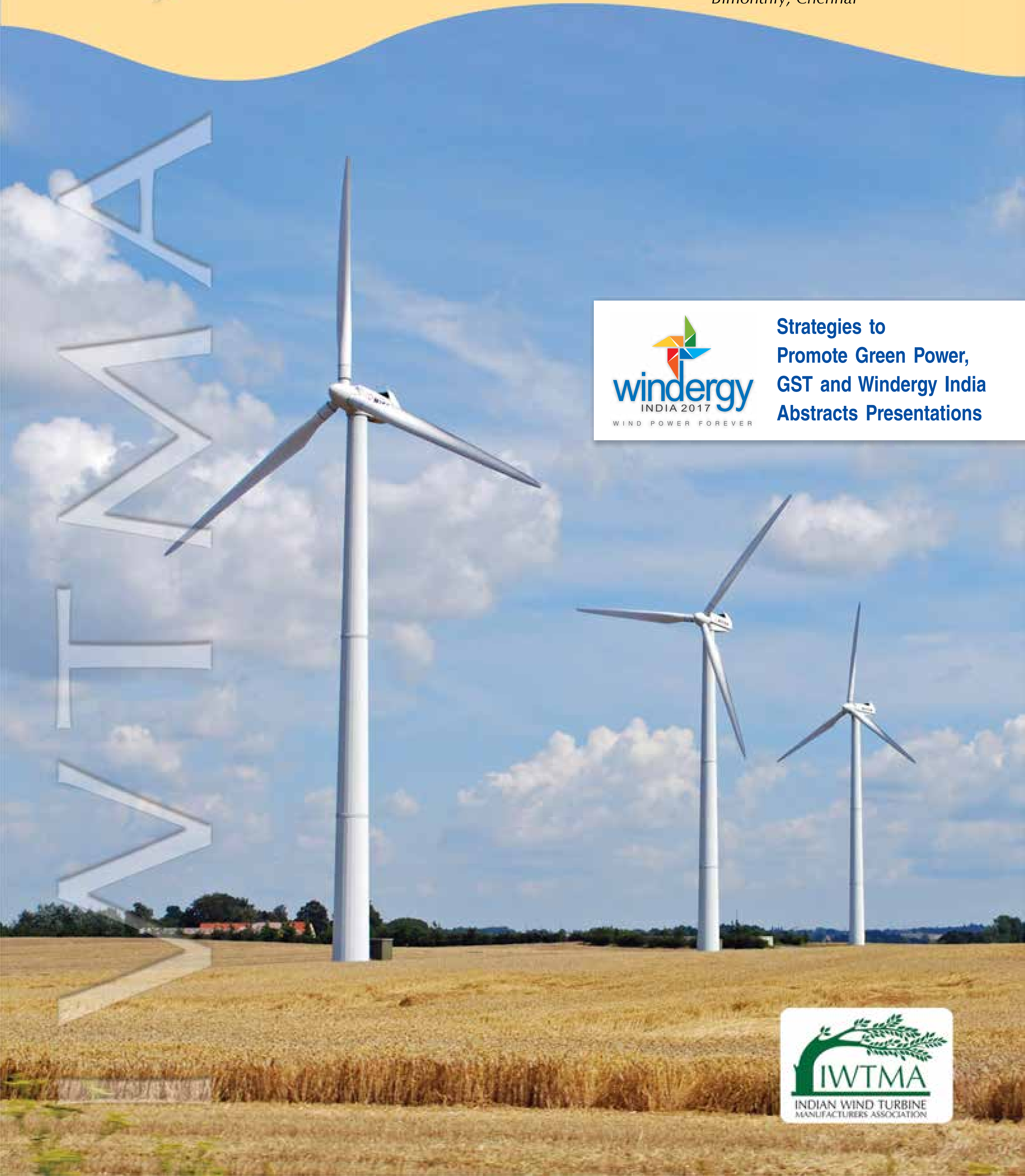
Indian Wind Power

Volume: 3 Issue: 3 August - September 2017 ₹ 10/-
Bimonthly, Chennai

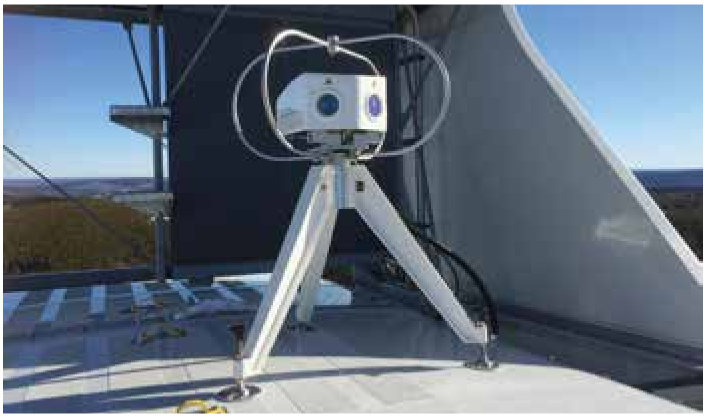


Increasing AEP with the Nacelle-Mounted WindEYE™ LiDAR

Presenter:
Martin Rambusch
Chief Commercial Officer, Windar Photonics

Author:
Rune Kvolsgaard
Marketing Manager, Windar Photonics

(This presentation has received the Best Paper Award during "Windergy India 2017" - Abstract Presentations)

LiDAR Sensor Installed on Wind Turbine Nacelle

Introduction to Windar Photonics LiDAR Technoloy

Wind turbine misalignment is a common problem in the wind energy industry, and well known amongst IPPs, wind turbine OEMs, and suppliers of optimisation equipments for the wind energy industry. Yaw misalignment occurs when the turbine is not aligned with the oncoming wind, resulting in less energy production and increased load cycles on the turbine, which in effect means more wear and tear on the mechanical parts of the wind turbine.

Wind turbines are equipped with wind vane anemometry, which is usually located at the rear part of the nacelle roof. The problem with the standard anemometry is that the measurements are performed after the wind has passed the rotor, which at best provides a distorted measurement of the wind direction, effectively resulting in a turbine that is constantly being slightly misaligned with the direction of the wind.

Windar Photonics' (Windar) nacelle-mounted LiDAR, the WindEYE™, circumvents the problems described above by measuring the wind direction and wind speed 80m in front of the turbine. The WindEYE™LiDAR is based on a continuous wave laser with a fixed length of 80m that measures via two beams in an angle of 60° with a sampling rate of 1Hz. By utilizing the Doppler Effect, the WindEYE™ is able to measure the movement of aerosols in the air from which the wind direction and wind speed can be calculated. By integrating the WindEYE™ with the wind turbines control system, the wind turbine will receive wind speed and wind directions 80m before the wind reaches the rotor, leaving the turbine ample time to adjust to any changes in wind direction.

The WindEYE™ was verified by DTU (The Technical University of Denmark) in 2015 ("***An evaluation of the WindEye Wind LiDAR***", DTU Wind Energy E-0078, Ebba Dellwik, Mikael Sjöholm and Jakob Mann). Currently, the WindEYE™ LiDAR is being evaluated by NIWE (National Institute of Wind Energy). NIWE is operating under an R&D mandate to assist the Indian wind industry by evaluating solutions that can improve wind turbine performance; the Windar LiDAR is being evaluated by NIWE concerning the LiDAR's potential for impacting AEP and the lifetime of wind turbines.

Windar has performed more than 200 commercial projects, where the LiDAR has been installed on various turbine models in substantially different climates, ranging from Canada to India. The results from some of those installations are presented in the section "Results" of this article.

Methodology and Optimisation Process

The WindEYE™ LiDAR measures wind speed and wind direction by tracking the movement of aerosols in the air, as described in the introduction. A measurement campaign is initiated as a first step of the optimisation process, with the purpose of collecting a body of measurement data that is applicable for optimising the turbine. The campaign consists of two periods or phases:

1. **Initial Measurement Campaign**

   Initially, the LiDAR is connected as a secondary instrument that only gathers wind data, while the turbine is still controlled by the legacy anemometry. The duration of the measurement campaign is usually 4 weeks, but the measurement campaign is never concluded before sufficient data has been collected.

2. **Second Period – Wind Turbine Control Integration**

Before the second measurement period, the LiDAR is integrated with the control system, which makes the LiDAR the primary sensor concerning wind direction, enabling the turbine's yawing to be based on the real-time LiDAR measurements. The purpose of the second measurement period is to ensure that the integration between the LiDAR and the control system is operating as intended vis-à-vis the yaw functionality, and to gather additional data to validate the results of the optimisation process.

Data Handling

A significant part of the optimisation process involves analyzing the data gathered during the measurement periods; the basic methodological steps of the data handling is outlined below.

The measurement data needs to be filtered for any measurement distortion (such as blades blocking the LiDAR's beams) and is normalized according to the IEC-61400-12-1 standard, before the data can be used for calculation. After the filtration, the measurement data is divided into segments, or bins, based on the wind speed (according to the IEC-61400-12-1 standard), which gives a clear indication of the degree of misalignment in relation to wind speeds. Afterwards, the mean and absolute mean values are calculated per wind bin.

AEP Estimation

To calculate the estimated AEP increase, the following formulas are used:

1: Cos^2

- $$AEP_{gain} = \sum_{i=cut_{in}}^{i=Rated} \left(\left(\frac{\cos \phi'^2}{\cos \phi^2} \right) - 1 \right) + \left(\left(\frac{\cos |\phi'|^2}{\cos |\phi|^2} \right) - 1 \right) * \mathrm{PDF(i)} * 100$$

2: Cos^3

- $$AEP_{gain} = \sum_{i=cut_{in}}^{i=Rated} \left(\left(\frac{\cos \phi'^3}{\cos \phi^3} \right) - 1 \right) + \left(\left(\frac{\cos |\phi'|^3}{\cos |\phi|^3} \right) - 1 \right) * \mathrm{PDF(i)} * 100$$

The final AEP estimation is an average of the results of the above two methods. By using both methods, an estimate is reached that corresponds well with the actual increases to energy production.

Sample Results from Real-Life Campaigns

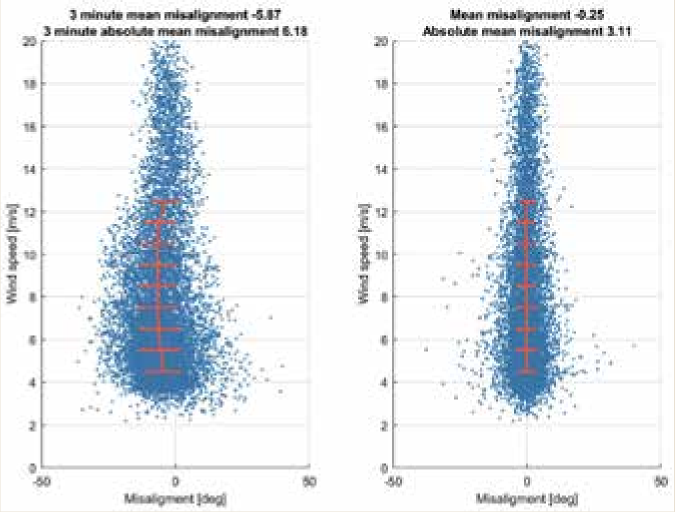
The results that Windar has accumulated through optimisation projects and measurement campaigns have primarily been performed in constellation with commercial partners, such as independent power producers and wind turbine OEMs. In the following paragraphs, the results from two optimisation

Turbine 1 Results

Wind Turbine model	Vestas V90 - 2MW
Campaign start	March 8, 2016
Campaign stop	Ongoing
Time period analyzed	March8-May18,2016
Mean yaw error	-5.87°
Mean abs. yaw error	6.18°
Mean yaw error after realigment	-0.25°
Mean abs. yaw error after realigment	3.11°
AEP gain	2.05%

Wind speed interval [m/s]	Observed misalignment		Misalignment after correction	
	Mean	Absolute	Mean	Absolute
[4 - 5]	-4.24	6.15	0.03	3.04
[5 - 6]	-5.57	7.00	-0.30	3.58
[6 - 7]	-6.14	6.97	-0.28	3.27
[7 - 8]	-6.81	7.01	-0.10	3.38
[8 - 9]	-6.53	6.12	-0.50	3.38
[9 - 10]	-6.61	6.54	-0.31	3.15
[10 - 11]	-7.05	5.89	-0.35	2.99
[11 - 12]	-5.97	5.23	-0.47	2.62
[12 - 13]	-3.93	4.71	0.03	2.60
All	-5.87	6.18	-0.25	3.11

Turbine 1 - Data Per Wind Speed Interval



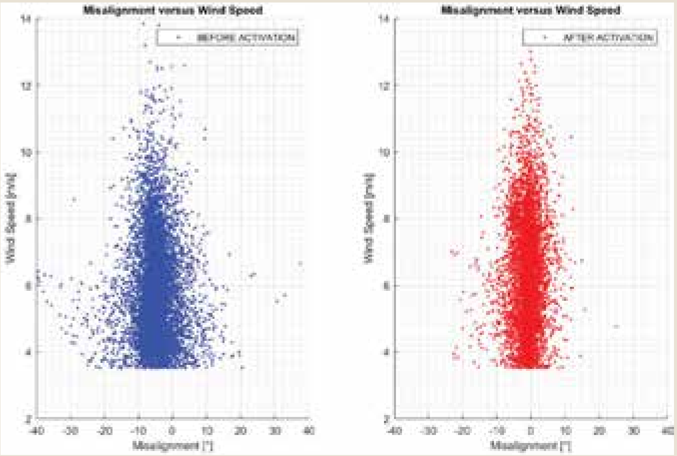
Turbine 1: Estimated Yaw Misalignment as a Function of Wind Speed

Turbine 2 Results

Wind Turbine model	GE 1.5 MW
Time period analyzed	01/08/16 - 05/10/16
WindTIMIZER Activation	13/09/16
Median yaw error	-5.23°
Median absolute yaw error	3.24°
Median yawerror with WindTIMIZER	-0.76°
Median absolute yaw error with WindTIMIZER	2.23°
AEP gain as is	1.0-1.5 %
AEP gain with offset in passive mode	1.2-1.7 %

Wind speed	Observed misalignment		Misalignment after correction	
[m/s]	Median	Absolute median	Median	Absolute median
3.5	-3.99	3.06	-0.78	0.99
4	-4.28	3.18	-0.73	1.41
4.5	-4.86	2.91	-0.79	1.32
5	-5.32	2.64	-0.59	1.4
5.5	-5.33	2.11	-0.52	1.31
6	-4.93	1.98	-0.68	1.17
6.5	-4.69	1.73	-0.54	1.16
7	-4.97	1.6	-0.65	1.28
7.5	-4.98	1.52	-0.59	1.28
8	-5.22	1.72	-1.2	1.97
8.5	-5.43	1.92	-1.06	1.98
9	-5.87	2.32	-0.82	2.18
9.5	-5.74	2.26	-0.18	1.72
10	-6.06	2.2	-1.3	1.59
10.5	-6.78	2.34	-0.89	2.18
All	-5.23	2.23	-0.76	1.53

Turbine 2 - Data Per Wind Speed Interval



Turbine 2: Estimated Yaw Misalignment as a Function of Wind Speed

campaigns on two different turbine platforms are presented. Be aware that the results from one turbine model is of course not representative for all installations on that particular turbine model, as the results are more causally dependent on the meteorological conditions on site, nearby topography, and the turbine's control system settings, than the turbine model.

In general, Windar has seen increases to AEP by 1-4%, which averages out to about 1.5% across 200 installations. As such, the below results are not representative for all 200 installations, but have been chosen with the intention of displaying the variability of the results derived from the optimisation process across turbine platforms and climates.

AEP Improvements and Cost-Efficient Wind Turbine Optimisation

From the verification report performed by DTU, it is clear that the LiDAR is performing as intended with a high degree of correlation with the measurements done by sonic anemometers mounted on a met mast. The commercial projects further serves as a utilitarian proof of concept, as Windar has succeeded in optimising hundreds of turbines in a commercial context so far.

Based on the above results, it is clear that the Windar LiDAR can reduce yaw-misalignment, which is especially evident in relation to "Turbine 1" and "Turbine 2". "Turbine 2" was initially subject to a lesser degree of yaw-misalignment, which is likewise reflected in the results, as there simply was less yaw-misalignment to correct in the first place.

The final optimisation results vis-à-vis AEP increases varies between 2.05% on "Turbine 1" and 1.2-1.7% on "Turbine 2", which in general are appreciable increases to the energy production from the assets. Especially "Turbine 1" benefited tremendously from the optimisation, as the AEP was increased by more than 2%.

We hope the present article has helped to illuminate how Windar's LiDARs can be used to correct yaw misalignment and increase the annual energy production from assets that suffer from yaw misalignment. However, yaw optimisation is not the only way that the data from the LiDAR can be utilised; the data can likewise be used to detect wake situations, turbulence, gusts, and wind shear. Sadly, it is not within the scope of this small article to describe the theoretical implications and methodology of those detection technologies, but you are always more than welcome to get in touch with Windar Photonics if you would like to know more about the various applications of the WindEYE™ LiDAR in relation to wind turbine optimisation.

www.windarphotonics.com