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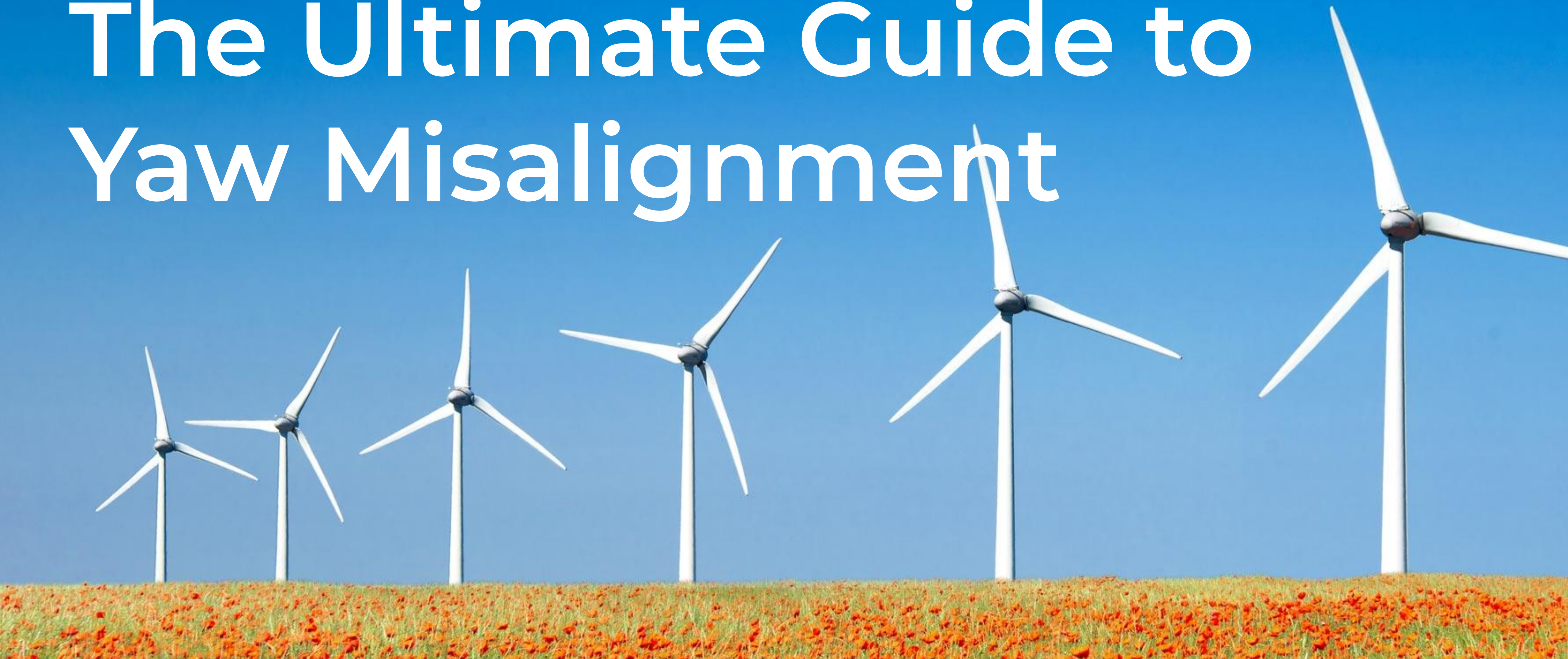
The Ultimate Guide to Yaw Misalignment



Introduction

Yaw misalignment is a common issue that affects wind projects all around the world.

Despite high visibility on the issue, we find wind plant owners continue to lose revenue due to this issue.

We have put together this comprehensive guide to help owners gain a better understanding of yaw misalignment, including:

- What it is
- Why it matters
- What causes it
- Methods for detection
- Methods for correction

We hope that this will be a helpful resource for you on your optimization journey.

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What is Yaw Misalignment

Yaw misalignment is a phenomenon in which wind turbines do not face directly into the wind and cannot generate optimal power.

There are two main types of yaw misalignment: dynamic and static. Left unattended, yaw misalignment can impact your turbines' AEP and hence your revenues.

This section will explain how turbines typically account for changes in wind direction and the types of yaw misalignment they may experience.

How Turbines Adjust to Changes in Wind Direction

Any measured difference between wind direction and nacelle position is called yaw error (Figure 1).

When the turbine is pointing directly into the wind, yaw error should measure 0°.

When yaw error is too large for too long, the turbine controller signals the yaw motors to move the nacelle back to 0°, realigning it with the wind.

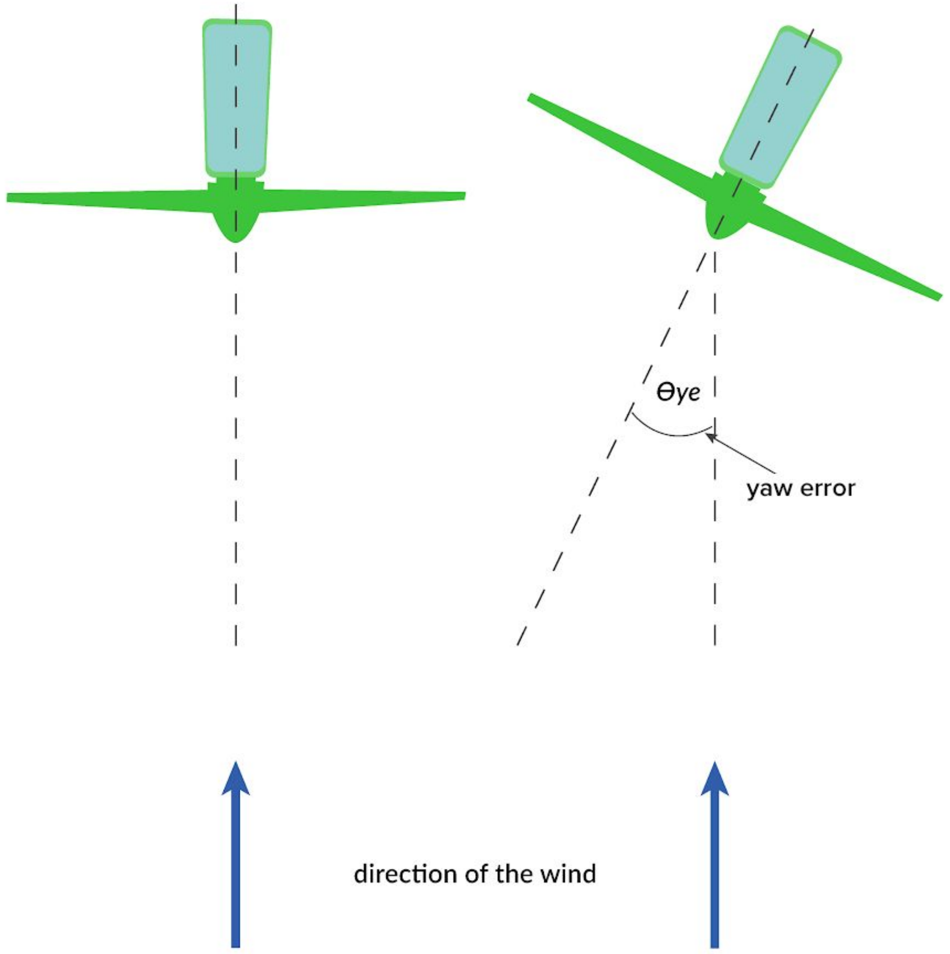

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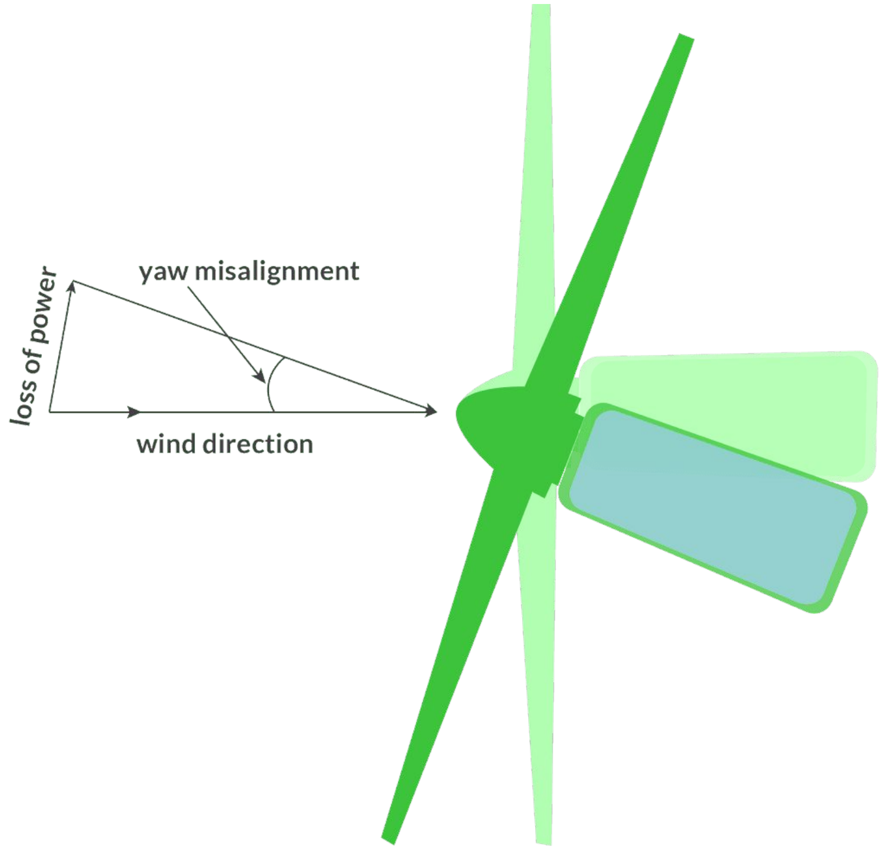
FIGURE 2

Static Yaw Misalignment

Static yaw misalignment occurs when measured yaw error is 0°, but the turbine is not pointing directly into the wind.

The turbine cannot see the difference between measurement and reality, making the misalignment invisible to the turbine controller (Figure 2).

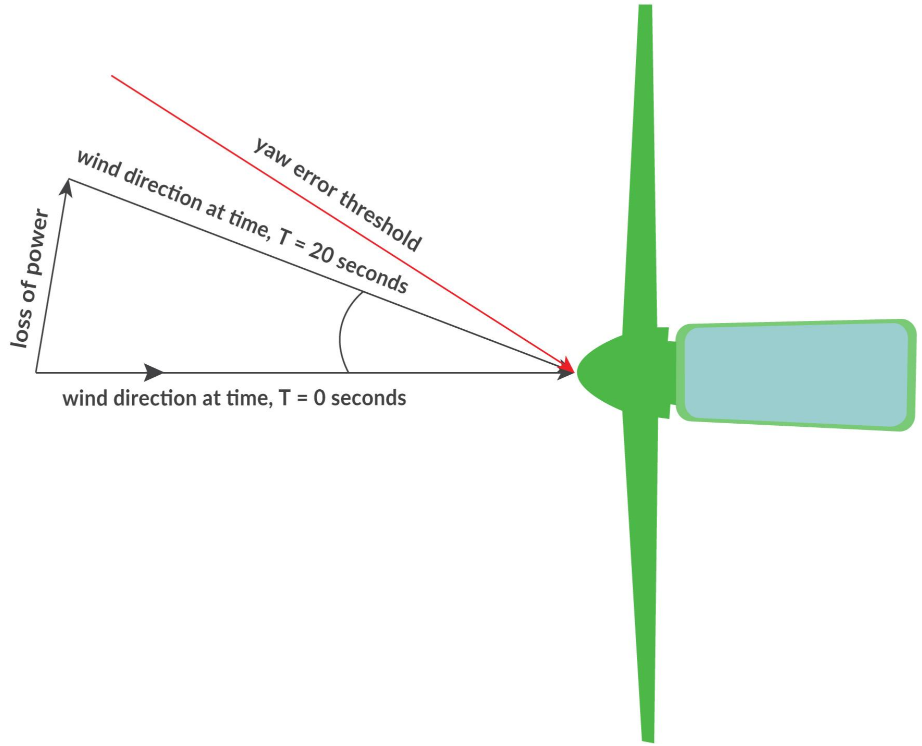
This type of misalignment can have negative effects on your wind project.



measurement	(light green)	yaw error value - 0°
actual	(green)	static yaw misalignment

Dynamic Yaw Misalignment

FIGURE 3



Controllers do not immediately react to changing wind direction. They wait for the yaw error to exceed a specific threshold for a given period of time before signaling the nacelle to move (Figure 3).

Dynamic yaw misalignment occurs when the wind direction
has changed, but the nacelle has not yet moved.

Dynamic yaw misalignment can be optimized, but they cannot be eliminated because wind is constantly changing direction. In most cases it has a smaller impact on performance than static yaw misalignment, because it is corrected by the yaw controller.

Why Yaw Misalignment Matters

Your turbines produce the most energy when the rotor is perpendicular to the wind direction.

Static yaw misalignment compromises your turbines' performance by lowering AEP and increasing loads leading to decreased operating margins.

Power Output

Power is only generated by wind flowing perpendicular to the rotor. Figure 4 shows that static yaw misalignment leads to loss of power, specifically in Region 2 and 2.5 of the power curve.

Figure 5 shows an example:

- **Red line:** The power curve shows the degradation caused by static yaw misalignment
- **Green line:** When the misalignment was corrected, the power curve improved

FIGURE 4

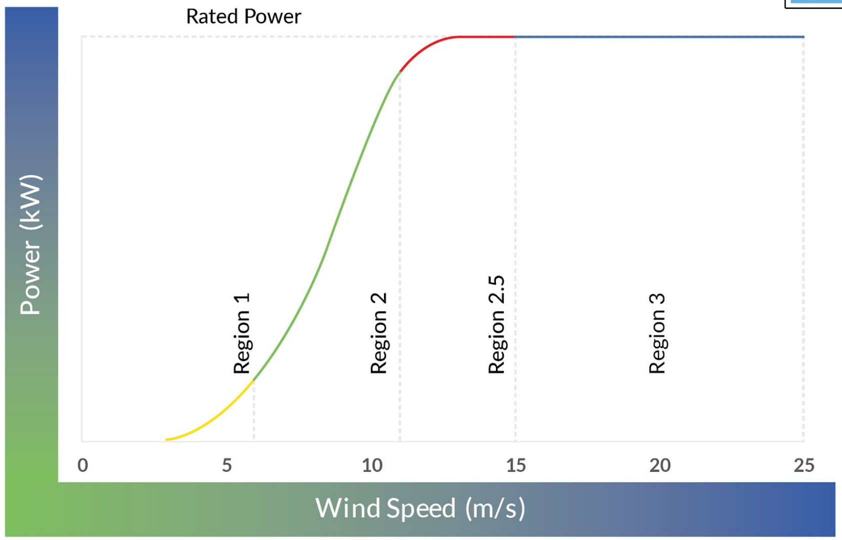
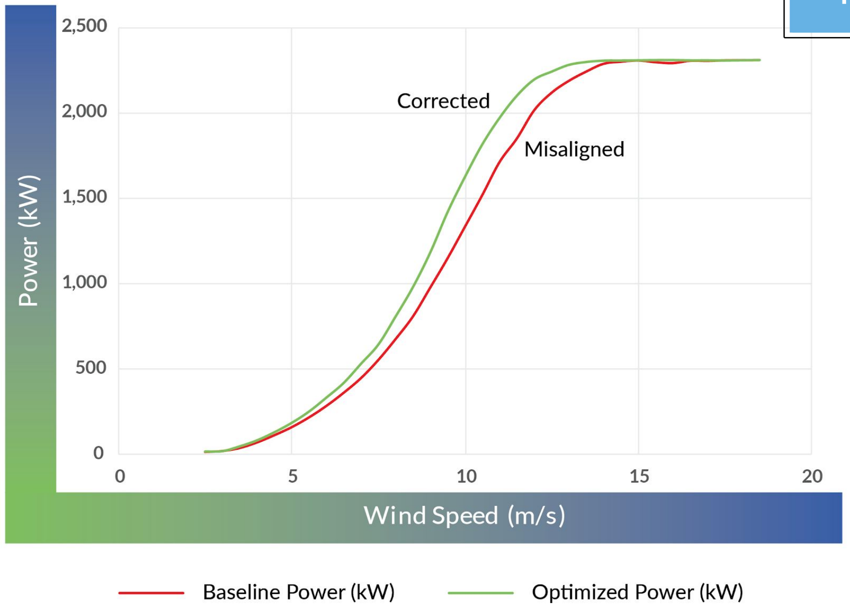
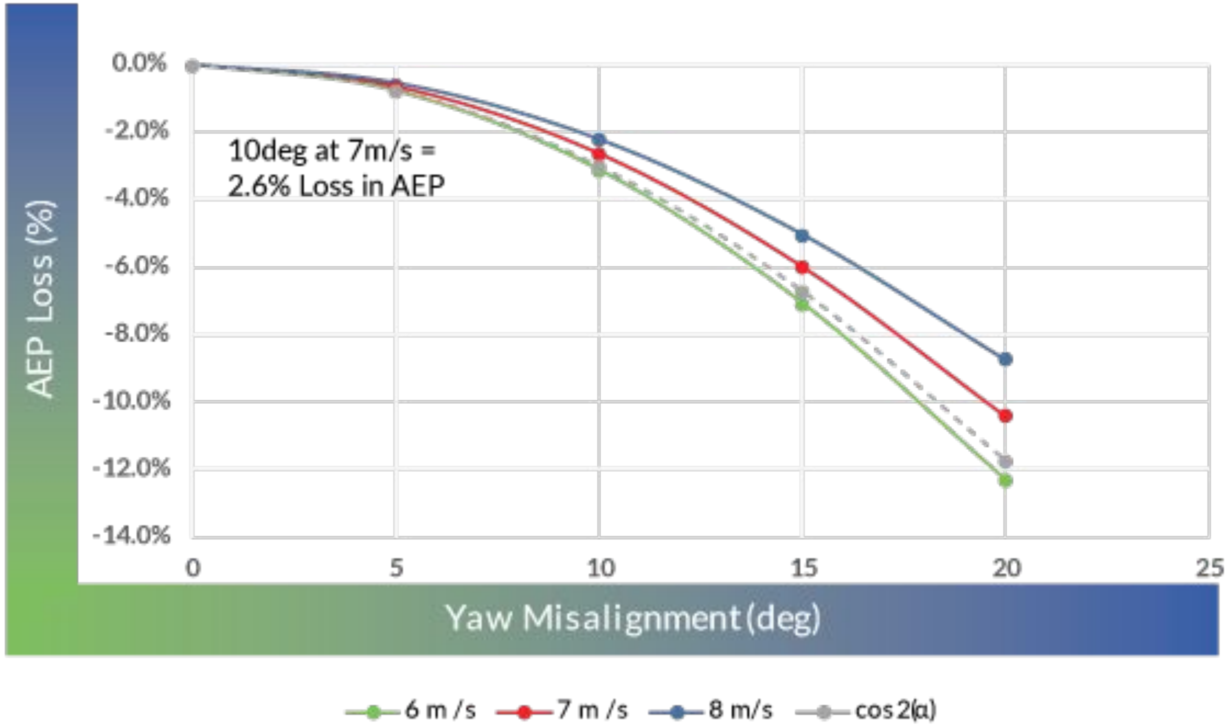


FIGURE 5



Power Output

FIGURE 6



Loss in output for different degrees of yaw misalignment for sites with different average wind speeds.

The bigger your misalignment, the lower your power output.

Our analysis has shown that loss of power typically varies with the square of the cos(θ).

- 4° yaw misalignment leads to a 0.5% loss in output
- 10° misalignment can lead to a 2.6% loss in power output

Sites with lower wind speed tend to show a greater percentage improvement in output because turbines spend more time in region 2 (Figure 6).

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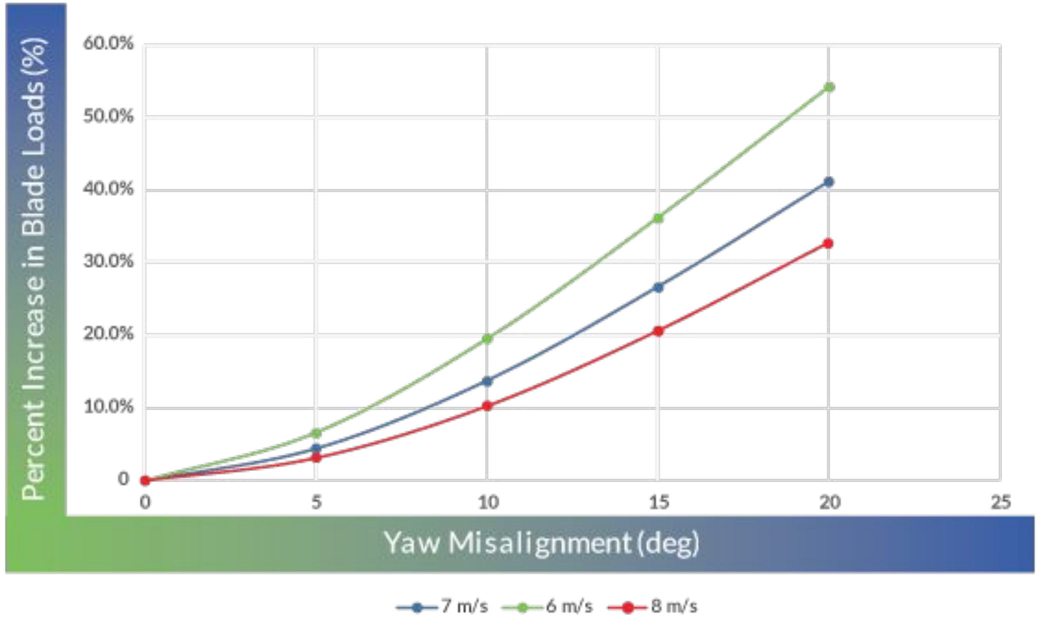
Turbine Loads

Static yaw misalignment results in different inflow angles for positional blade loading and creates a 1P for each blade, resulting in a 3P net effect.

Turbines are designed to withstand small yaw misalignment, but as yaw error increases, so does loading (Figure 7).

- The effect only becomes visible on turbines when yaw misalignment is very high (10+)
- According to some models, an 8° degree yaw misalignment, could decrease the expected lifetime of the turbine yaw system by 6 years

FIGURE 7



Yaw misalignment and blade loads for different wind speeds

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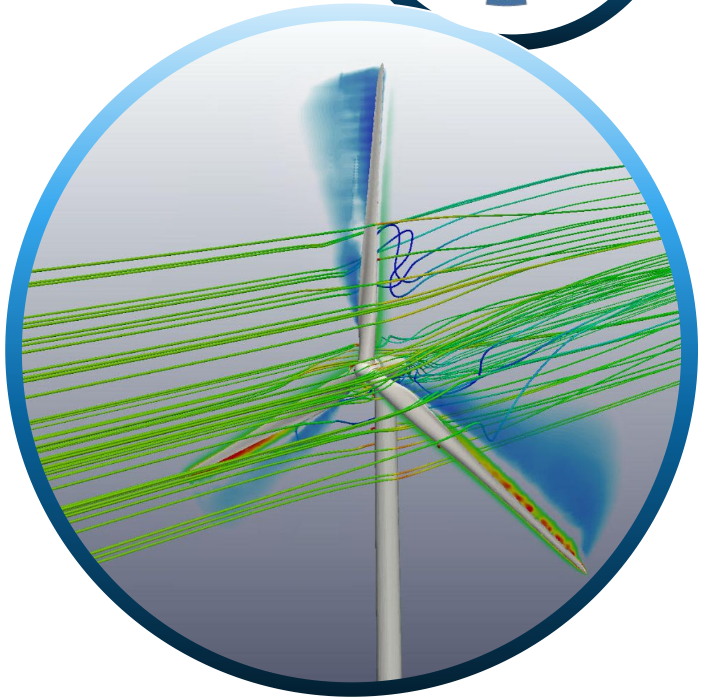
What Causes Static Yaw Misalignment?

Although static yaw misalignment is invisible to the turbine controller, its effects are painfully obvious to the wind plant operator. For this reason, it's critical to identify the underlying causes of the misalignment.

Working with numerous wind projects with different turbine models, we have found that this problem doesn't have a single or even a dominant cause.

Static yaw misalignment can arise from hardware or software issues.

Hardware Issues



Sometimes, static yaw misalignment is caused by your hardware.

Common physical issues that cause static yaw misalignment include:

Physical misalignment between nacelle anemometer and nacelle neutral axis.

This issue may occur if the anemometer is not aligned correctly during installation, or it has been moved, adjusted, or bumped during turbine service or repairs.

Change in wind direction due to wind flow through the rotor plane.

Wind flow across the rotor plane changes the observed wind direction downwind of the rotor. If this is not accounted for, it will lead to misalignment.

Software Issues

Even when there are no hardware issues present, your software issues may
cause static yaw misalignment. Common software causes include:

Incorrect nacelle transfer function (NTF).
Some turbines use a nacelle transfer function (NTF) to account for wind flow across the rotor. Typically, a single NTF is used for all turbines on a farm. If the NTF is incorrect or out of calibration, it can lead to yaw misalignment.

Incorrect yaw offset parameter.
Some wind plants apply a generic offset for all turbines of a particular model, usually based on a LiDAR campaign on a few turbines. While this has the potential of addressing part of the problem, it can make the problem worse for some turbines, if their misalignment is different.

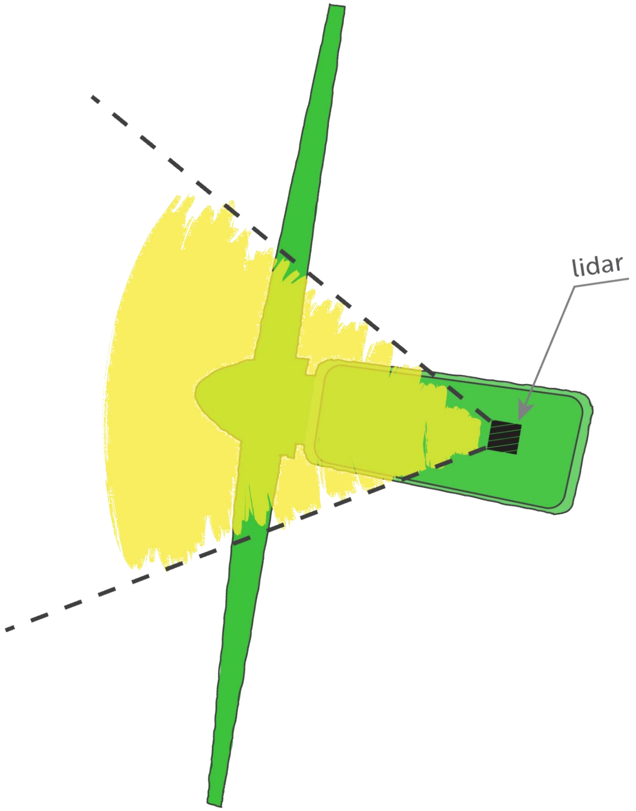
Detecting Yaw Misalignment

You know yaw misalignment can have detrimental effects on your wind project, but you need a reliable way to detect the issue.

In this section, you will find an overview of the standard detection solutions available, ranging from expensive new hardware to software solutions that utilize your existing SCADA data.

LiDAR

Light detection and ranging (LiDAR) systems can be mounted on top of the nacelle to gauge wind direction in front of the rotor. LiDAR uses laser beams directed upwind of the turbine to determine
wind speed and yaw misalignment.



Pros

- Continuous monitoring of wind speed and direction

Cons

- Very expensive and must be moved from turbine to turbine
- Results from a few turbines cannot be applied universally
- Must be aligned perfectly with the nacelle
- Equipment must be sent for periodic maintenance
- Good for R&D, but not as a scalable solution

Spinner Anemometer

Source: Romo Wind

Traditional anemometers are mounted on the nacelle behind the rotor blades, which distort the wind flow. For more effective detection, a spinner anemometer can be mounted on the spinner in front of the blades.

Pros

- Unaffected by flow of wind across the rotor
- Permanently installed on turbine
- Detects static yaw misalignment in real-time

Cons

- Expensive: Each turbine needs its own spinner anemometer
- The spinner needs to be calibrated for each turbine type
- Calibration is often inaccurate

Met Tower

A nearby met tower can be used to calculate wind direction. Met towers are traditionally installed when siting wind projects, so you likely already have one. However, the method is outdated and, ultimately, costly.

Pros

- Could be already Installed on the project

Cons

- Wind direction from met towers is accurate within +/-5°
- Only works for turbines in flat topography within 2-5 rotor diameters of the met towers
- Sensors on a met tower may not be calibrated

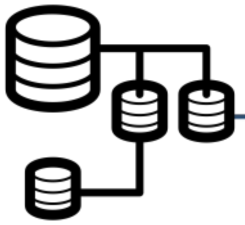
SCADA Data-Based Detection Solutions

A data-based approach has recently emerged as an alternative to the expensive, difficult to install, and often unreliable hardware-based detection systems.

Data-based solutions **require no additional hardware** as they use the turbine's own SCADA data to estimate and correct yaw misalignment.

Pros

- No downtime or additional equipment
- Ability to scale the number of turbines being analyzed
- Results available within a few months
- Provides continuous monitoring



Cons

- Requires owner to have access to SCADA data

Find Your Ideal Optimization Solution

Wind is complex. Accurate analysis of the existing SCADA data requires a combination of physics-based models and machine learning techniques, all while taking into account differences in turbine models. It's important to find a partner with demonstrated expertise to help you optimize your wind project effectively.

Earlier this year, WindESCo helped UPC Renewables **increase AEP by 2% by using existing SCADA data to correct yaw misalignment.** The entire process is documented in a detailed case study. **Download your free copy** to learn more.

DOWNLOAD NOW

Correcting Yaw Misalignment

Now that you have a full understanding of yaw misalignment, **it's time to discuss possible correction methods.**

As you consider your options, **take your existing Operations and Maintenance (O&M) agreements into account.** If the OEM or a third party is responsible for O&M of your wind project, you will need to work closely with them to implement changes safely, efficiently, and without violating your contracts.

There are two primary methods to correct static yaw misalignment: **changing turbine parameters** and **physically adjusting** the nacelle anemometer.

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Turbine Parameter Adjustments

You may be able to solve static yaw misalignment by changing turbine parameters.

- **Constant value.** Adjusting this single parameter to compensate for misalignment allows you to align the nacelle position accurately.
- **Wind speed-dependent table.** Calculate the observed yaw misalignment for each wind speed and adjust each value in the table accordingly.

It's crucial to **adjust values correctly.** Otherwise, you risk causing a more severe misalignment. Also note that turbines vary greatly: a +ve sign for yaw error for one OEM could be -ve another OEM.

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Mechanical Adjustments

If software adjustments cannot address your yaw misalignment, you may need to adjust the components physically. **This is the least efficient method of correcting misalignment**.

Every anemometer has a unique mounting configuration. A technician will have to scale each turbine and make individual adjustments to each anemometer. This approach **requires more time and energy** than turbine parameter adjustments.

If you decide to correct yaw misalignment with physical adjustments, you will need to work closely with your operations and maintenance team.

Thank you for reading The Ultimate Guide to Yaw Misalignment. Before you begin to increase revenue and decrease maintenance costs by detecting and correcting static yaw misalignment, there’s one more thing we want you to know: WindESCo experts are here to help you.

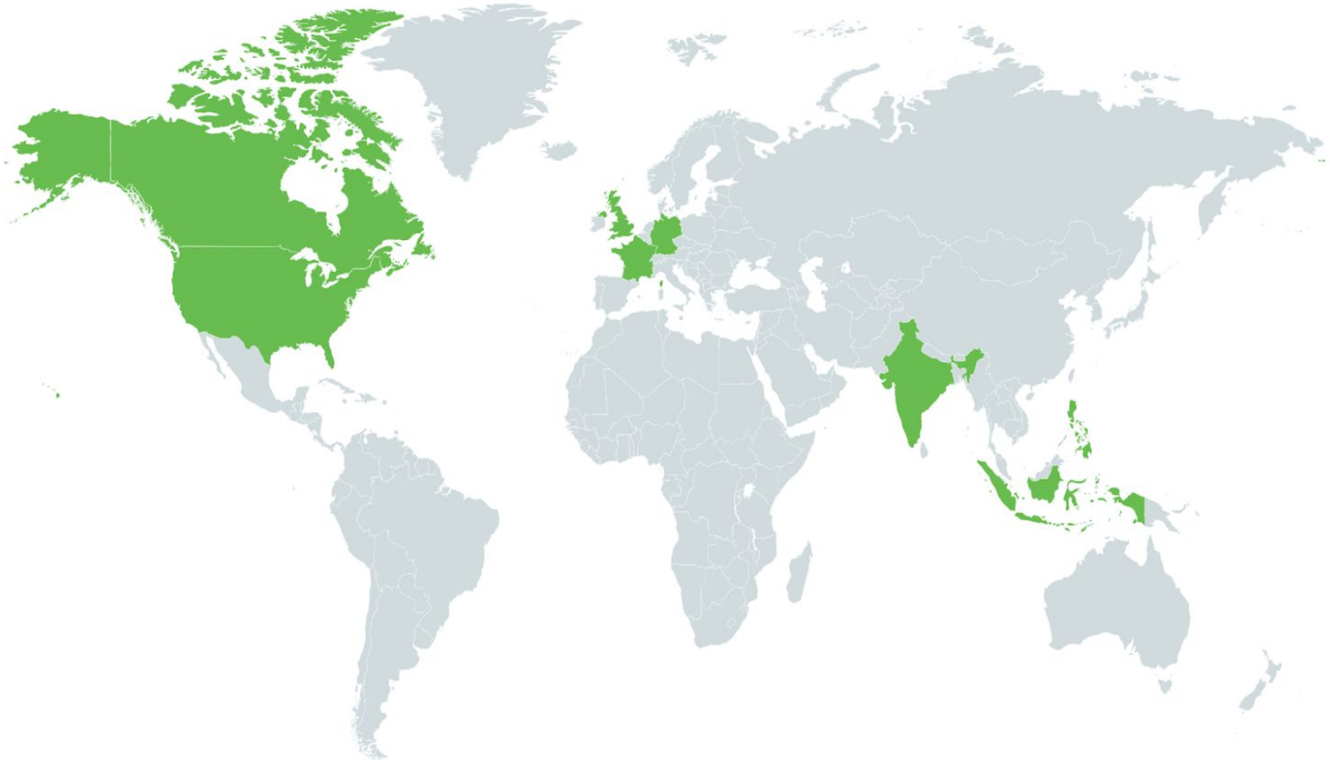
If you need additional clarification, more information, or help with applying this knowledge to your wind project’s unique requirements, schedule a consultation. Our team has years of experience and demonstrated success in helping wind plants correct static yaw misalignment. We are happy to help you explore your options. No strings attached.

REQUEST A FREE CONSULTATION

8
Countries

3
Continents

8
OEMs



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