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Automated rotor imbalance monitoring using high-frequency SCADA data

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Abstract

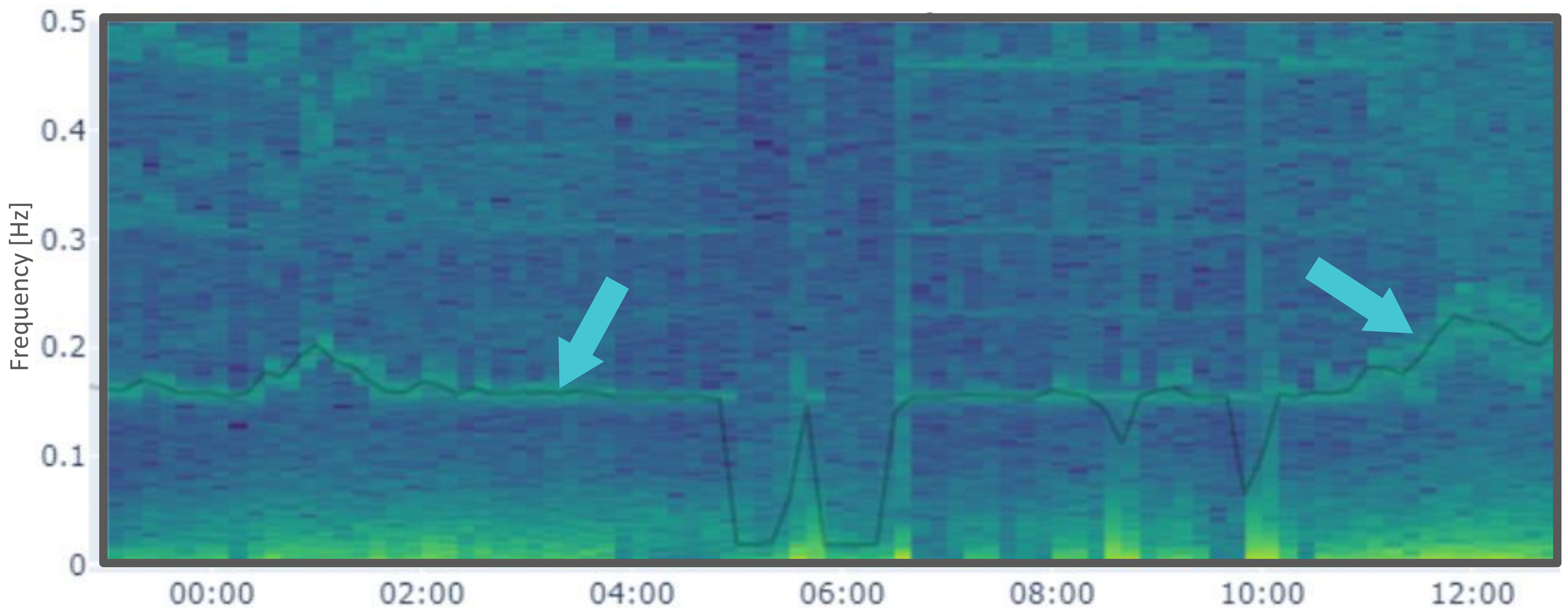
Wind turbines generate a large volume of operational data. In the industry, the standard practice for collecting and analyzing SCADA has been to aggregate data at 10-minute intervals. While manufacturers typically collect data at a higher frequency, this level of detail has not always been made available to the end users, such as wind farm owners and asset managers.

In the past the 10-minute data aggregation interval provided good a balance between data volume and detail, but with the increasing focus on data-driven decision making and the availability of new technologies and tools for data analysis and storage**, there is a growing demand for access to higher frequency datasets**. With access to data analytics using higher frequencies, wind turbine owners and asset managers will gain deeper insights into turbine performance, identify potential issues more quickly, and ultimately optimize operations.

In this study, we investigate **the harmonic analysis of the high-frequency rotor speed signal to detect rotor imbalance**, with a focus on ensuring that the final metric is both usable and compatible with current asset management practices. We also **present real-life examples,** where the new metric provided valuable insights for asset managers on a day-to-day basis.

Creating an imbalance metric

The **spectral analysis of high-frequency rotor speed signals** is a well-established method for revealing information on **the state of imbalance in a wind turbine[1, 2].** This may be caused by mass imbalance on the rotor blade structure (e.g., an uneven mass distribution during manufacturing or due to gradual water ingress) or aerodynamic imbalance caused by a pitch offsets leading to an uneven torque intake on the blades.



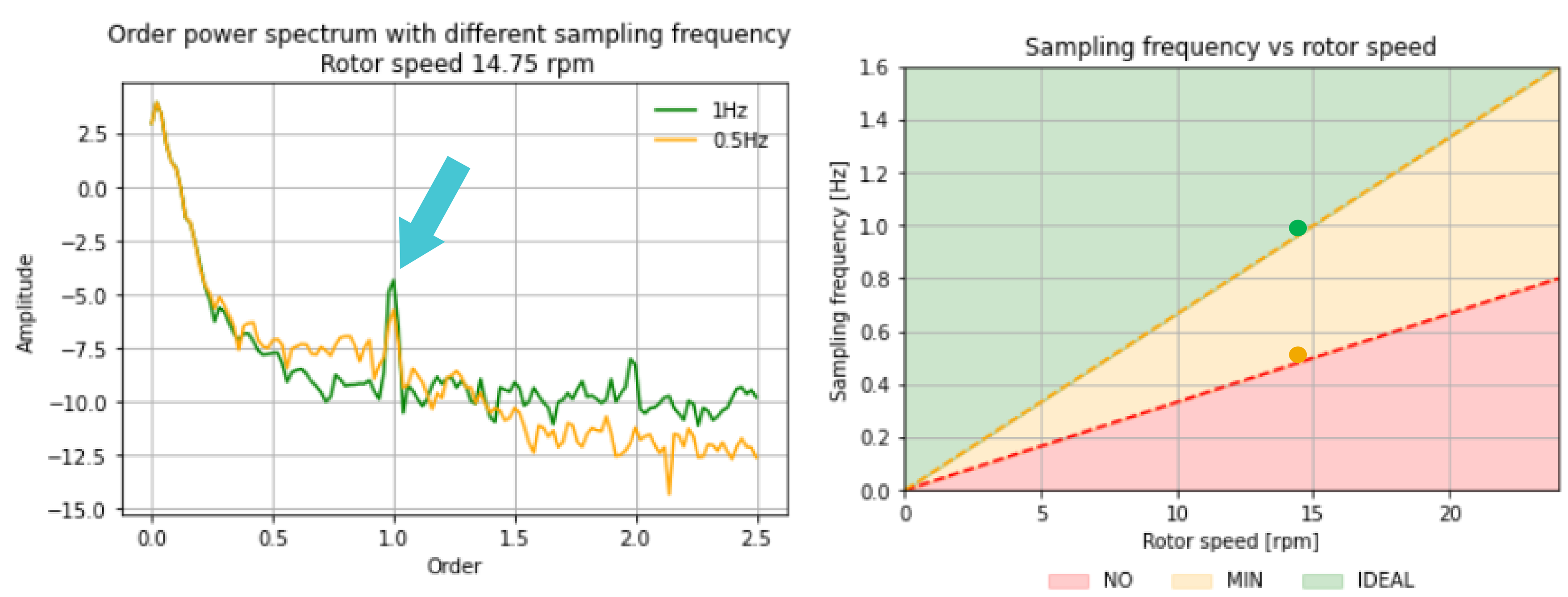
Spectrogram illustrating the presence of harmonics in the high-frequency rotor speed signal. Rotor Speed was overlayed to visualize the direct proportionality. (1 turbine - 12hours)

When imbalanced, the rotor will vibrate at a frequency directly proportional to its speed of rotation, the new metric will therefore rely on a standard spectral analysis:

1. We measure the **1p component** in the rotor speed using Fast Fourier Transform (**FFT**), which corresponds to oscillations occurring once per full rotation of the rotor. **The higher the amplitude, the higher the imbalance.**
2. **Order tracking** is used to handle **varying rotor speed**, providing a robust estimation of the 1p amplitude. If the rotor speed is not available, the **generator speed can be converted** to an equivalent rotor speed.
3. The amplitude is derived using Signal-to-Noise Ratio, **SNR,** concepts.
4. The 1p amplitude is **computed every 10 minutes** which **ensures backward compatibility with existing historical 10-minute SCADA data** and facilitates comparative analysis among turbines.

Optimal sampling frequency

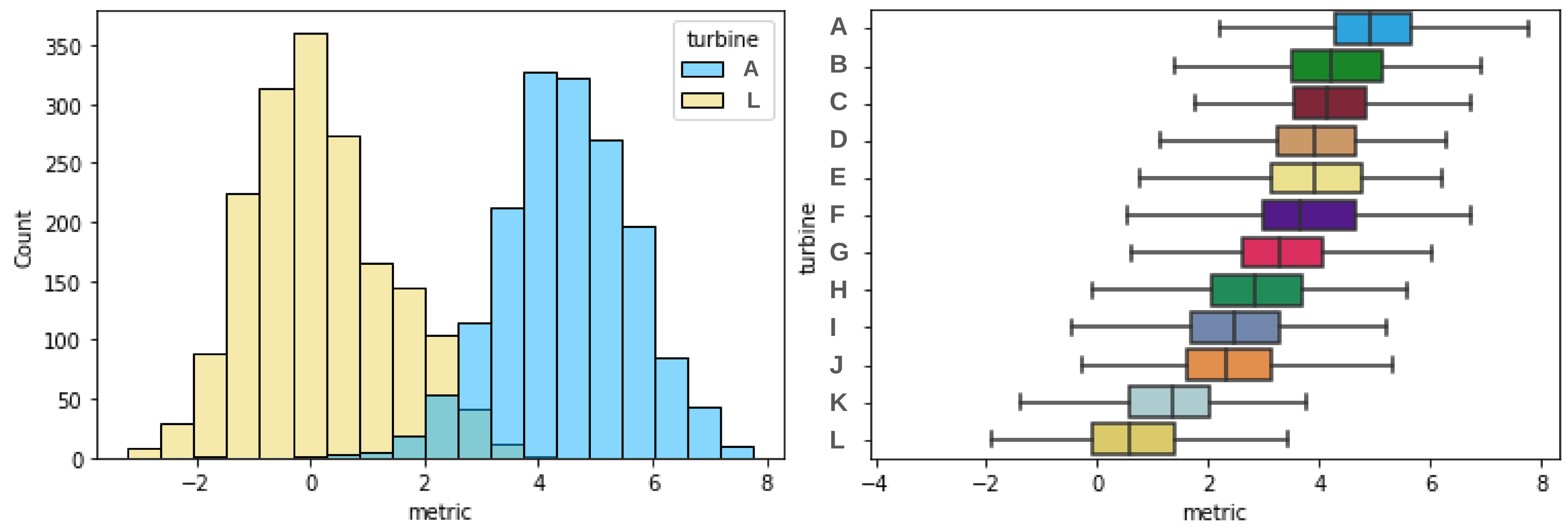
The **Nyquist-Shannon sampling theorem** dictates that at least 2 points per revolution are needed to **avoid aliasing**, but ideally, a sampling frequency should provide twice that amount, 4 points per full rotor rotation. Given the range of RPM of a turbine, **we only compute the metric when 1hz data are available**.



Left graph: At 14.75 RPM, 1 Hz and 0.5 Hz sampling rate are acceptable but the peak at 1P is more pronounced at 1Hz. Right graph: Summary of sampling frequency requirement for the metric.

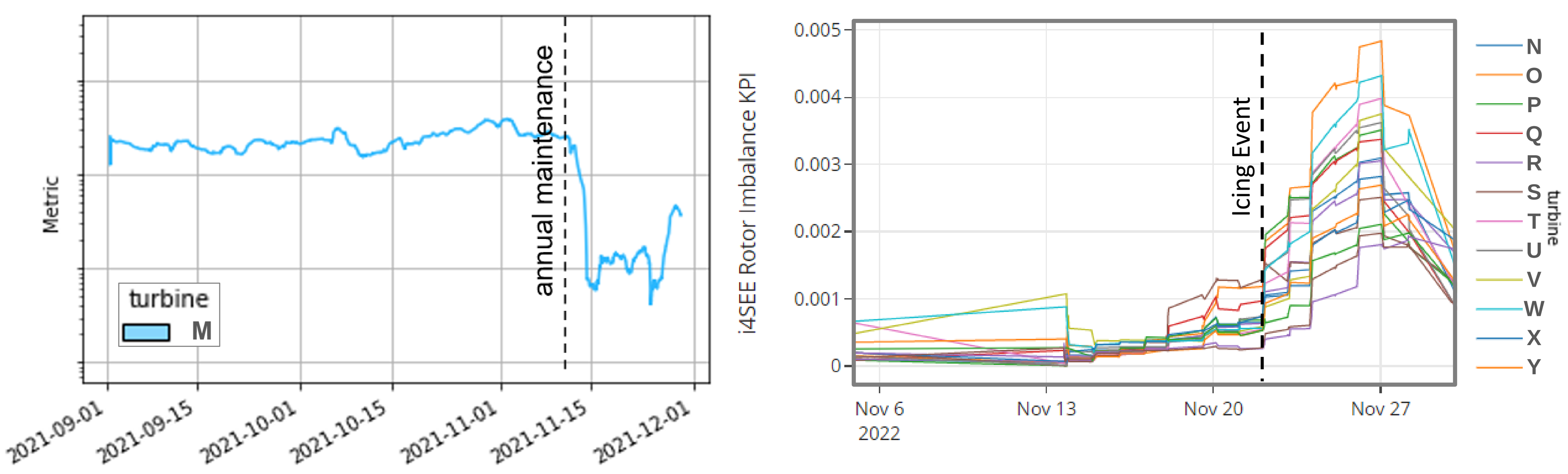
Results: Distribution & Timeseries

After computing the imbalance metric every 10 minutes, we analyze its **statistical distribution on a monthly basis** per turbine. This enables **comparison of similar turbines**, provided they have a similar high-frequency rotor speed sampling rate:



*Imbalance metric monthly distribution comparison for 2 turbines (left) and for the whole wind farm (right). In both cases, we see **turbine A** has a higher relative imbalance than **turbine L**.*

Monitoring the trend of this analysis at a portfolio level can provide valuable insights. It can help **identify wind turbines** that may be experiencing **deteriorating health** and **prioritize their inspection** and maintenance operations accordingly. By monitoring the metric monthly timeseries for one or multiple turbines, it is possible to correlate the amplitude of the imbalance with on-site events:



*The **left graph** illustrates an **improvement** in rotor imbalance after the OEM performed the **annual maintenance**. The **right graph** depicts an episodic and **global degradation** in rotor imbalance across the entire wind farm, which we found to be correlated with a severe **icing event** that occurred on this high-altitude wind farm.*

By identifying anomalies in imbalance, asset managers can **make informed decisions on the effectiveness of interventions or retrofits**.

Conclusions

- **Detection of global rotor imbalance is possible** using high frequency SCADA given a minimum sampling rate of 1Hz.
- Aggregating the imbalance metric at a 10-minute level ensures **compatibility with historical SCADA data**, facilitating further comparative analysis.
- **Monthly distribution** analysis of the metric **provides insight** on a wind farm or **portfolio level**, allowing for prioritized inspections and maintenance operations.
- **Individual timeseries** analysis of the metric enables the assessment of the **impact of maintenance** or **environmental events** on wind turbines.

References

1. Caselitz, Peter; Giebhardt, Jochen (2005). *Rotor Condition Monitoring for Improved Operational Safety of Offshore Wind Energy Converters. Journal of Solar Energy Engineering, 127(2), pp. 253*
2. M. R. Shahriar, P. Borghesani and A. C. C. Tan, "Speed-based diagnostics of aerodynamic and mass imbalance in large wind turbines," 2015 IEEE International Conference on Advanced Intelligent Mechatronics (AIM), Busan, Korea (South), 2015, pp. 796

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