Modelos ensamblados para estimación de vida remanente del generador

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Jornada de Análisis Operativo de Parques Eólicos
October 2nd, 2025, Madrid

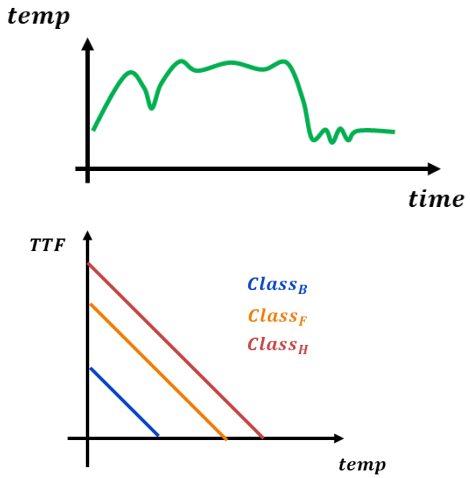
Physic-based models for health monitoring

Leverage readily available SCADA data to assess generator component health

- Light weight and easy to implement.
- Do not require training data (out of the box).
- Can be tuned to match site data.

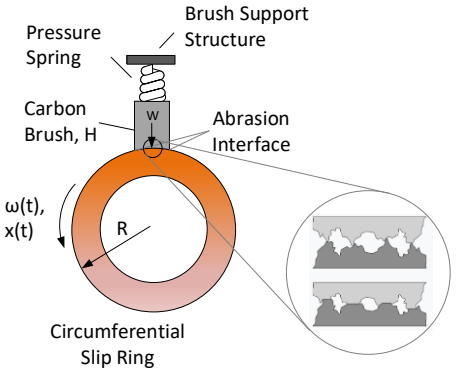
1. Generator insulation thermal degradation

Arrhenius' law and Miner's rule to assess thermal degradation in generator winding insulation



2. Slip ring Wear Model

Tribological model to estimate brush length reduction (wear) during operation



Generator insulation thermal damage

Thermal damage model

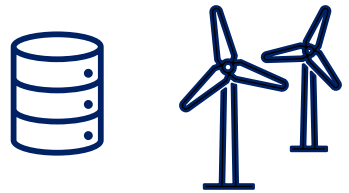
Generator

- Annual failure rate between $1\% - 4\%$
- Replacement cost between: $80k€ - \$200\ k€$
- Significant lead time.

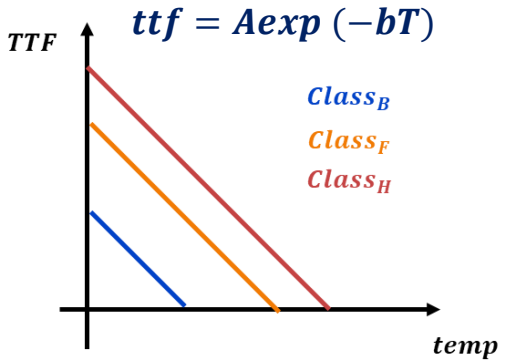
Thermal damage among the most common failure modes

- **Fatigue: >30%**
- **Wear: ~10%**
- **Insulation failure: ~10%**

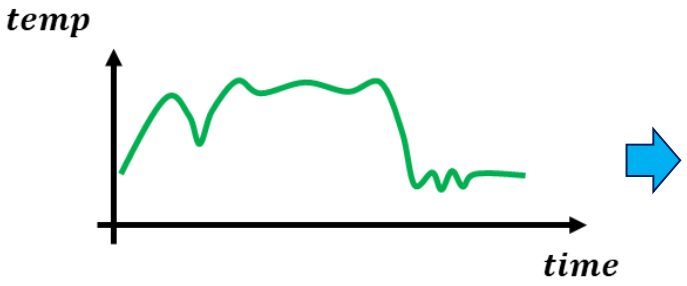
SCADA



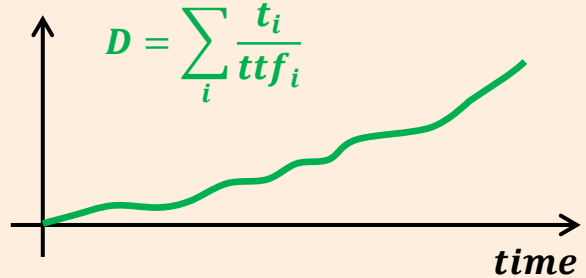
Insulation endurance curve



Coil temperature time series

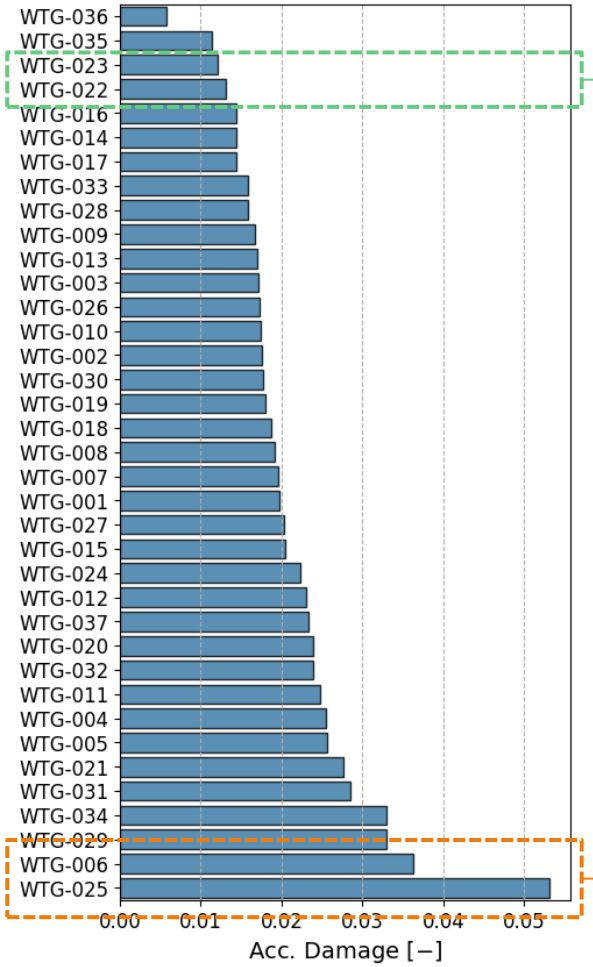


Damage accumulation over time

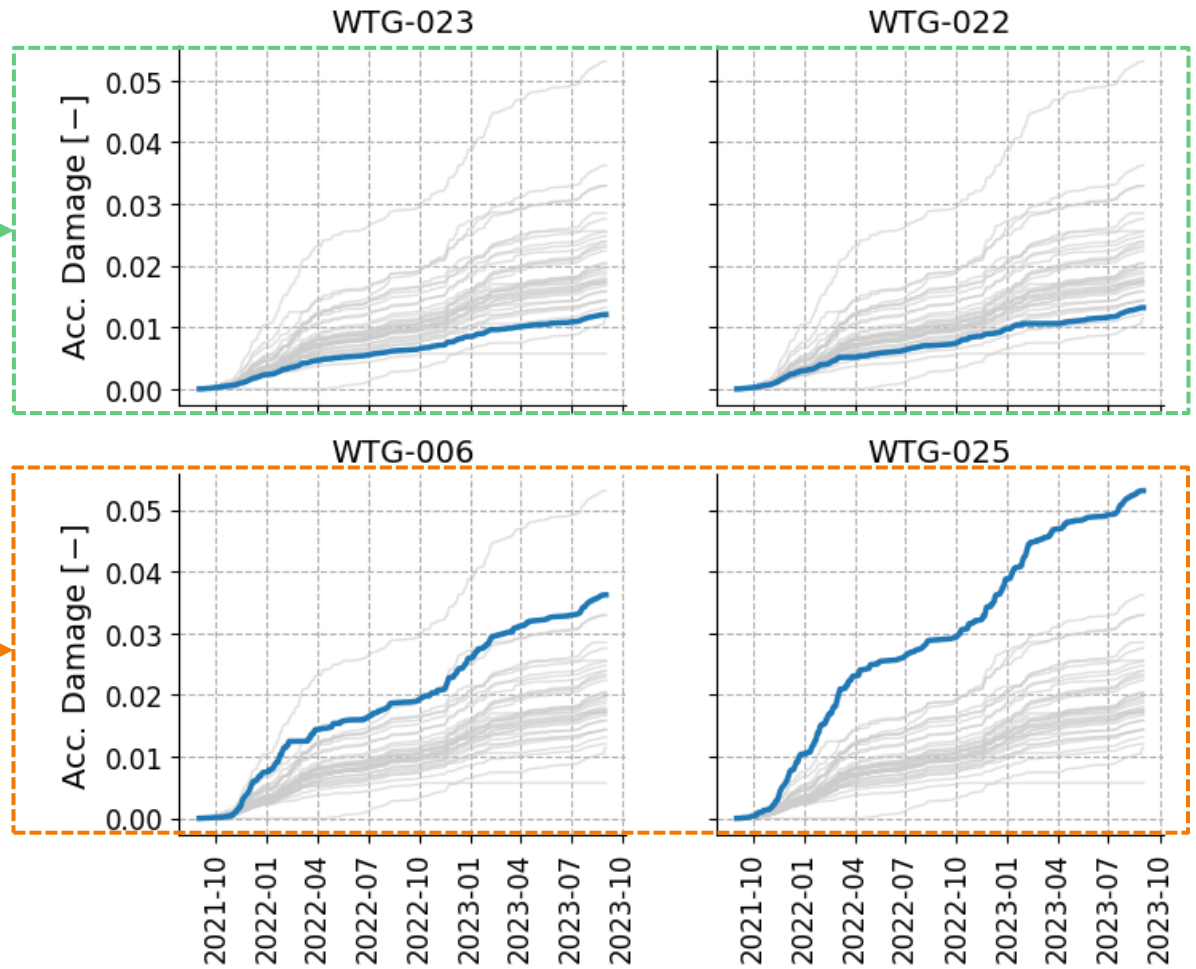


Thermal damage monitoring Monitoring - Example

Aggregated results



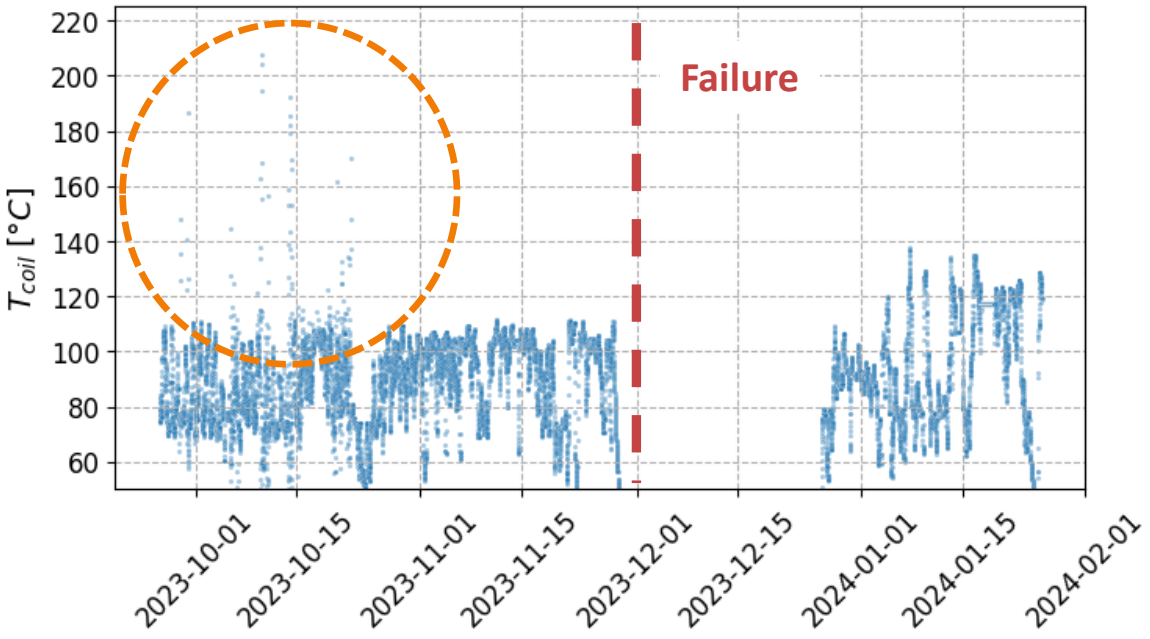
Damage accumulation history

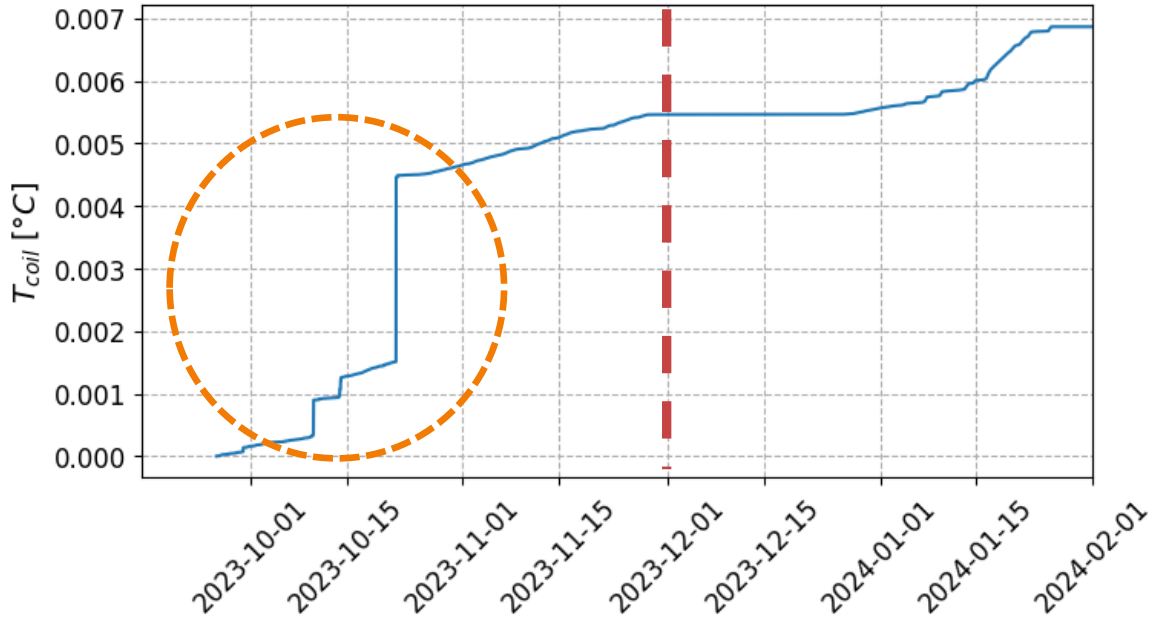


Verification

Tested methodology on a turbine with known electrical failure of the generator

- Few high temperature events during the weeks prior to the failure.
- Significant jump in the accumulated damage.





Slip ring brush wear

Slip ring wear model

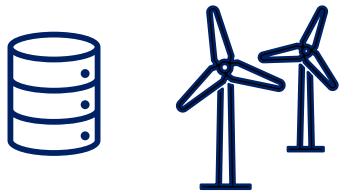
A critical component?

- Brush need to be replaced during periodic maintenance.
- Industry report that brushes tends to wear faster than expected.

Failure to replace brushes on time can lead to…

- **Arc flash**
- **Electrical fault + transients**
- **Turbine fire**

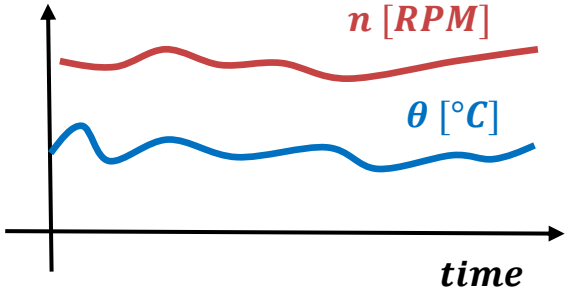
SCADA



Slip ring properties

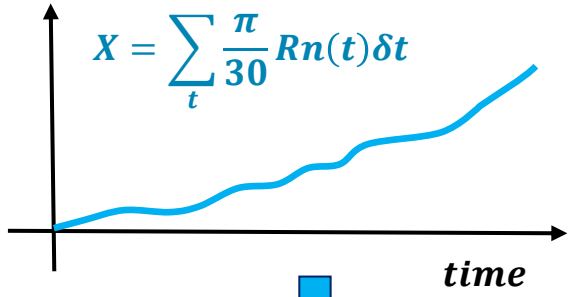
- Radius (R)
- Hardness (H)
- Contact Force (W)

Slip ring operating conditions



Total sliding distance (at contact)

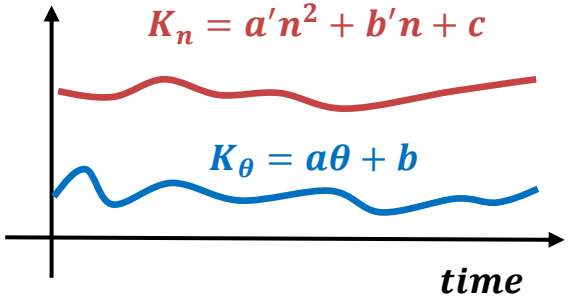
$$X = \sum_t \frac{\pi}{30} Rn(t)\delta t$$



Wear coefficients

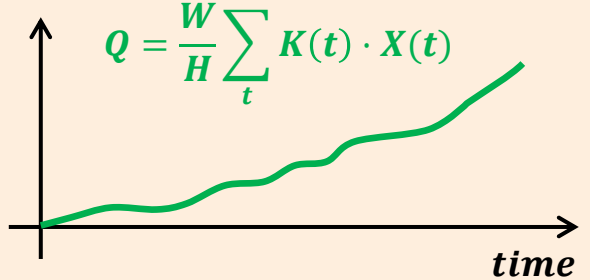
$$K_n = a'n^2 + b'n + c$$

$$K_\theta = a\theta + b$$



Time series of total wear

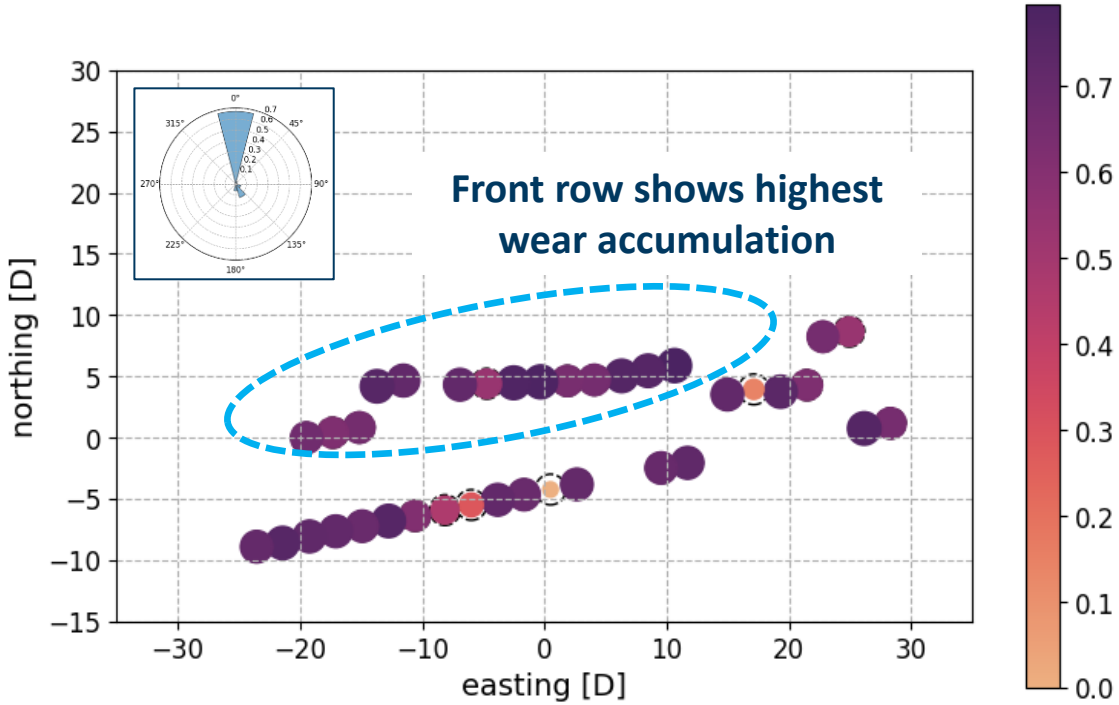
$$Q = \frac{W}{H} \sum_t K(t) \cdot X(t)$$

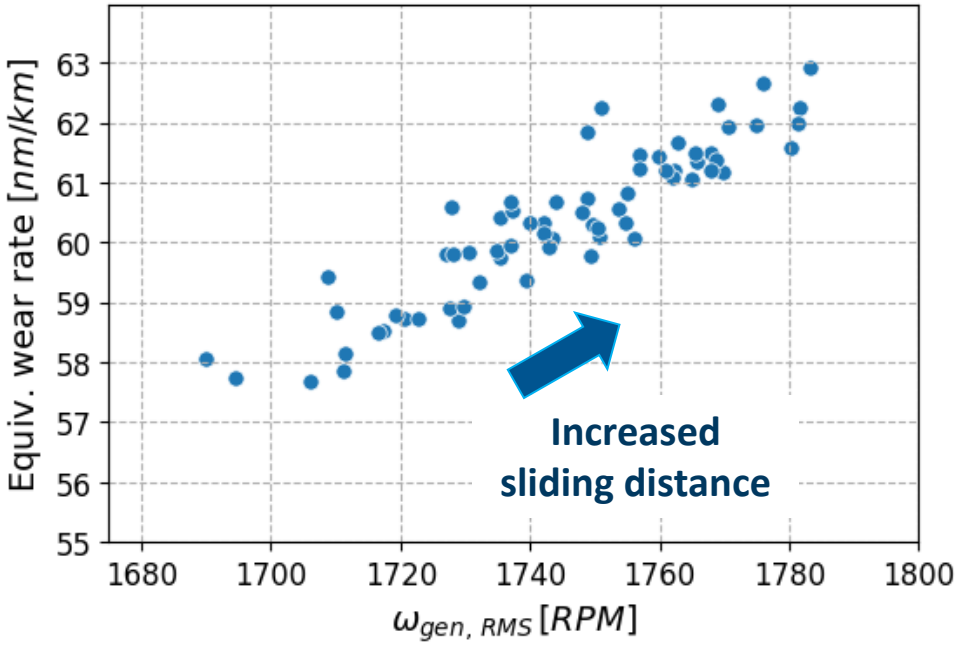


Results and validation

Applied model on two neighboring wind farms where excessive wear rate was reported by the operator

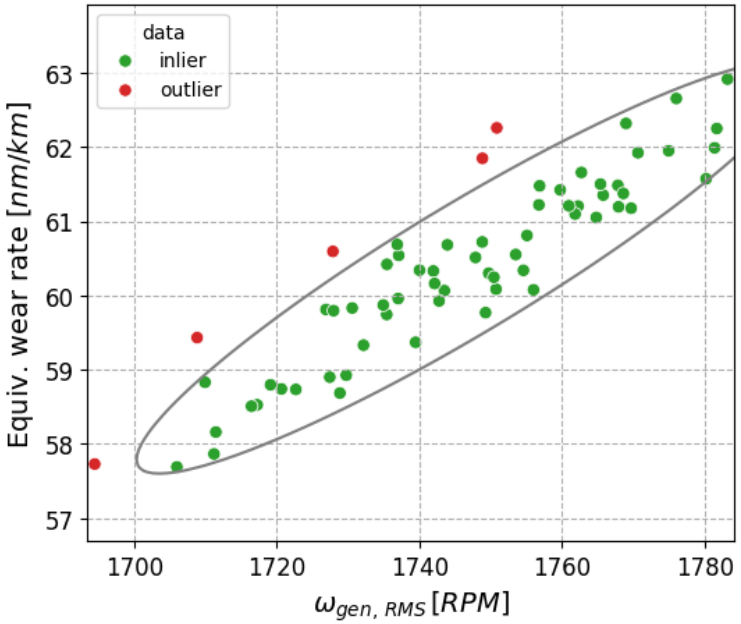
- Compared prediction to maintenance log to validate model prediction.
- Detected 10 out of the 13 replacement over the period covered by SCADA data.
- Linked wear accumulation with turbine operating conditions.



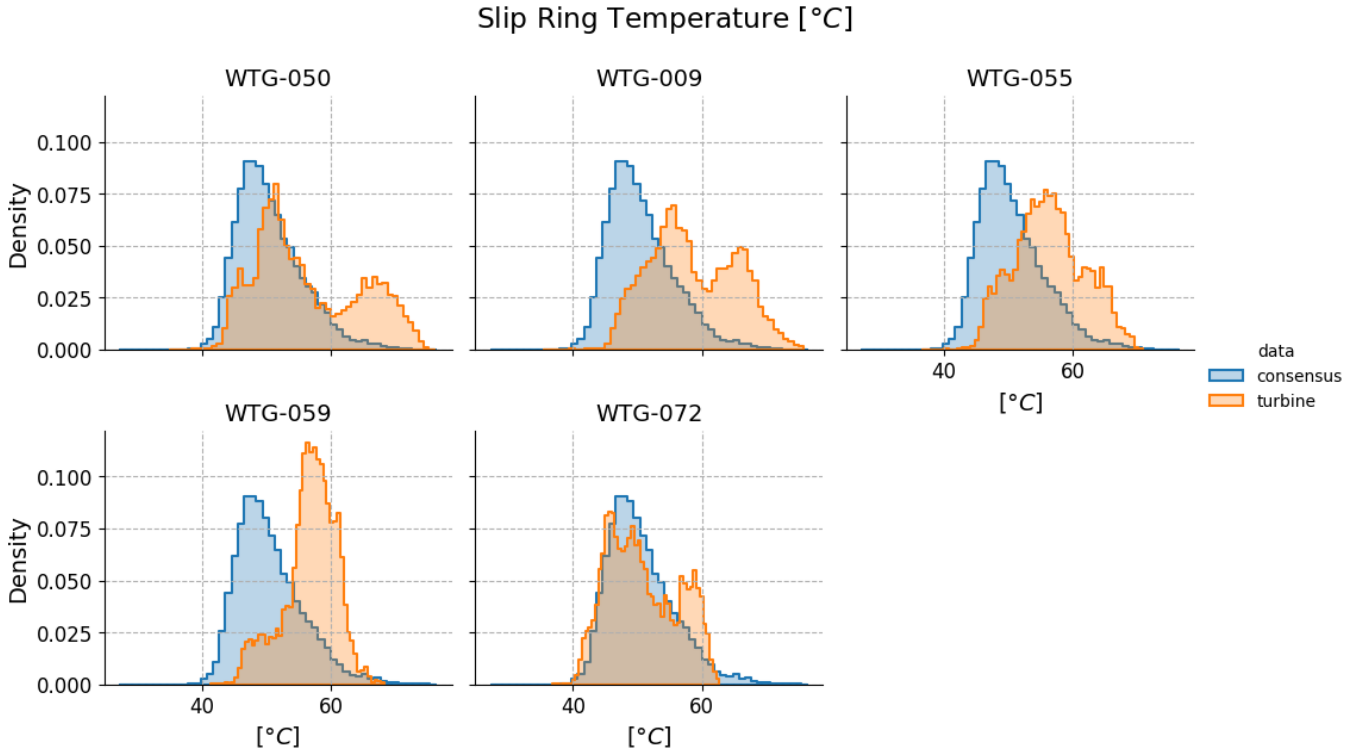


Can we go further?

Abnormal wear rate



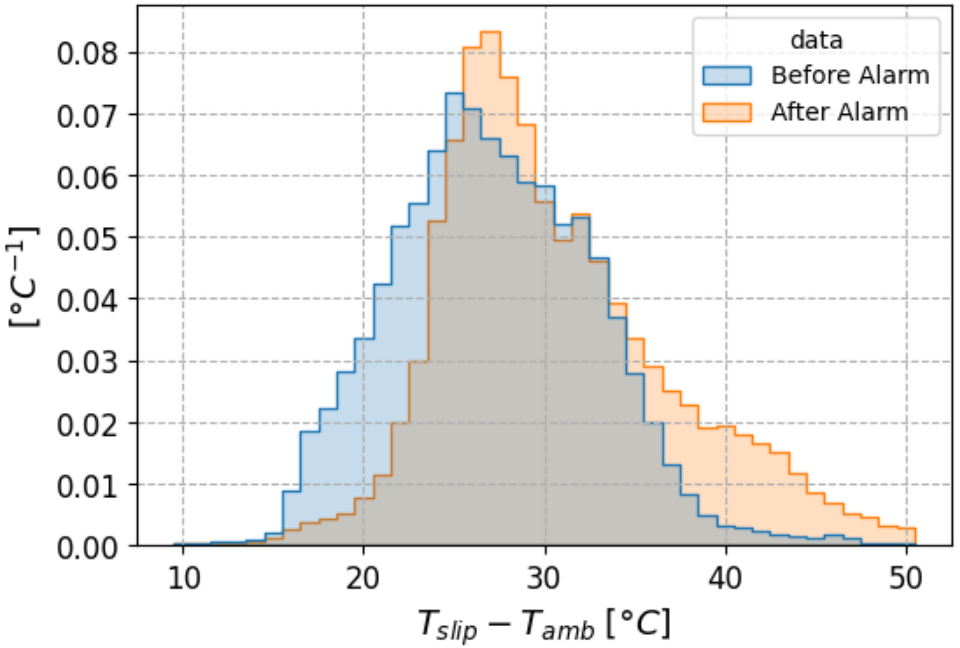
Temperature anomaly



Site inspections confirmed presence of damage !

Toward's real time monitoring

Alarm on August 15th, 2023



Normal behavior model to detect temperature anomalies

Concluding remarks

Summary and next steps

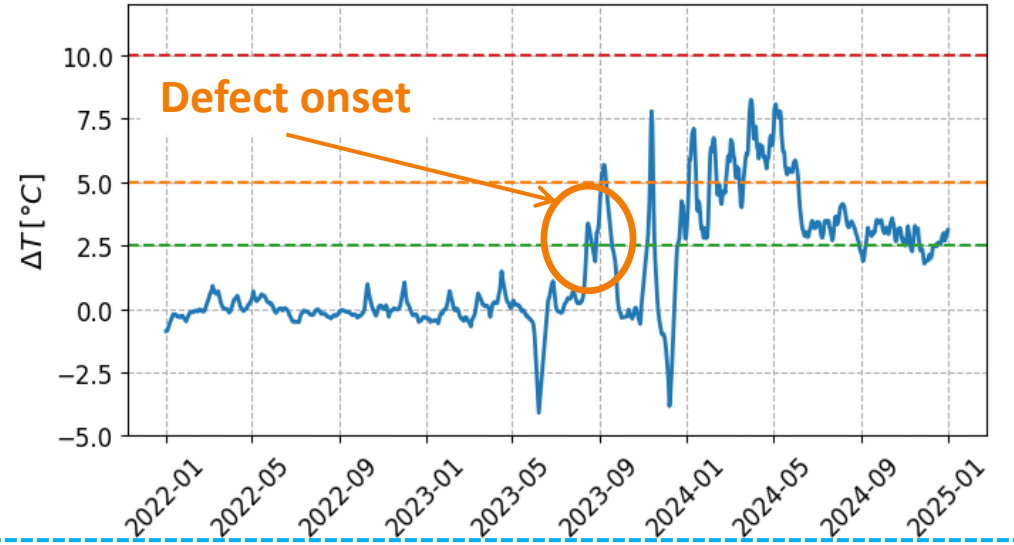
Introduce lightweight models to monitor generator's component health

- Provide an efficient way to rank turbine and prioritize inspection and maintenance.
- Good correlation with field data.
- Able to capture the underlying physic of the components' failure modes.

Next steps:

- Validation on multiple sites
- Adjust model constant to different turbine models (quantitative).
- Further developing alarm triggering using machine learning or cross comparison between turbines

Slip ring temperature anomaly detection (work in progress…)



Thank you for your attention

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