Load Estimation for Condition Monitoring in Wind Turbines Based on Physical Modeling

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Michael Pagitsch, Georg Jacobs, Dennis Bosse, Tobias Duda

CWD Center for Wind Power Drives | RWTH AACHEN UNIVERSITY

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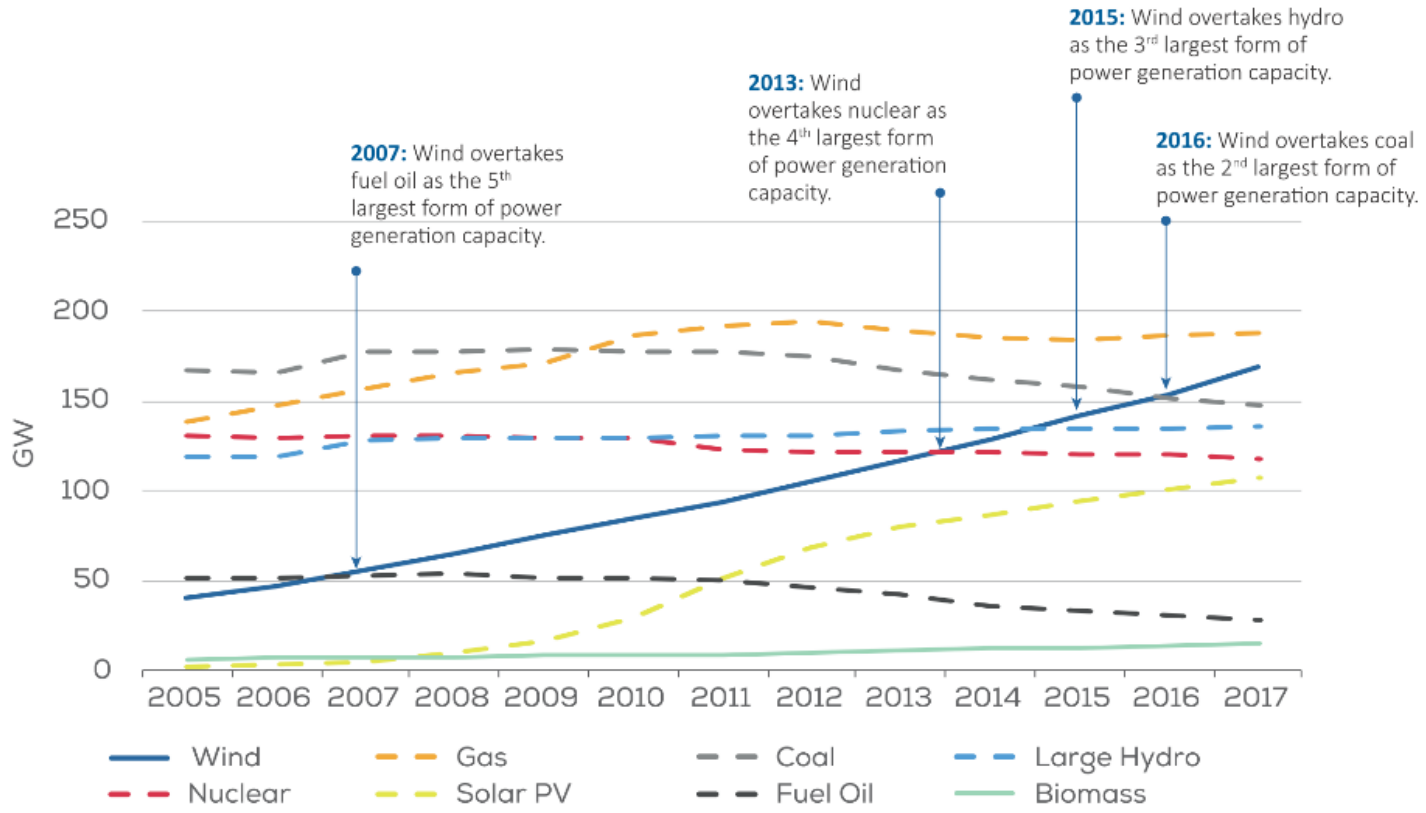
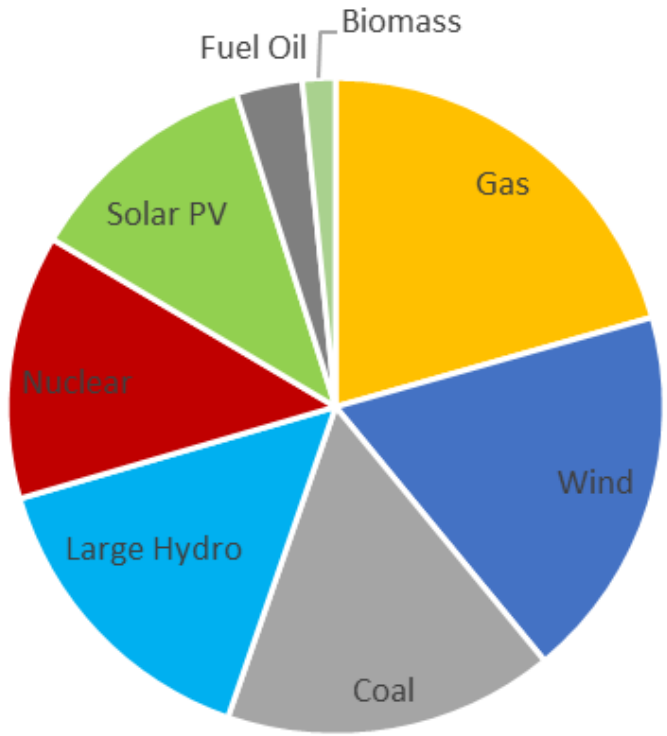
Total power generation capacity in the EU





WindEurope: Wind in power 2017. Annual combined onshore and offshore wind energy statistics, 2018

Motivation

Availability

*"ability of an item **to be in a state to perform as and when required**, under given conditions, assuming that the necessary external resources are provided"*

- Condition monitoring
  - Avoid long downtimes
  - Enable immediate reaction to failures

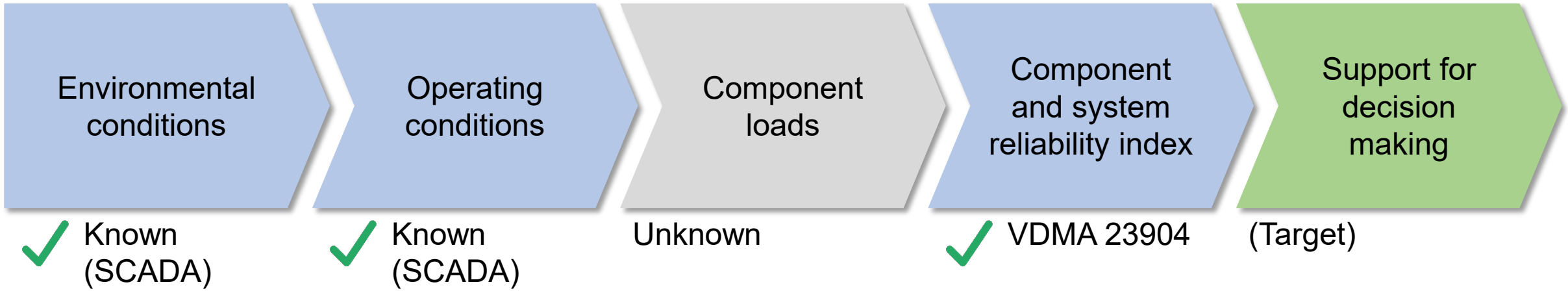
Reliability

*"ability of an item **to perform a required function** under given conditions **for a given time interval**"*

- Adjustment of operational management
  - Demand- and degradation-oriented
  - Prevent under- or overloading of individual WTs proactively
  - Adapt load situation to assumptions made in the design process

DIN EN 13306:2017: Maintenance – Maintenance Terminology

Motivation

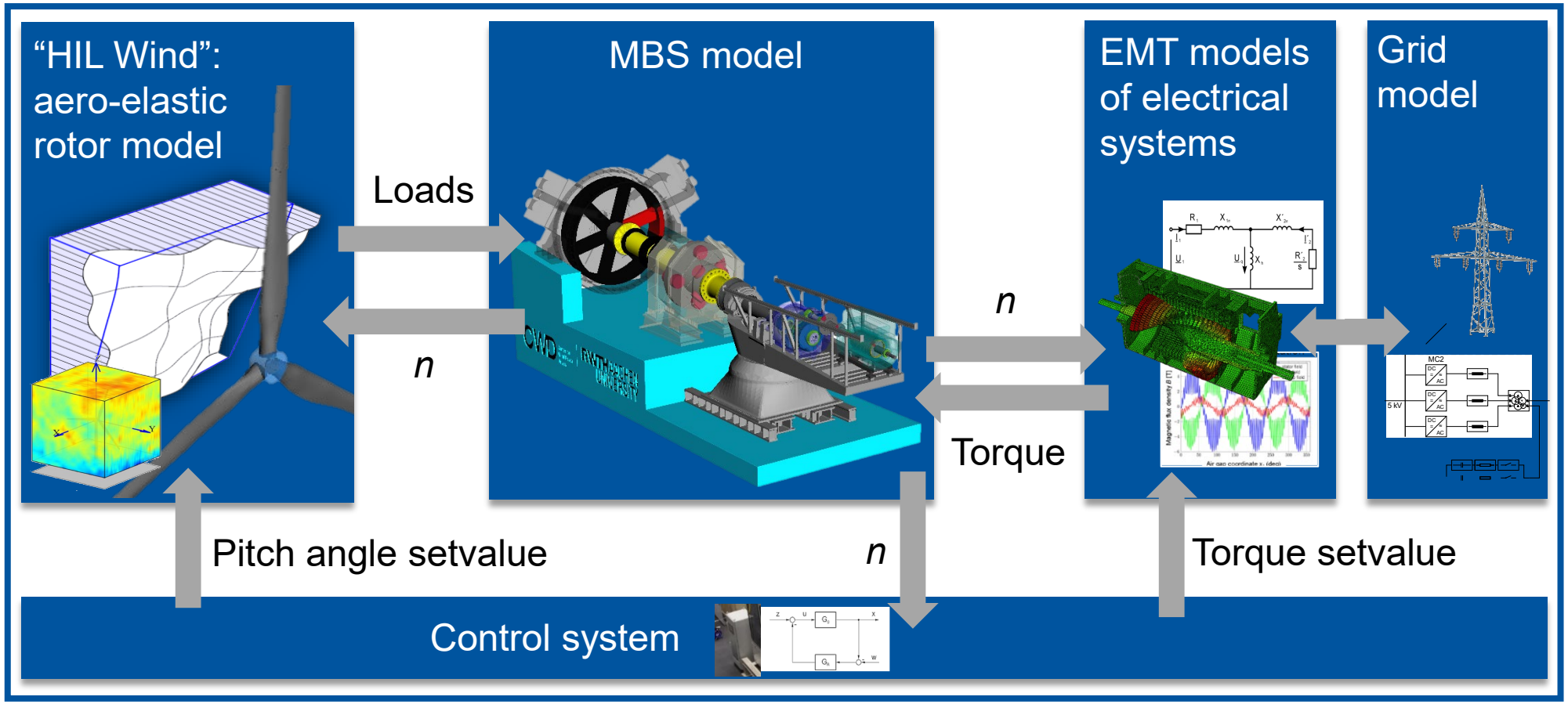


- Target: **Model-based load monitoring**
- Continuous calculation of a system reliability index for support in decision making
  - Degradation-oriented adaption of operational management
  - Spare parts stockkeeping
  - Appropriate maintenance strategies for old WTs
  - Wind farm life extension

VDMA 23904:2019: Reliability Assessment for Wind Energy Gearboxes

Motivation

Reference model: Validated multi-physical model of a full size research turbine



Matzke D et al. 2018 *J. Phys.: Conf. Series* **1037** 062025

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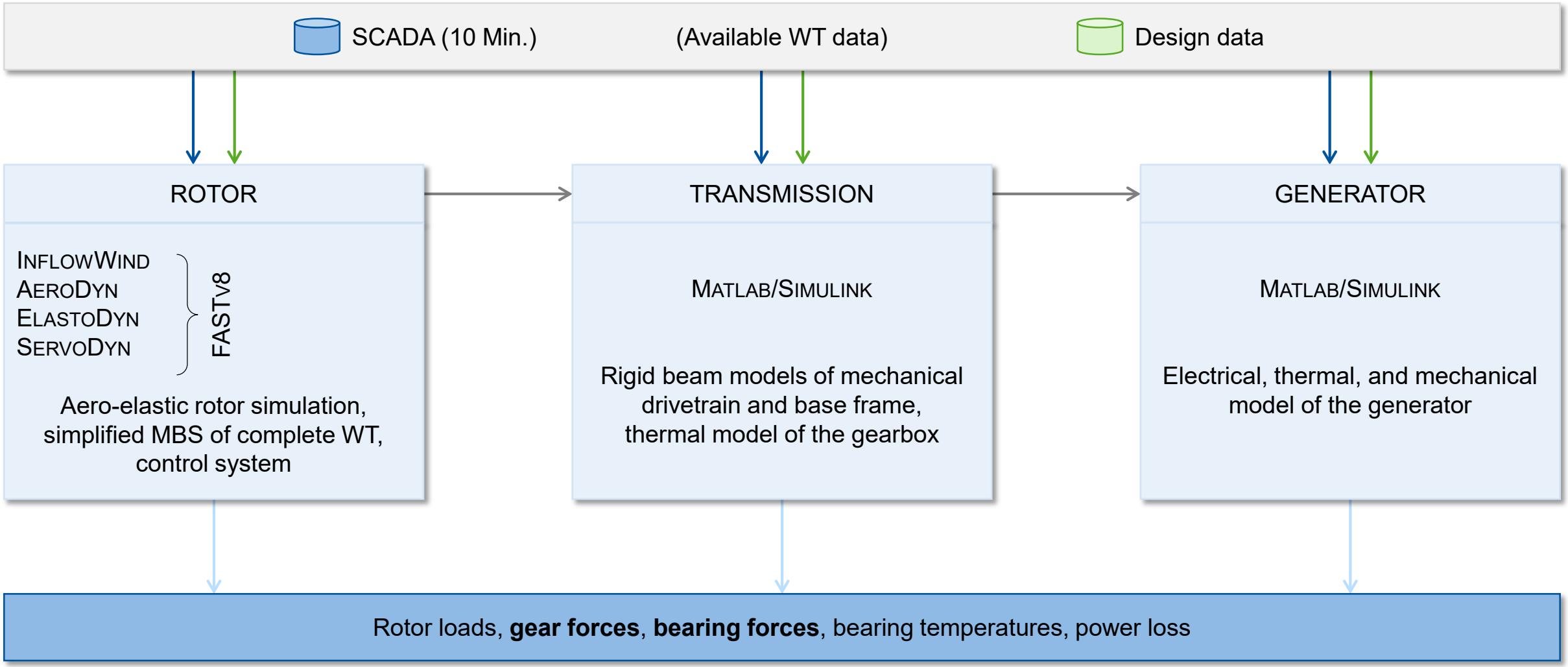
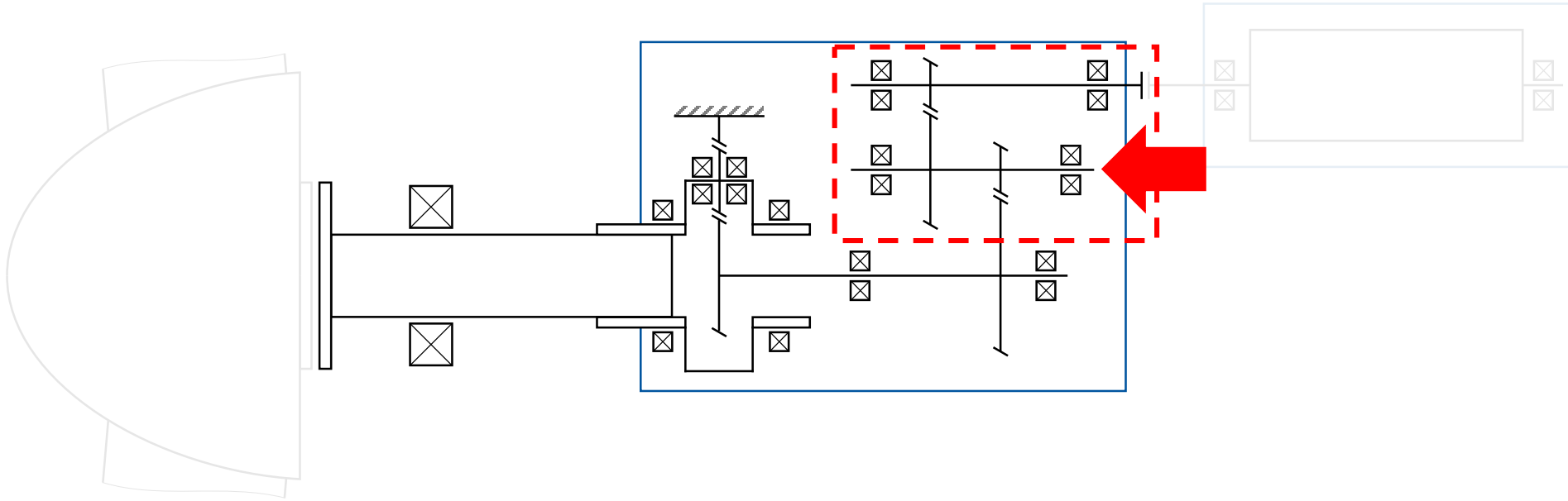
Model-based load monitoring



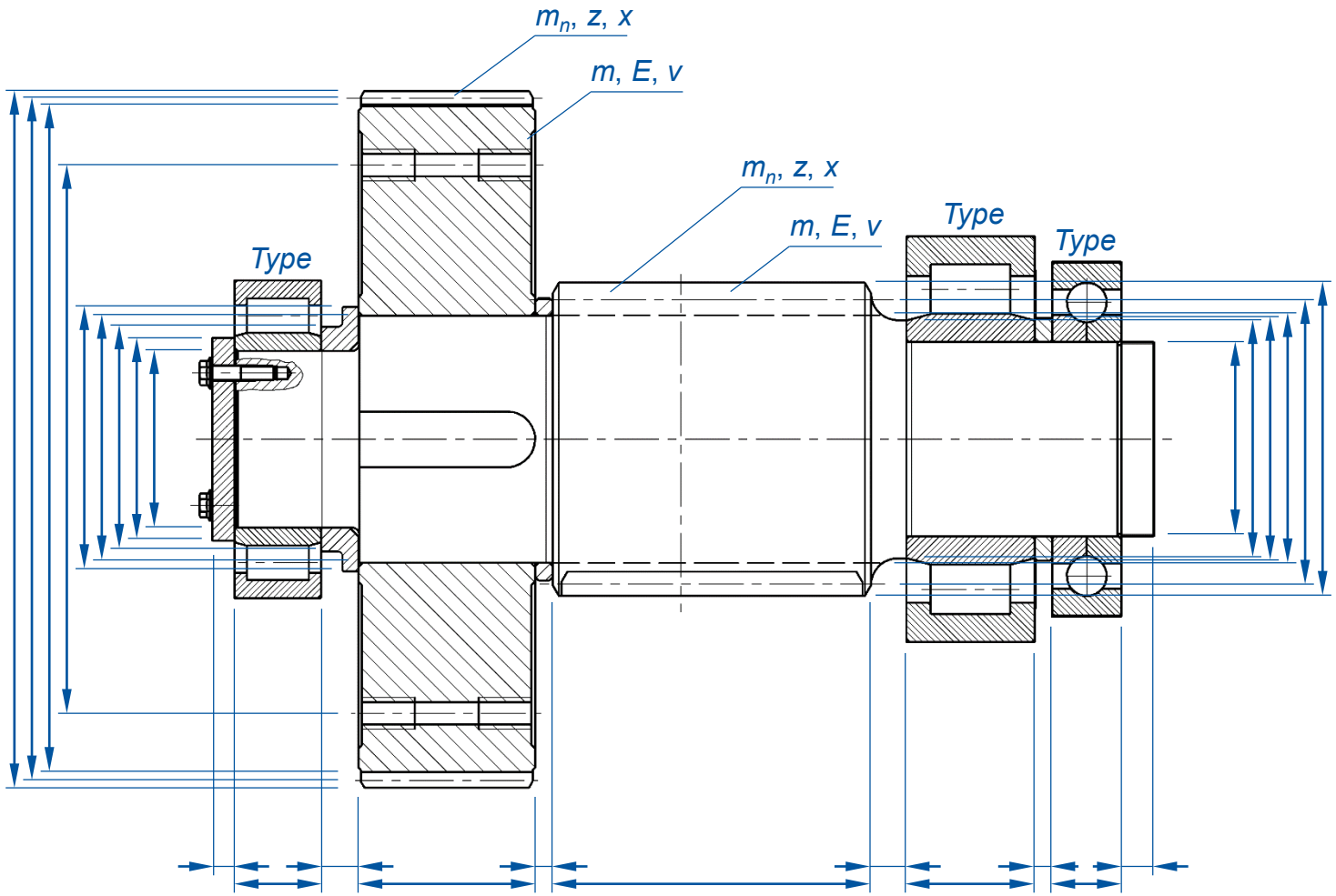
Model-based load monitoring

ROTOR	TRANSMISSION	GENERATOR

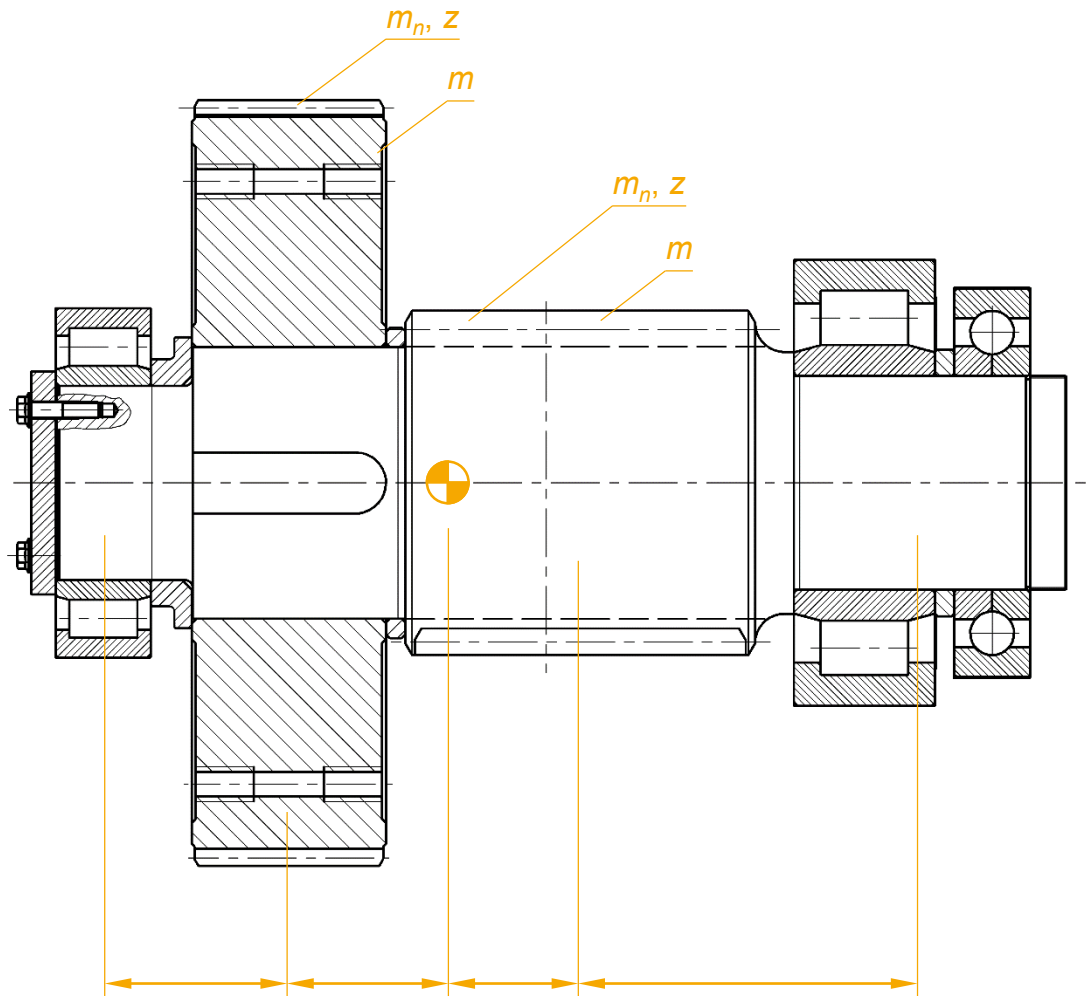


Geometry; masses and moments of inertia of major WT components; bending characteristics (tower, blades); control system	Drive train configuration Overall dimension Inner dimensions Masses of rotating parts	**24 parameters for considered sub-system**	Generator type Overall dimension Rotor mass

MBS-model: Parameter requirements



Analytical model: Parameter requirements



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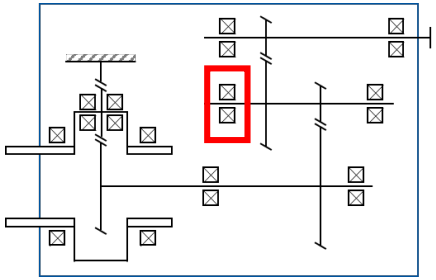
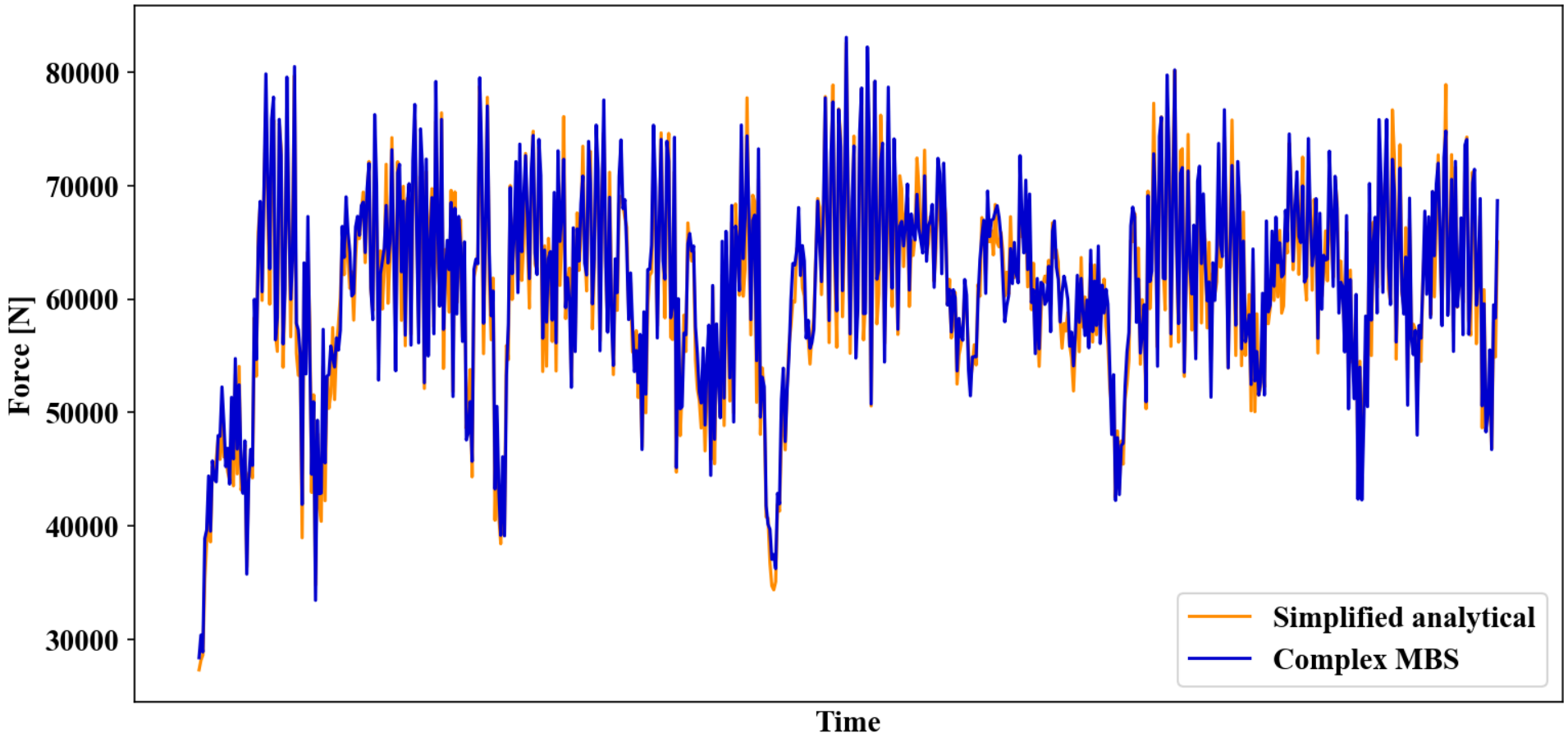
Model validation

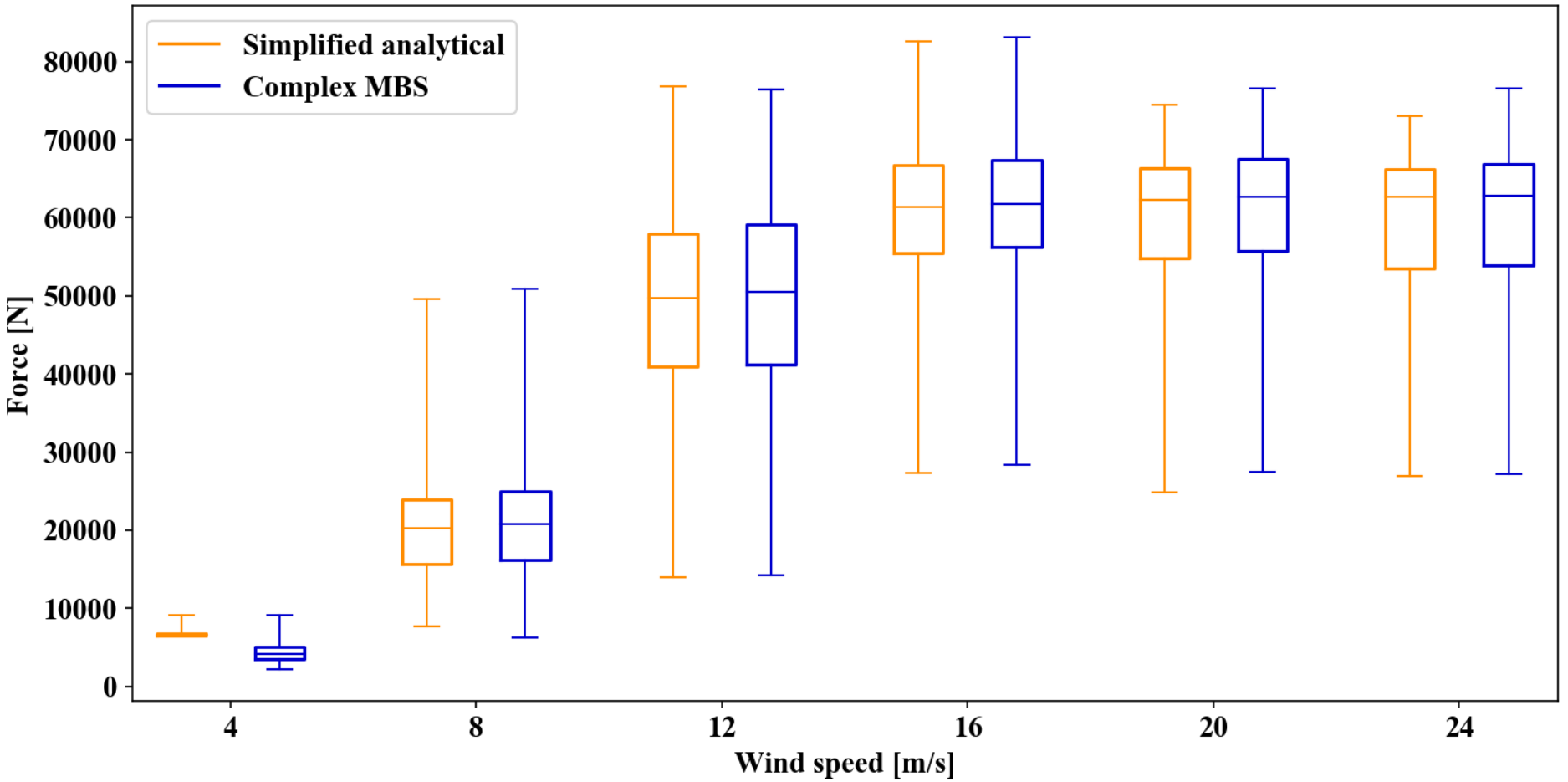
Rotor-side bearing of intermediate speed shaft (floating bearing)

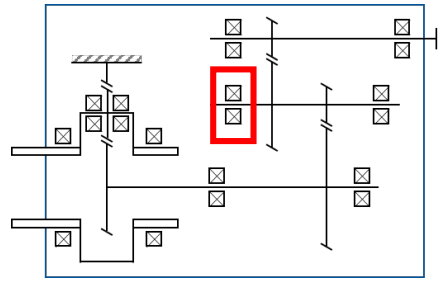




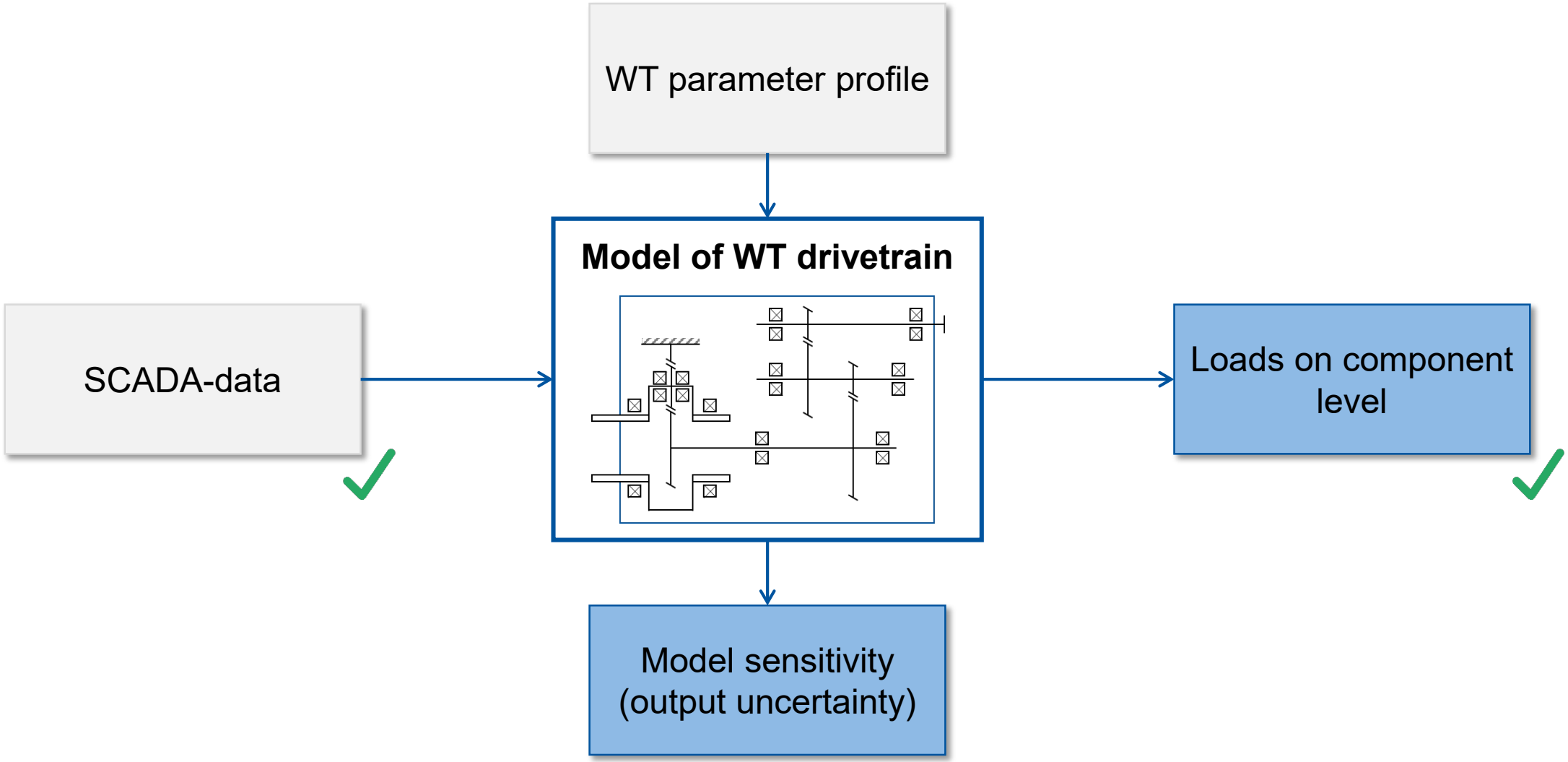
Model validation

Comparison of bearing forces in complete operating range of research WT





Model validation



Model validation: Assessment of output uncertainty

Derivation of a description model from individual parameter profile

$$y = c_0 + \sum_{i=1}^{n} c_i x_i + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} c_{ij} x_i x_j + \varepsilon$$

$$\Delta y = c_0 + \sum_{i=1}^{n} c_i \Delta x_i + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} c_{ij} \Delta x_i \Delta x_j$$

y: Model output
x_i: Parameter (1 … n)
ε: Error term
c_i, c_{ij}: Coefficients

Δy: Model output uncertainty
Δx_i: Parameter uncertainties (1 … n)

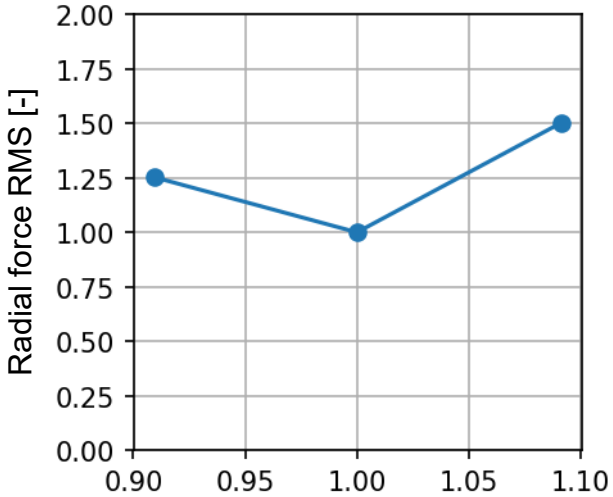
2 Steps:

1. Parameter reduction by identification of main effects (c_i)
2. Multi-factorial computer experiments to identify interactions (c_{ij})

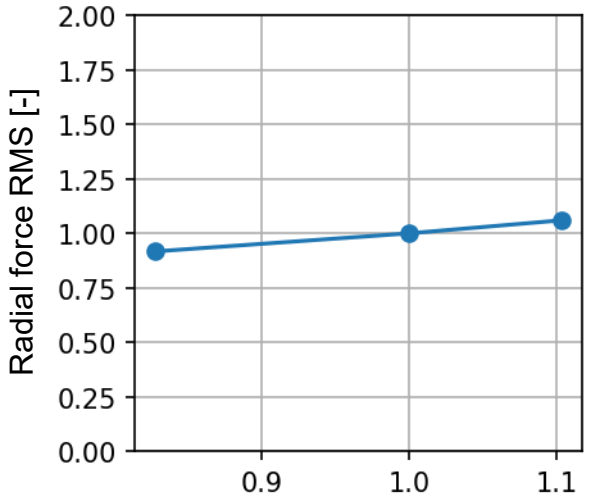
Siebertz K, van Bebber D, Hochkirchen T 2010 *Statistische Versuchsplanung* (Berlin: Springer)

Model validation: Assessment of output uncertainty

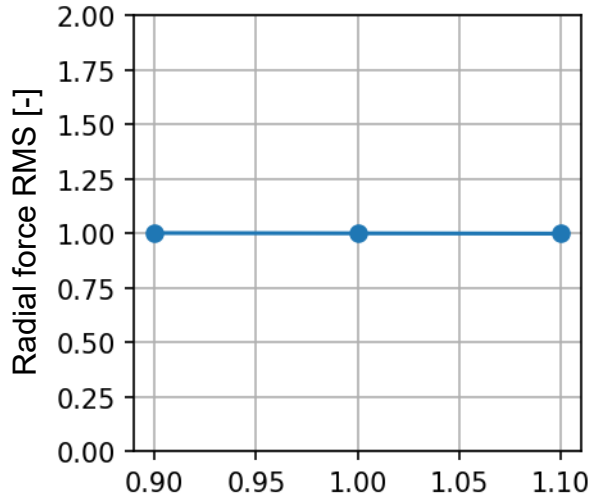
Main effect diagrams



Geometry (Positions of shafts, positions of bearings and gears), modulus



Helix angles



Masses of rotating parts, gear width

Reduction of parameters to be considered in the multi-factorial sensitivity analysis by 30 %

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Conclusion and outlook

Accomplishments

- Developed a generic WT model for calculating inner loads from SCADA records
  - Real-time capable
  - Minimal parameter requirements
- Outputs used for continuous calculation of a reliability index
  - Continuous decision support throughout the WT‘s service life
- Introduced a method for accuracy assessment of model outputs

Next steps

- Multi-factorial parameter variation (computer experiment) for identifying parameter interactions
- Application of a prototype to field data
  - Prove practical applicability

Thank you!

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