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Developing an Aeroelastic Stability Process for Large Wind Turbines Using Multibody Simulation

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Abstract

Future wind turbine designs will likely be stability-driven in contrast to the current loads-driven designs. Design of large wind turbines needs to be verified and approved and eventually modified to have safe aeroelastic stability margins at its operating and idling conditions. For wind turbines with more flexible designs aeroelastic stability analysis needs to be part of the certification.

Known rotor related aeroelastic instabilities which can occur for wind turbines are :

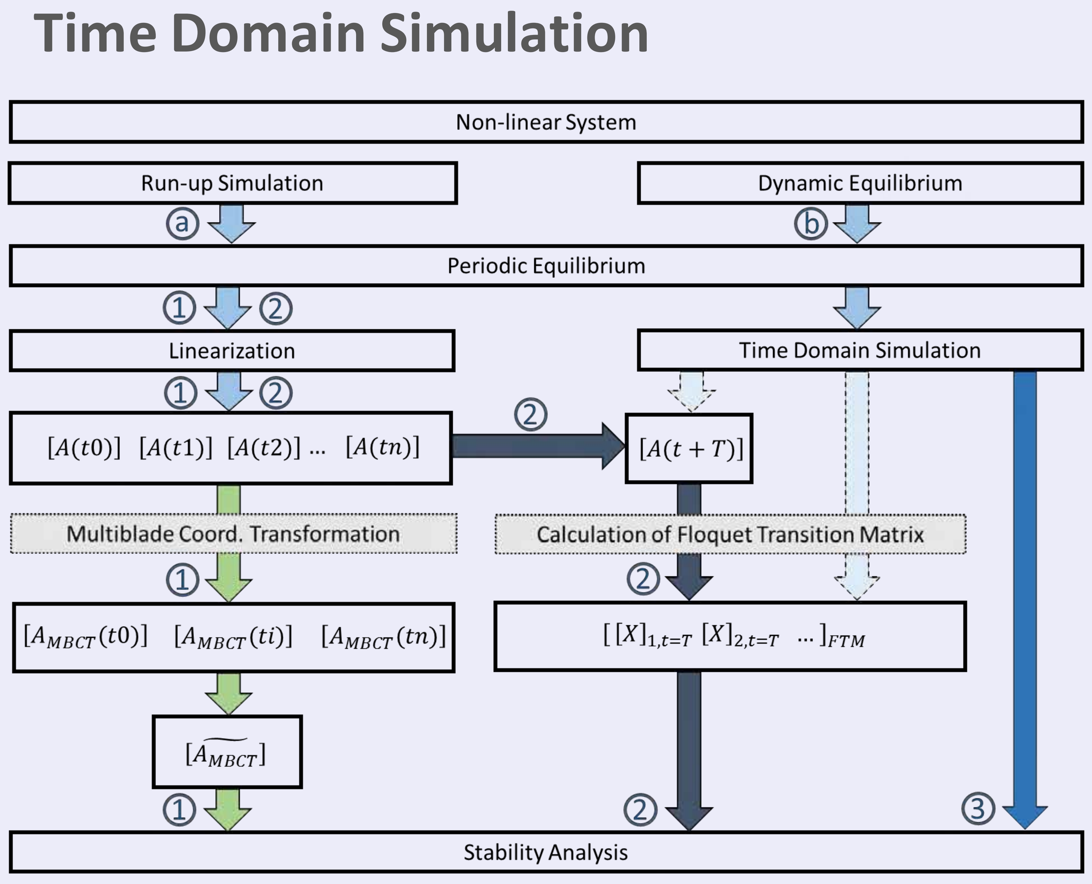
- **Rotor blade classical flutter** [1], [2]
- **Rotor whirl flutter** [3]
- **(Aero-) mechanical instabilities**
- **Stall induced instabilities** [1], [2]

Stability analyses of wind turbines (WT) with time periodic characteristics currently require software tools dedicated to this specific investigations.

Objectives

This paper presents a method for analyzing wind turbine stability based on general purpose multibody simulation tools with all relevant aero-, servo- and hydroelastic effects included. As part of this method a post processing tool has been developed which offers different stability analysis approaches, specifically

- **Multiblade Coordinate Transformation**
- **Floquet Theory**
- **Time Domain Simulation**



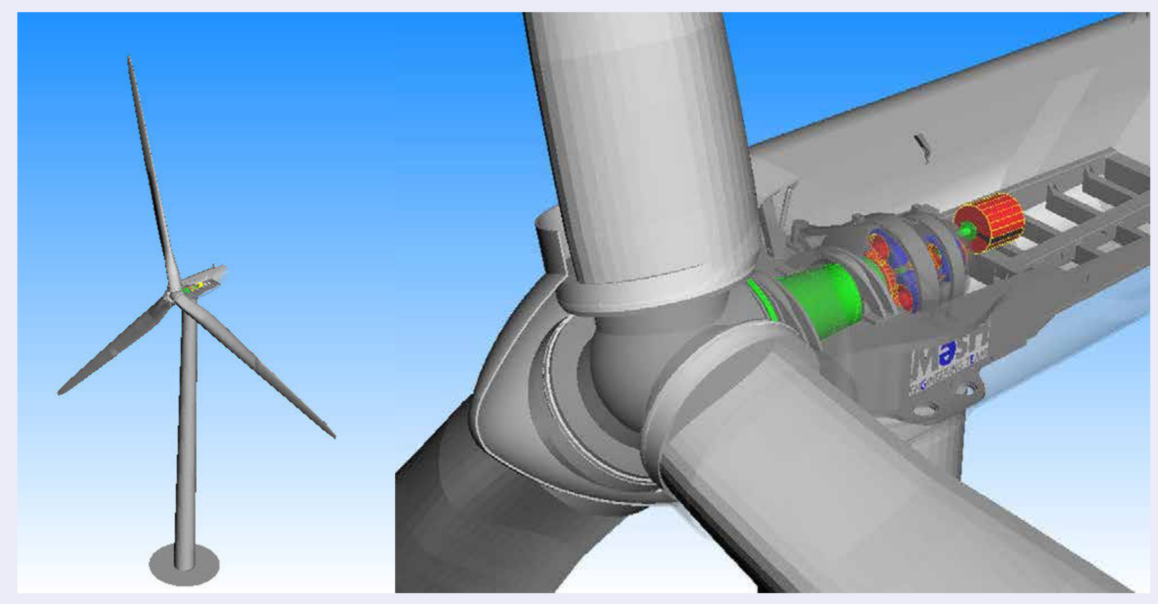
MBCT: Multiblade Coordinate Transformation
FTM: Floquet Transition Matrix

Above scheme represents the different available methodologies for analyzing wind turbine stability with the proposed procedure.

In the following, the application of Floquet Theory and Multiblade Coordinate Transformation (MBCT) are described.

Methods

The application of the considered methods requires a linearization of the full non-linear aeroelastic model [4] of the WT around an equilibrium, resulting in a linear time-periodic system in the time discrete form.



Stability analysis using MBC-Transformation:

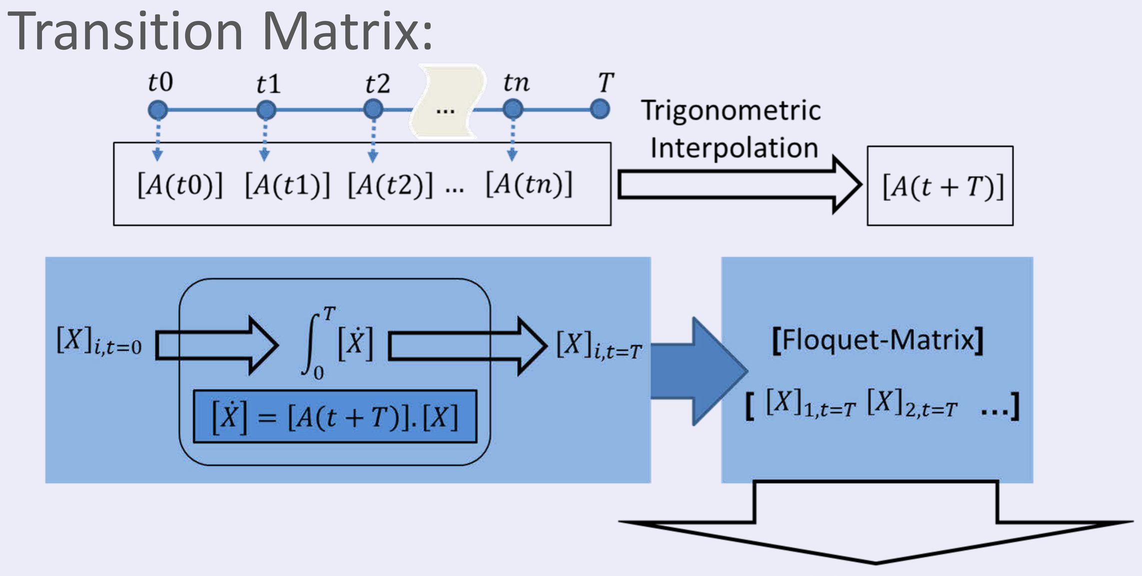
This coordinate transformation is used to change a linear system matrix from time periodic to time invariant. In this coordinate system, instead of blade modes, rotor modes are considered:

In the stability analysis process, system matrices [A] of the WT are generated for the different rotor rotation velocities and blade azimuth angles. These matrices are sorted and then transformed into the multiblade coordinates:

$$\begin{bmatrix}[\dot{X}]_{tower}\\ [\dot{X}]_{blade\,1}\\ [\dot{X}]_{blade\,2}\\ [\dot{X}]_{blade\,3}\end{bmatrix} = [A]\cdot\begin{bmatrix}[X]_{tower}\\ [X]_{blade\,1}\\ [X]_{blade\,2}\\ [X]_{blade\,3}\end{bmatrix} \Rightarrow \begin{bmatrix}[\dot{X}]_{tower}\\ [\dot{X}]_{MBC\_0}\\ [\dot{X}]_{MBC\_1c}\\ [\dot{X}]_{MBC\_1s}\end{bmatrix} = [A]_{MBCT}\cdot\begin{bmatrix}[X]_{tower}\\ [X]_{MBC\_0}\\ [X]_{MBC\_1c}\\ [X]_{MBC\_1s}\end{bmatrix}$$

Stability analysis using Floquet Theory:

With the help of trigonometric interpolation the time periodic system matrix of a WT-model is calculated as a function of time which is then used to calculate the Floquet Transition Matrix:



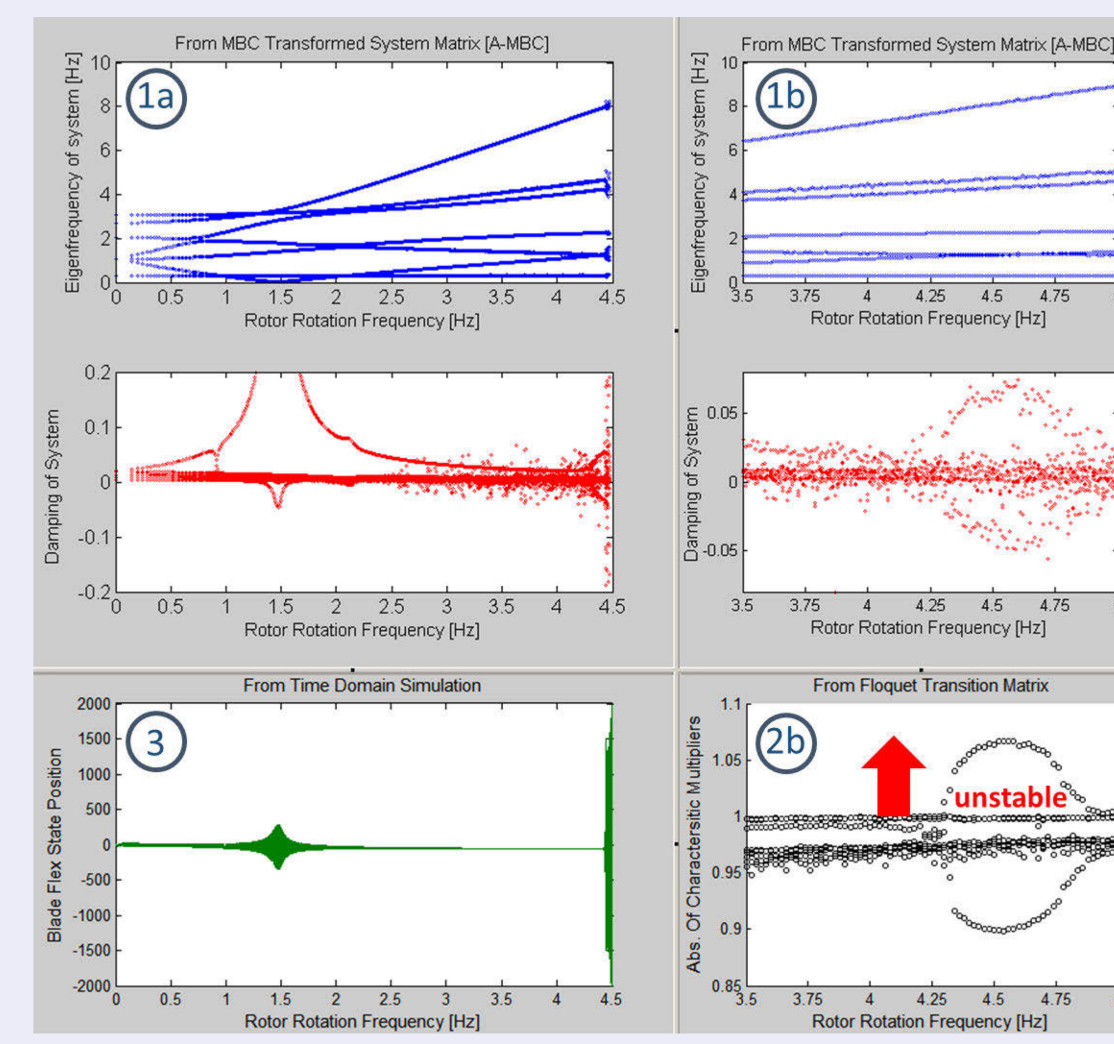
With the Floquet Transition Matrix stability analysis can be done with the calculation of the characteristic multipliers or exponents.

Results

Application to a WT-Model:

Exemplary a 5-MW reference wind turbine [5], simulated in multibody simulation tool SIMPACK, was selected for the stability analysis. To simplify the results the number of modal DOF of the model was reduced:

- **Rotor blades: 1st lead-lag mode each**
- **Tower: 1st and 2nd bending, 1st torsion**



(1a) **frequency and damping of the WT system after MBCT based on run-up simulation**

(1b) **frequency and damping of the WT system after MBCT based on dynamic equilibrium**

(2b) **characteristic multipliers of FTM based on dynamic equilibrium**

(3) **Time history of rotor blade state**

Conclusions

A method for stability analyses based on general purpose multibody simulation software has been developed and successfully demonstrated.

An instability of an exemplary reference WT could be predicted using the Multiblade Coordinate Transformation, the Floquet Theory and a Time Domain Simulation.

References

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