Integration of STAS Turbine with plant flow model

SINTEF

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Introduction

- Wind turbines placed in the same wind power plant (WPP) interact with each other through aerodynamic and electrical coupling.
- Coordinated control of wind power plants should consider these interactions.
- The STAS framework [1] provides state-of-the-art turbine models including aeroelastic, electrical and control modules.
- Overall goal:
  Holistic WPP model for model-based optimal control that balances the partly contradictory objectives, e.g. power production and load reduction.

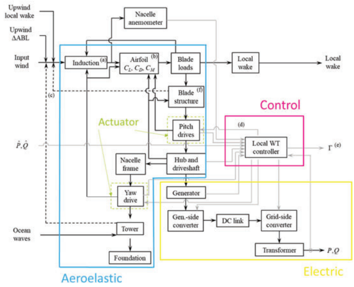
→ Integrate plant flow model with STAS Wind Turbines for WPP control.

STAS WPP [1]

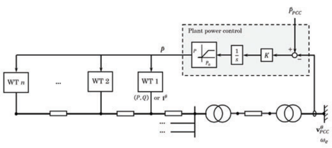
A unified state-space model of a wind power plant, for analysis of system dynamics, optimization, and control.

STAS Wind Turbine (WT) [2]:

- Different modules as shown in the figure
- Nonlinear and linearized sets of equations
- Newton-Raphson solution for steady-state operating points



Exemplary STAS WPP with electrical grid and simple WPP controller [3]:



$$\mathbf{N}\frac{d}{dt}\begin{bmatrix}\Delta\mathbf{x}_1\\ \vdots\\ \Delta\mathbf{x}_n\\ \Delta\mathbf{x}_E\\ \Delta\mathbf{x}_c\end{bmatrix} = \begin{bmatrix}\mathbf{A}_{11} & \dots & 0 & \mathbf{A}_{1E} & \mathbf{A}_{1c}\\ \vdots & \ddots & \vdots & \vdots & \vdots\\ 0 & \dots & \mathbf{A}_{nn} & \mathbf{A}_{nE} & \mathbf{A}_{nc}\\ \mathbf{A}_{E1} & \dots & \mathbf{A}_{En} & \mathbf{A}_{EE} & \mathbf{A}_{Ec}\\ \mathbf{A}_{c1} & \dots & \mathbf{A}_{cn} & \mathbf{A}_{cE} & \mathbf{A}_{cc}\end{bmatrix}\begin{bmatrix}\Delta\mathbf{x}_1\\ \vdots\\ \Delta\mathbf{x}_n\\ \Delta\mathbf{x}_E\\ \Delta\mathbf{x}_c\end{bmatrix} + \mathbf{B}\Delta\mathbf{u},$$

Methodology

Plant flow model: FLORIS (FLOw Redirection and Induction in Steady State) [4]

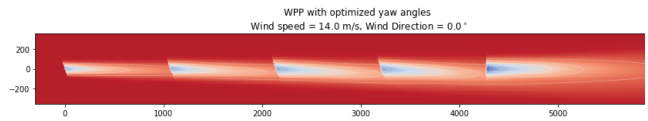
- Initializes the incoming wind characteristics, dimensions of the turbines and the wind power plant layout.
- Maximizes the power production by wake steering, i.e. optimizing the yaw angles of all turbines.
- Outputs inflow wind field, estimated power, and yaw angle for each turbine.
- Internal turbine model based on tabularized power coefficients.

STAS Wind Turbine model:

- Linearized at different operation points: wind speed, power command
- Interpolation between operation points for each turbine based on the information provided by the plant flow model.

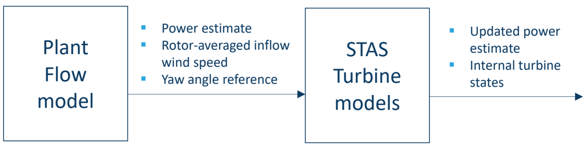
Simulation set-up:

- WPP layout: row of 5 turbines
- 10 MW turbines
- Yaw optimization tool FLORIS limited between 0 and 20 degrees.
- Gaussian wake model with wake growth based on turbulence intensity.
- Two steps: 1) Yaw optimization in FLORIS. 2) Linear interpolation of STAS models to calculate bending moments.



Results

Interface between STAS Turbine models and plant flow model:



- Plant flow model with simple turbine model provides the wind field and estimated power production for each turbine.
- STAS updates the power estimate considering the internal turbine states and control functions; and returns turbine settings.

Two-step simulation of 5-turbine WPP:

Inflow wind speed [m/s]	Power increase by yawing [%]	Change of blade root bending [%]	Change of tower base bending [%]
14	8.6	-1.5	13.1
12	6.7	3.1	11.2
10	7.1	0.6	12.3

→ Wake steering by yawing increases the power gain.

→ Mean bending moments are affected.

→ The turbine loading should be analysed in more detail (see Outlook).

Outlook

This work investigated how the STAS Turbine models can be integrated with plant flow models.
Future work towards a holistic model of a wind power plant for model-based optimal control:

- Build parameter-varying turbine models covering wider operational range.
- Amend the measures for loading, e.g. caused by rotor periodicity and crosswind velocities.
- Analyse loads at relevant parts in the turbine for different scenarios.
- Reduce STAS Turbine models to relevant states for WPP control.
- Optimize WPP together with STAS Turbine model using measures of structural loading to trade off power production and load reduction.
- Investigate other plant flow models for integration with STAS WPP.

References

[1] Merz, K. STAS WPP code. https://github.com/SINTEF-Energy-Wind/STAS-WPP
[2] Merz, K. (2018). STAS Aeroelastic 1.0 - Theory Manual.
[3] Merz, K. et al. An electromechanical model of the TotalControl reference wind power plant
[4] Gebraad et al. (2016). Wind plant power optimization through yaw control using a parametric model for wake effects - a CFD simulation study. Wind Energy, 19 (1), 95–114.

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