Active Power Control of Multi-Rotor Turbines for Fast Frequency Reserve

Horst Schulte, Urs Giger

Control Engineering Group, School of Eng.: Energy and Information Science, HTW Berlin
GGS Giger Gear Systems GmbH

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Hochschule für Technik und Wirtschaft Berlin
University of Applied Sciences

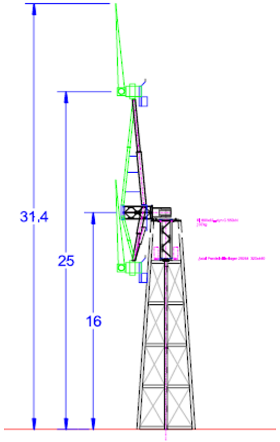
Overview

1. Introduction
2. Decentralized Active Power Control
3. Load Mitigation of Multi-Rotor Turbines
4. Simulation Studies
5. Conclusion

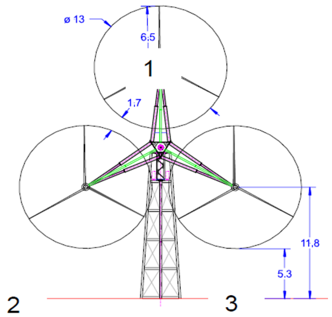
1. Introduction

Motivation

- Multi-Criteria Control Problem
  - Load mitigation in large structures by decentralized force control
  - Active power control für Fast Frequency Reserve (FFR) and Frequency Containment Reserve (FCR)



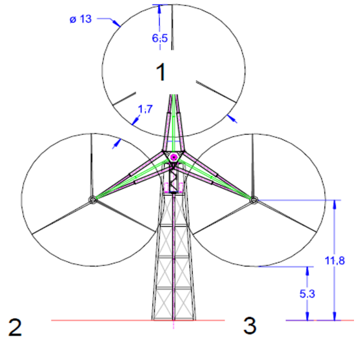
- Contribution
  - Decentralized Control Scheme for Multi-Rotor Turbines
  - Active Power Control and Analysis of the converter topology
  - Active Damping by Higher-level Trust Force Adaptation Control



1. Introduction

Methodes

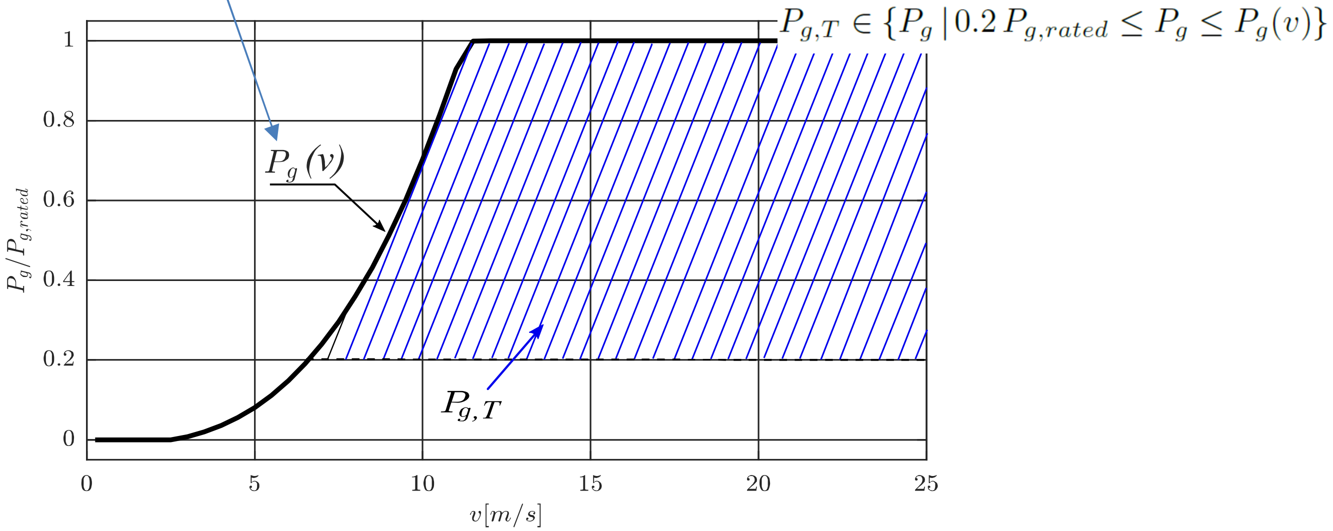
- Model-based Decentralized Controller Design
  - Individual Turbine-Level Power Control
- Data-driven load mitigation
  - Active Damping Control of Mechanical Structures by Torque and Force Control
- Validation
  - Proof of Concept
  - High-fidelity Simulation using Qblade
  - Experimental Validation (in Cooperation with Fraunhofer IWES)



2. Decentralized Active Power Control

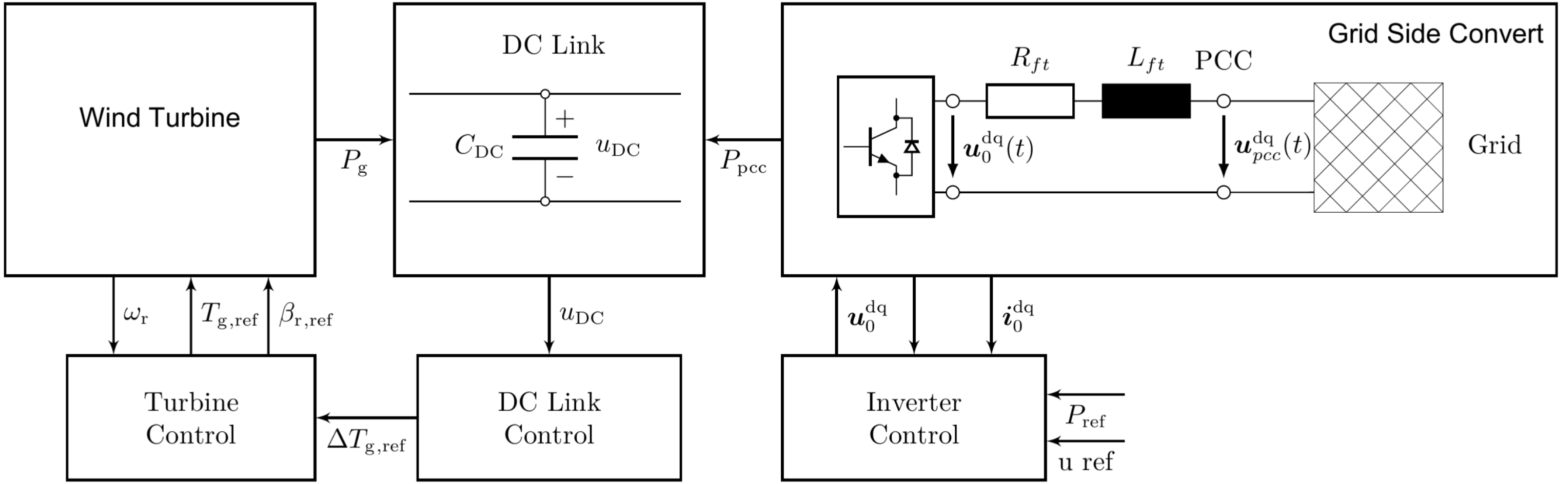
- General Concept: Demanded Power Curve

Maximum-Limit Power Tracking vs. Demanded Power Tracking



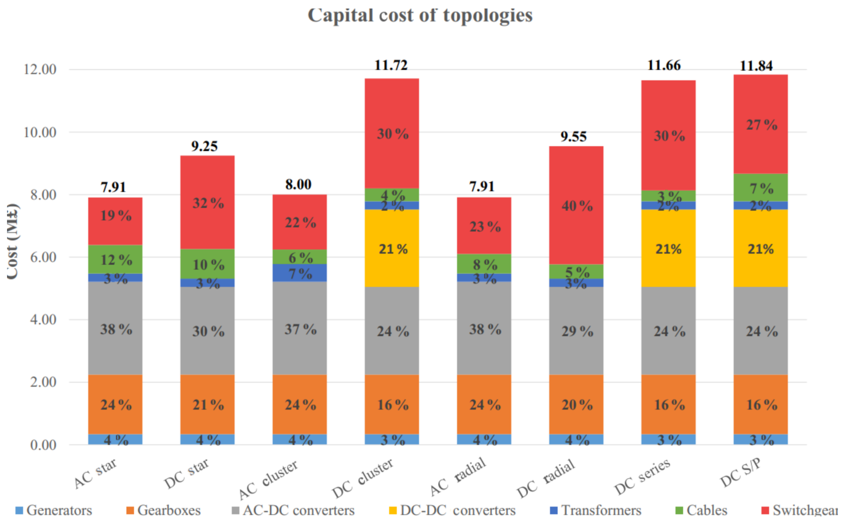
2. Decentralized Active Power Control

- Converter-controlled Power Flow (*Individual Rotor Level*)
  - Primary Control (Wind Turbine Control)
  - Secondary Control (Grid Side Inverter Control)



2. Decentralized Active Power Control

- *Multi-Rotor* Inverter Toplogy



P. Pirrie, D. Campos-Gaona, and O. Anaya-Lara; Comparison of electrical collection topologies for multi-rotor wind turbines; Wind Energ. Sci., 5, 1237–1252, 2020 https://doi.org/10.5194/wes-5-1237-2020

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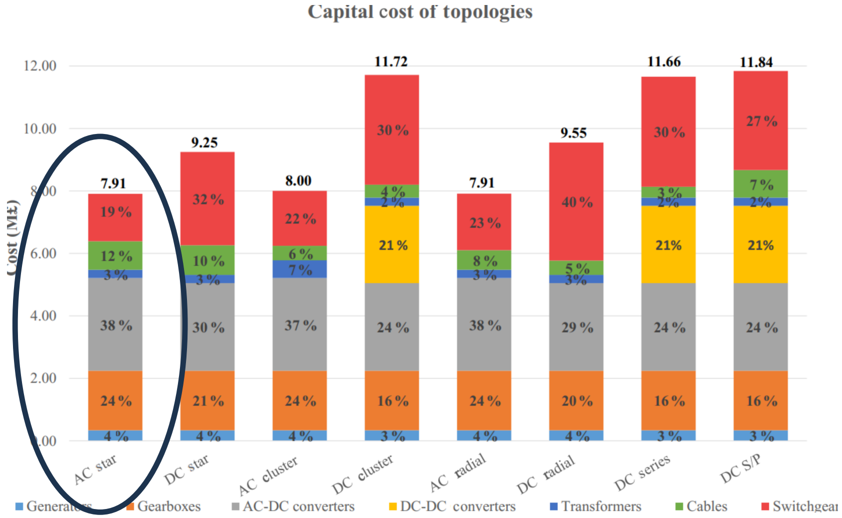

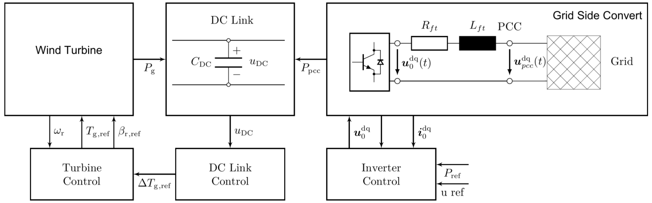

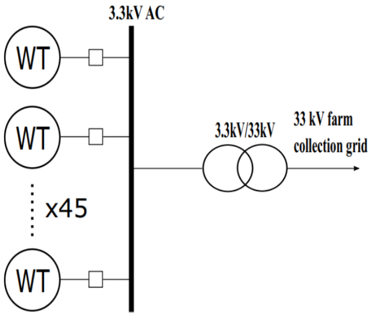

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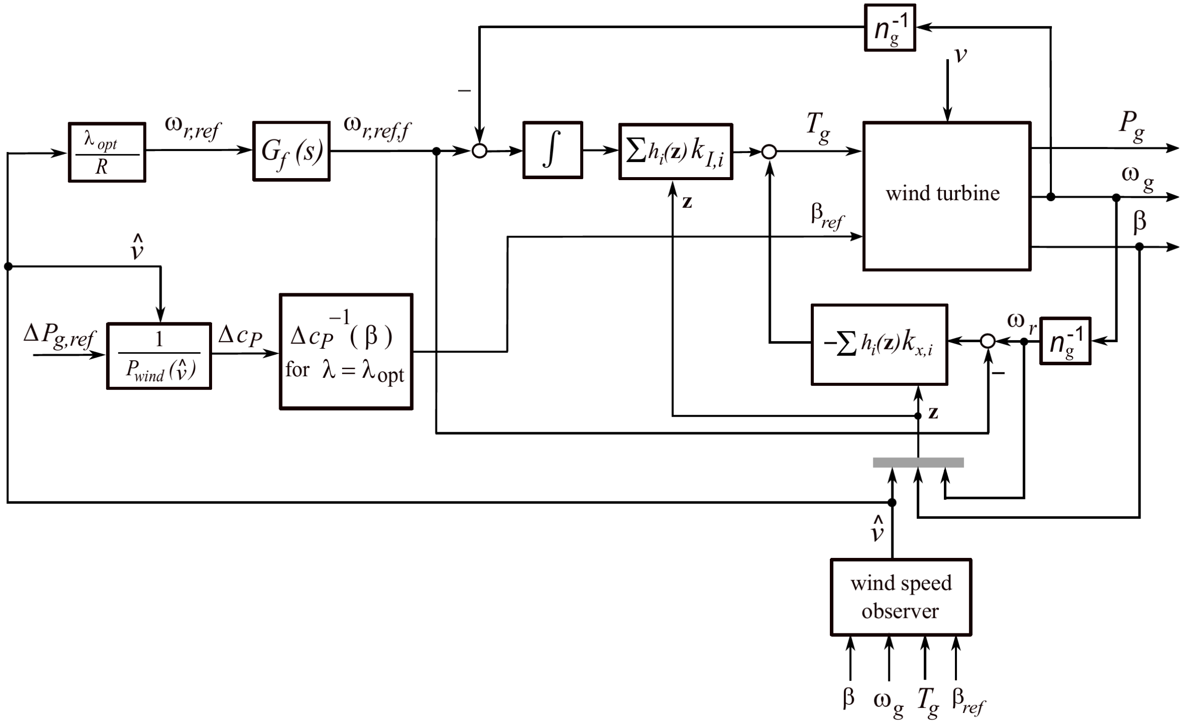
2. Decentralized Active Power Control

- Primary Turbine Control-Scheme: Below the Rated Wind Speed



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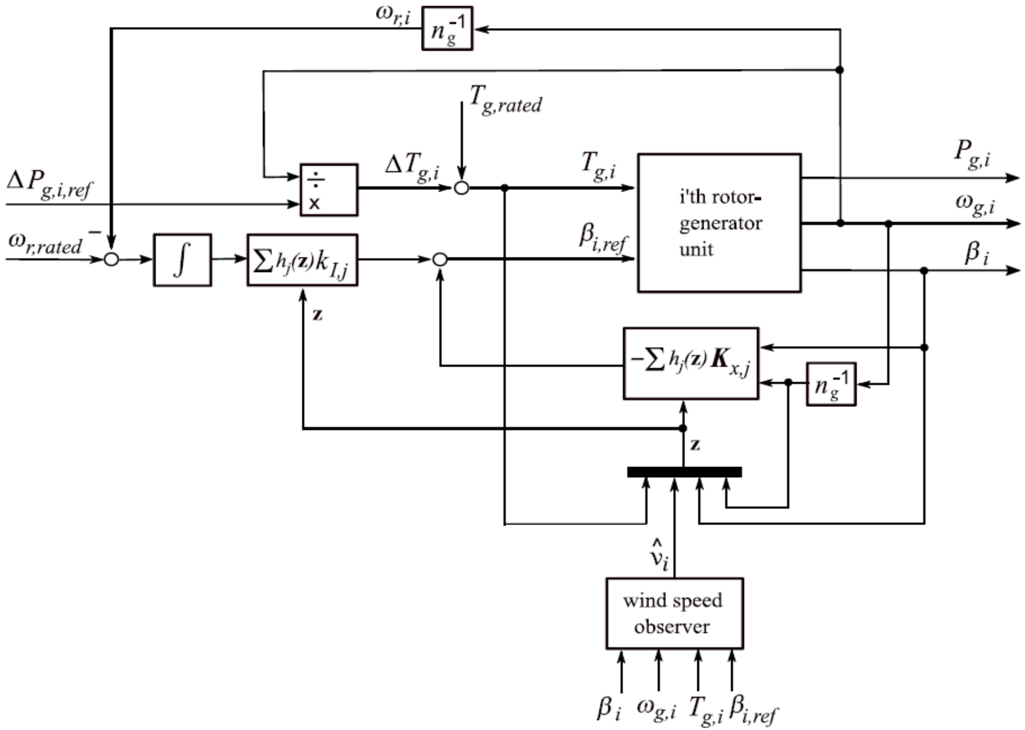
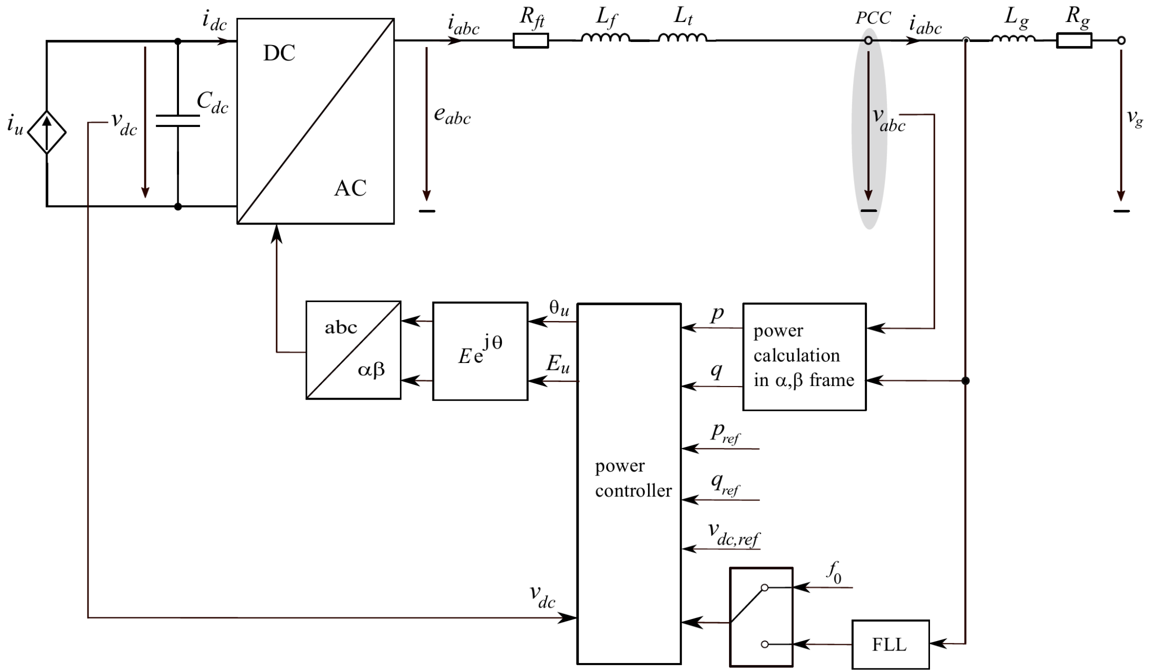


2. Decentralized Active Power Control

- Secondary Inverter Control: Grid-Forming Control for FFR



3. Load Mitigation of Multi-Rotor Turbines

Load Mitigation by Mixed Dezentralized control

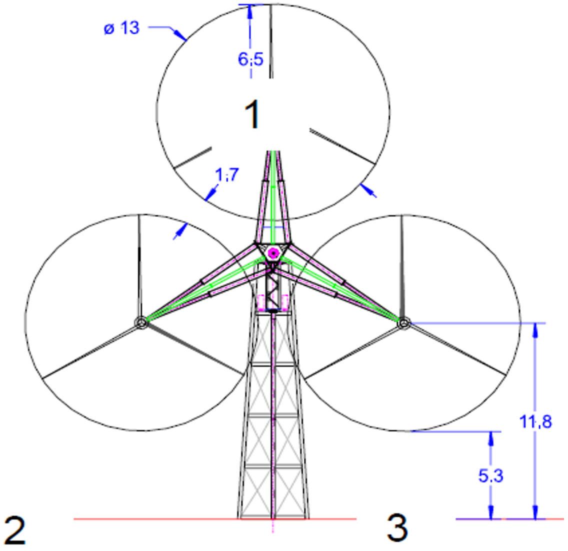
Requirements of a suitable multi-rotor control concept for load mitigation

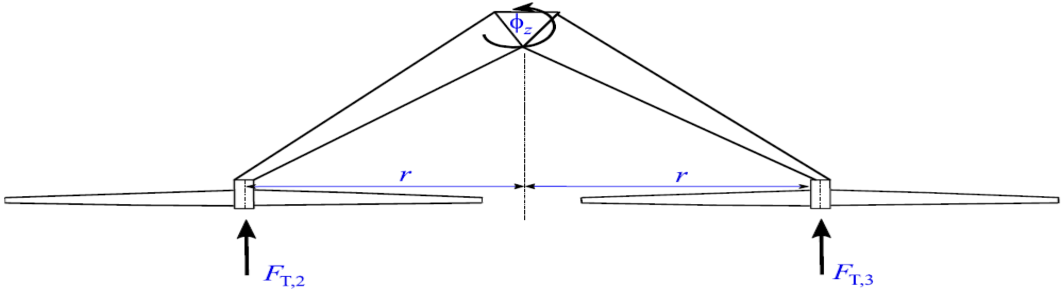
- Decentralized thrust-force / rotor-torque control on individual level
- Higher-level Load mitigation
- Structural damping through model-based controller design
- Agent-based Design with some higher-level prio-knowledge about the distributed mechanical tower/arm structure

3. Load Mitigation of Multi-Rotor Turbines

Control Scheme for Triple-Rotor Turbine

Illustrating Example: Load damping of the tower torsion of main axis

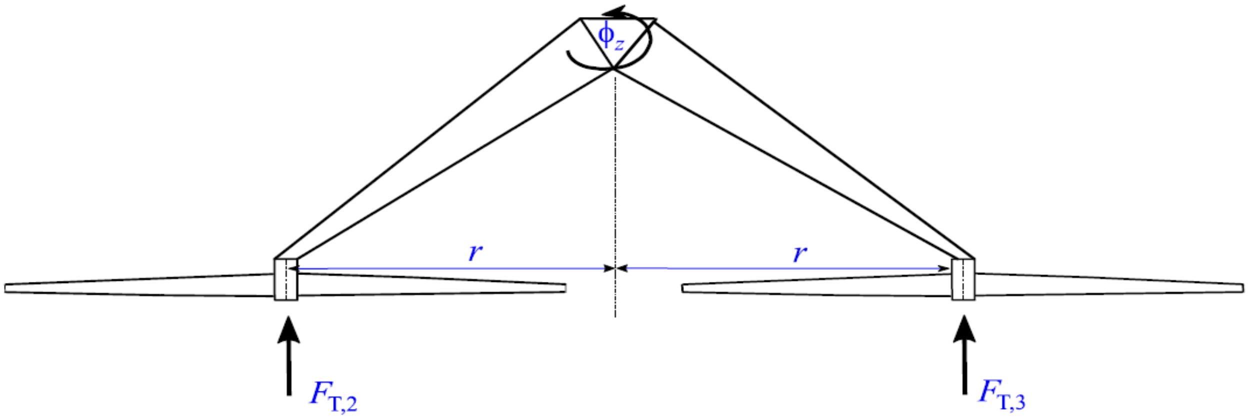




3. Load Mitigation of Multi-Rotor Turbines

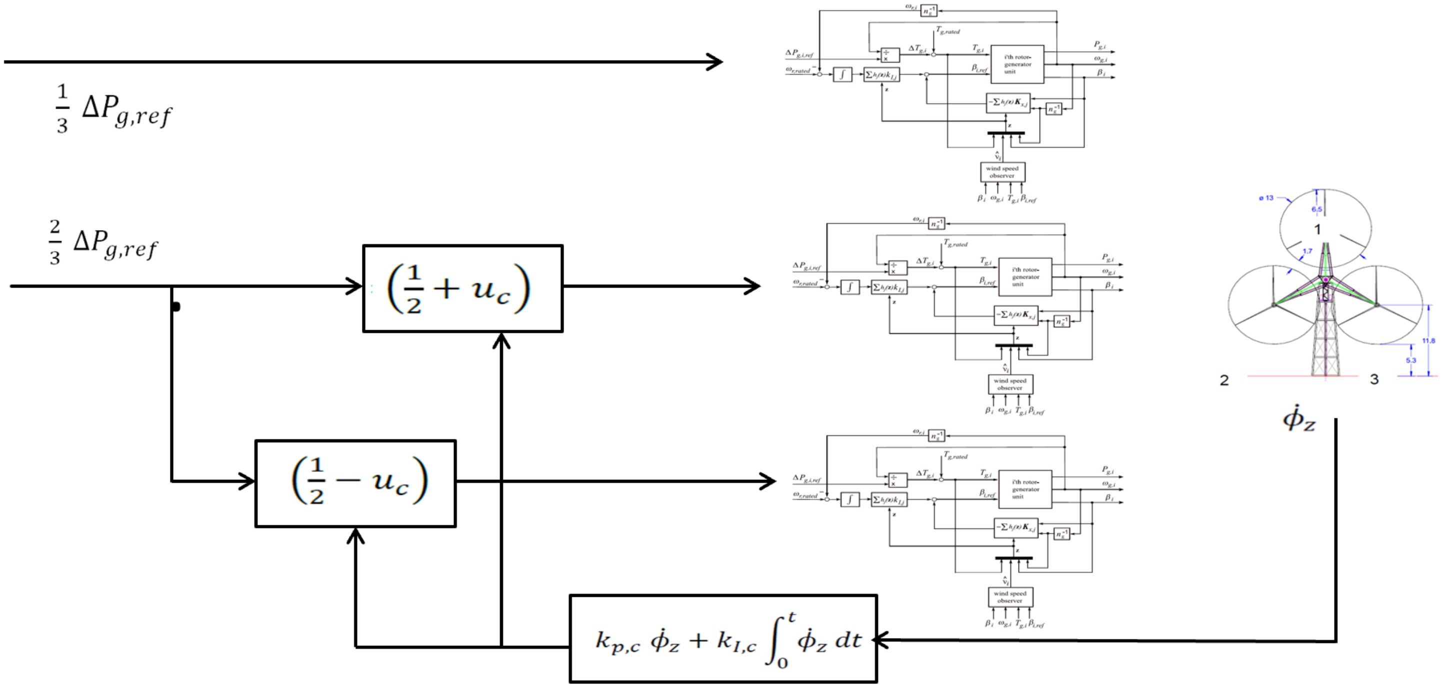
Main tower motion equation

$$J_z \ddot{\phi}_z = -k_z \phi_z - d_z \dot{\phi}_z + r\left(F_{T,3} - F_{T,2}\right)$$



3. Load Mitigation of Multi-Rotor Turbines

Control Scheme



3. Load Mitigation of Multi-Rotor Turbines

Control Law

Torsional vibration damper of the main tower

$$u_c = k_{p,c}\, \dot{\phi}_z + k_{I,c} \int_0^t \dot{\phi}_z \, dt$$

superimposed the demanded power tracking controller

$$\Delta P_{g,2,ref} = \left(\tfrac{1}{2} + u_c\right) \frac{2}{3}\, \Delta P_{g,ref}\,, \qquad \Delta P_{g,3,ref} = \left(\tfrac{1}{2} - u_c\right) \frac{2}{3}\, \Delta P_{g,ref}$$

4. Simulation Studies

Proof of Concept:

- Wind speed scenario

  t < 50s: wind is still uniform

  t > 50s : wind speed at

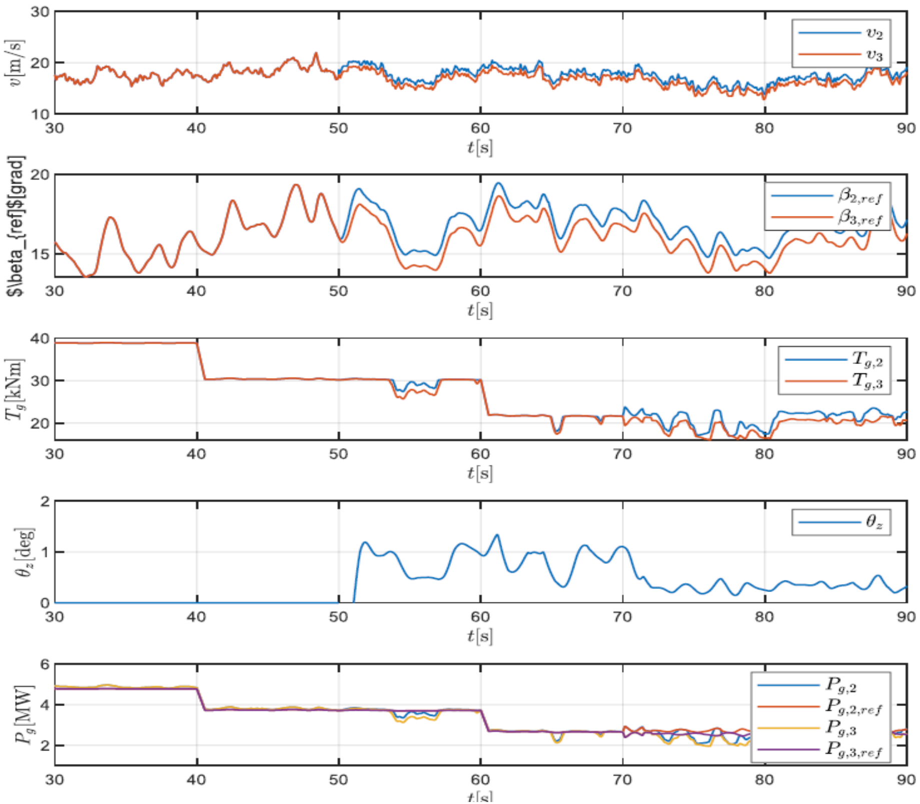
  rotor 2 & 3 differs 1 m/s

- <u>Power tracking</u>

  Total load derating up **t = 40s**

- <u>Load mitigation</u> is activated

  up **t = 70s**

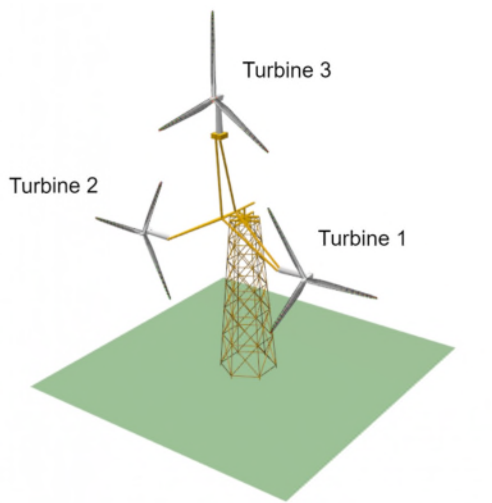


4. Simulation Studies

Validation by High-fidelity Simulation Tool using Qblade

- Qblade is an open-source software tool used for the design and analysis both aerodynamic and structural assessments for single and multi-rotor turbines
- Qblade can be used for onshore, offshore wind turbines (also floating)
- Tool can analyze the structural integrity of the multi-rotor considering materials and loads they will experience in operation
- Results were presented on Torque 2024

  Multi-Rotor Wind Turbine Control: Strategies for Pitch Replacement and Mechanical Load Mitigation The Science of Making Torque from Wind (Torque 2024), Firenze Fiera - Palazzo degli Affari, Florence, Italy, 29.05.2024



6. Conclusion

- Control concept of multi-rotor turbines for power tracking and load mitigation was presented

- Focus on basic control scheme, control laws, and clarification by simulation

- Current Research:
  - Data-driven Load Mitigation Control
  - Experimental Setup: Drive-train, PLC programming, Mechanical System
  - Grid-Forming Topology for Multi-Rotor Turbines