ATLAS
Principle to Product

SUPERGEN

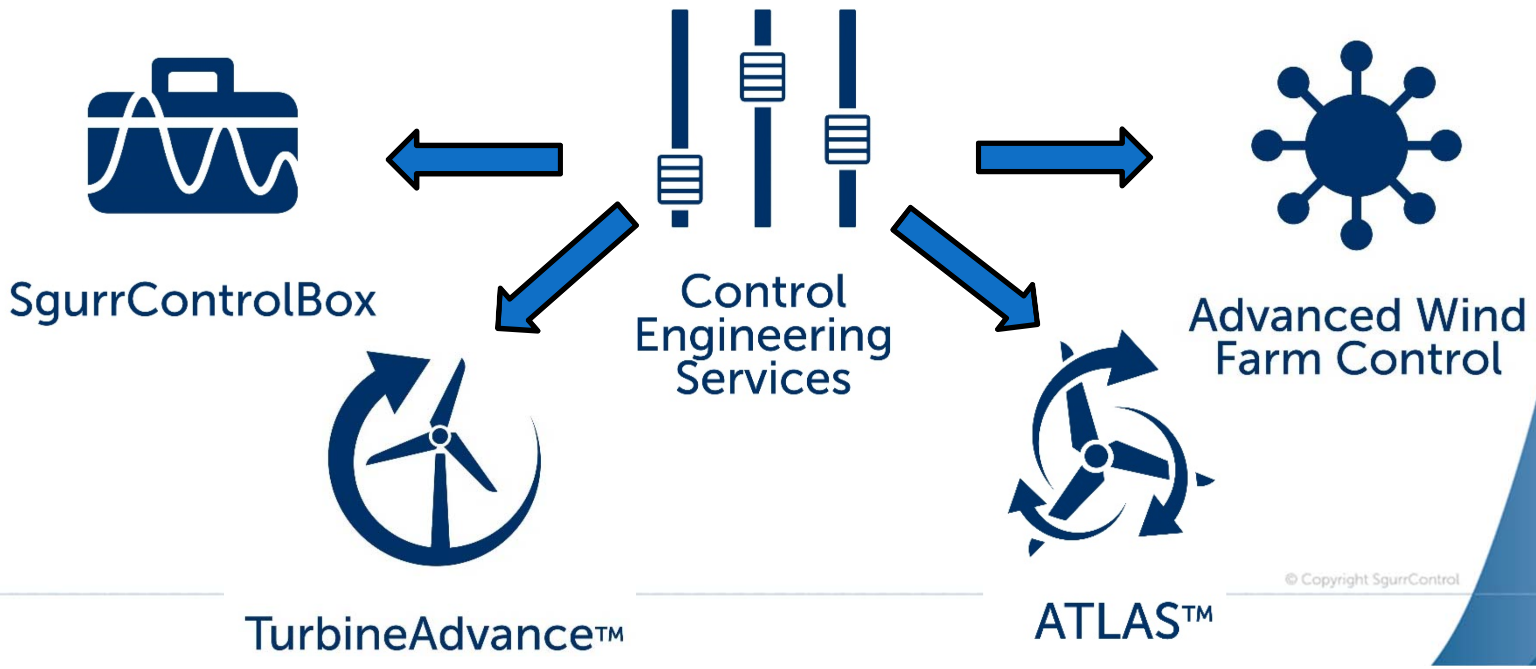
26th May 2016

Wind and tidal energy control experts

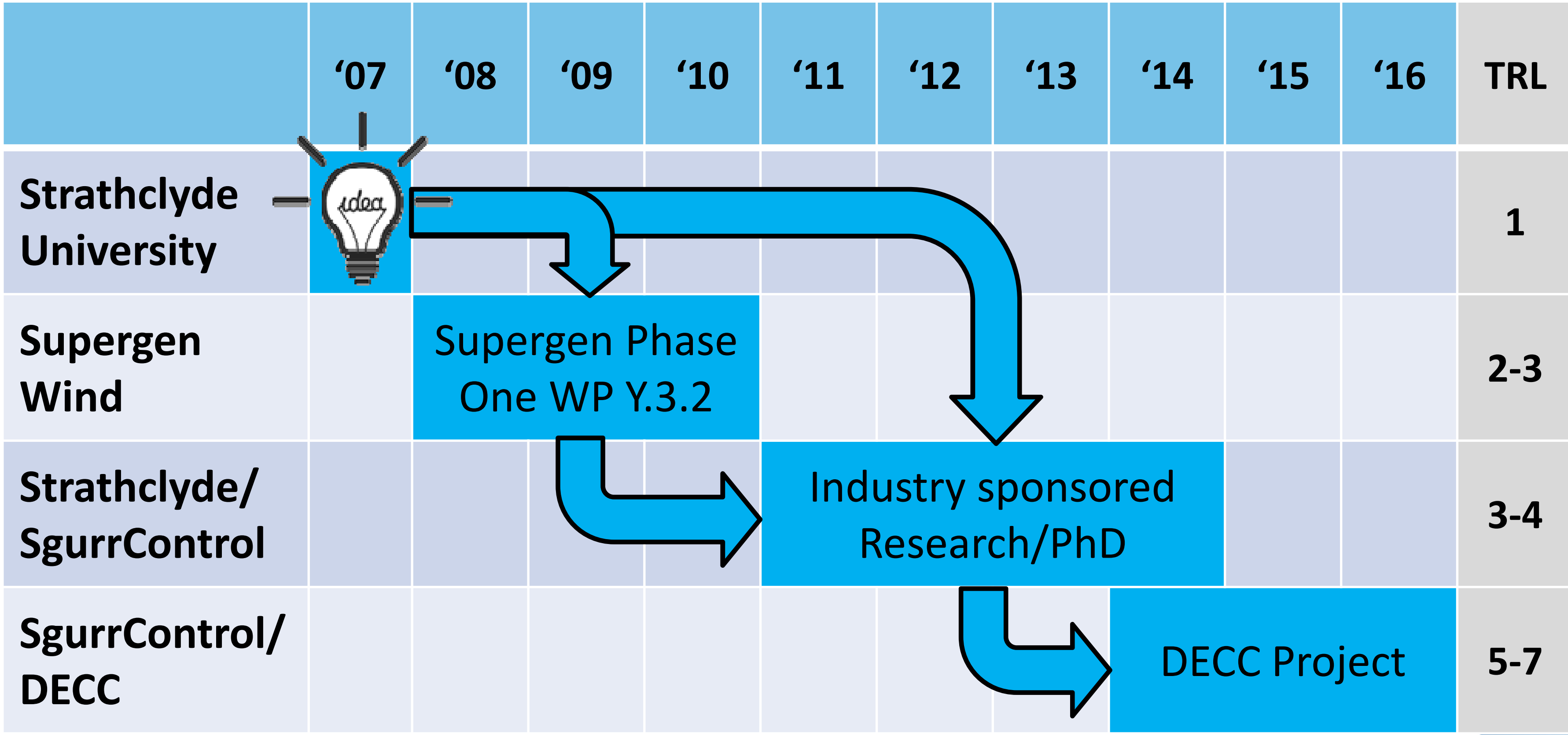
SgurrControl

Experts in wind and tidal energy control

- Engineering organisation providing **control solutions** to wind and tidal turbines to:
  - Optimise energy capture
  - Reduce damage on wind turbines
  - Minimise O&M costs
- Founded in 2008, joined SgurrEnergy in 2013



Principle to Product

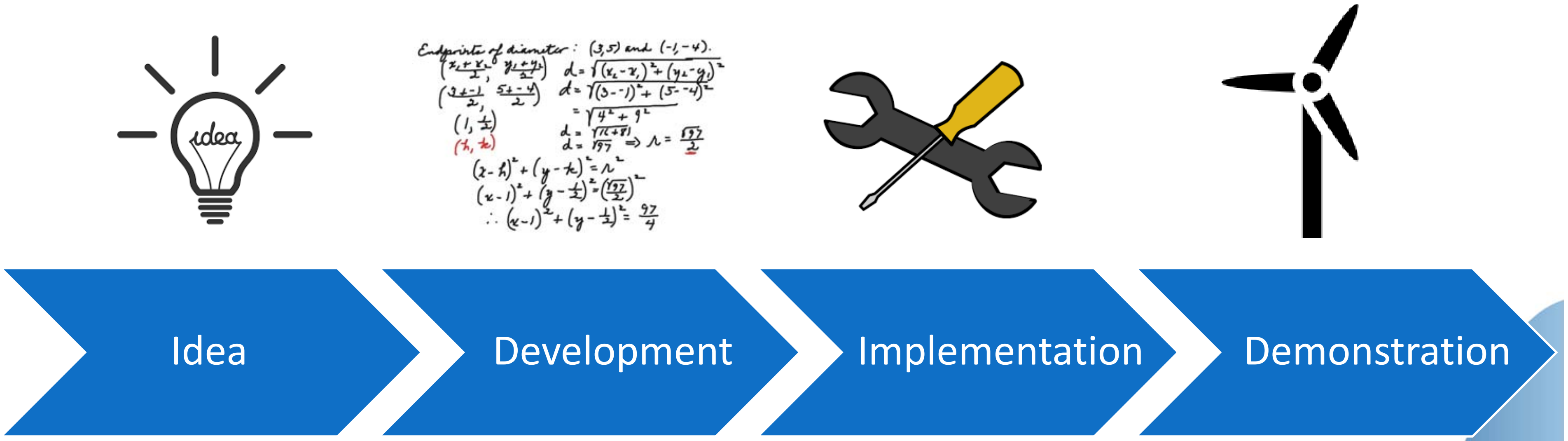


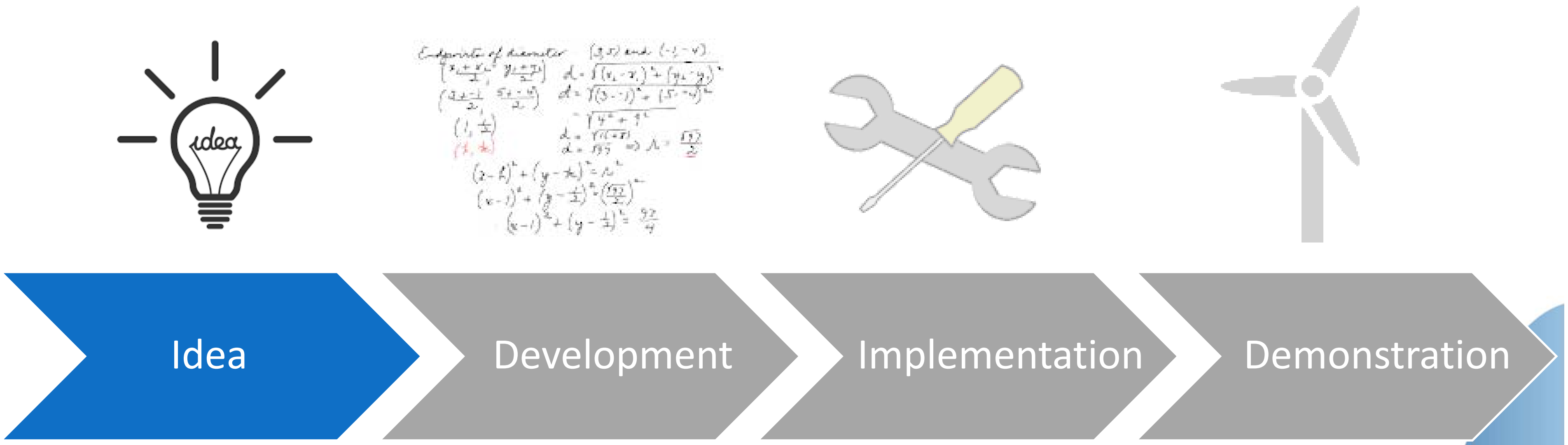
IBC

Individual Blade Control

ATLAS

Advanced Turbine Load Alleviation System


Idea
Development
Implementation
Demonstration



Idea
Development
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Demonstration

Control Overview

Supervisory Control

- Oversees total operation of wind turbine including
  - Start-up/shutdown
  - Safety of turbine operation
  - Fault handling
  - Data collection

Operational Control

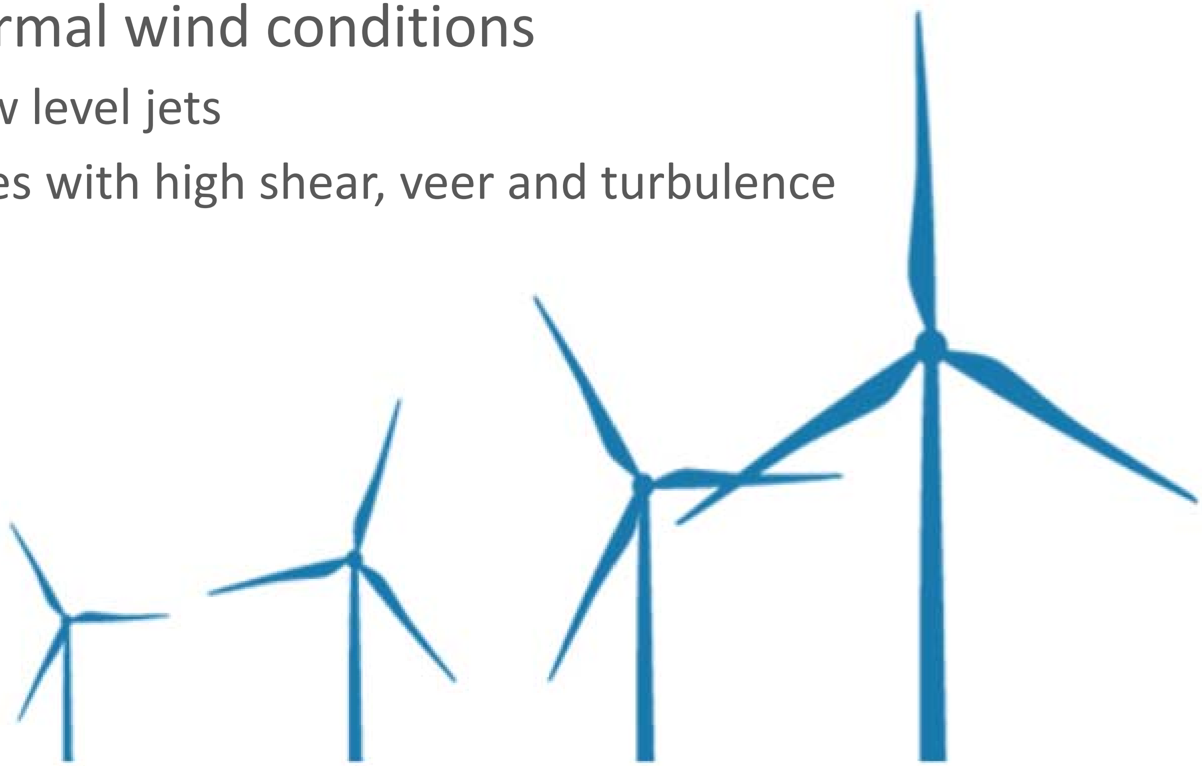
- Continuously adjusts dynamic state of wind turbine
  - Pitch, generator reaction torque and yaw

Operational Control

- Alters the pitch and generator torque demand to control the speed of the rotor
- Control is used to limit the power output above rated power and optimise power extraction below rated power
- Control is increasingly used to manage loads on the turbine
  - Drivetrain load alleviation
  - Tower load alleviation
  - Blade loads and rotor imbalance

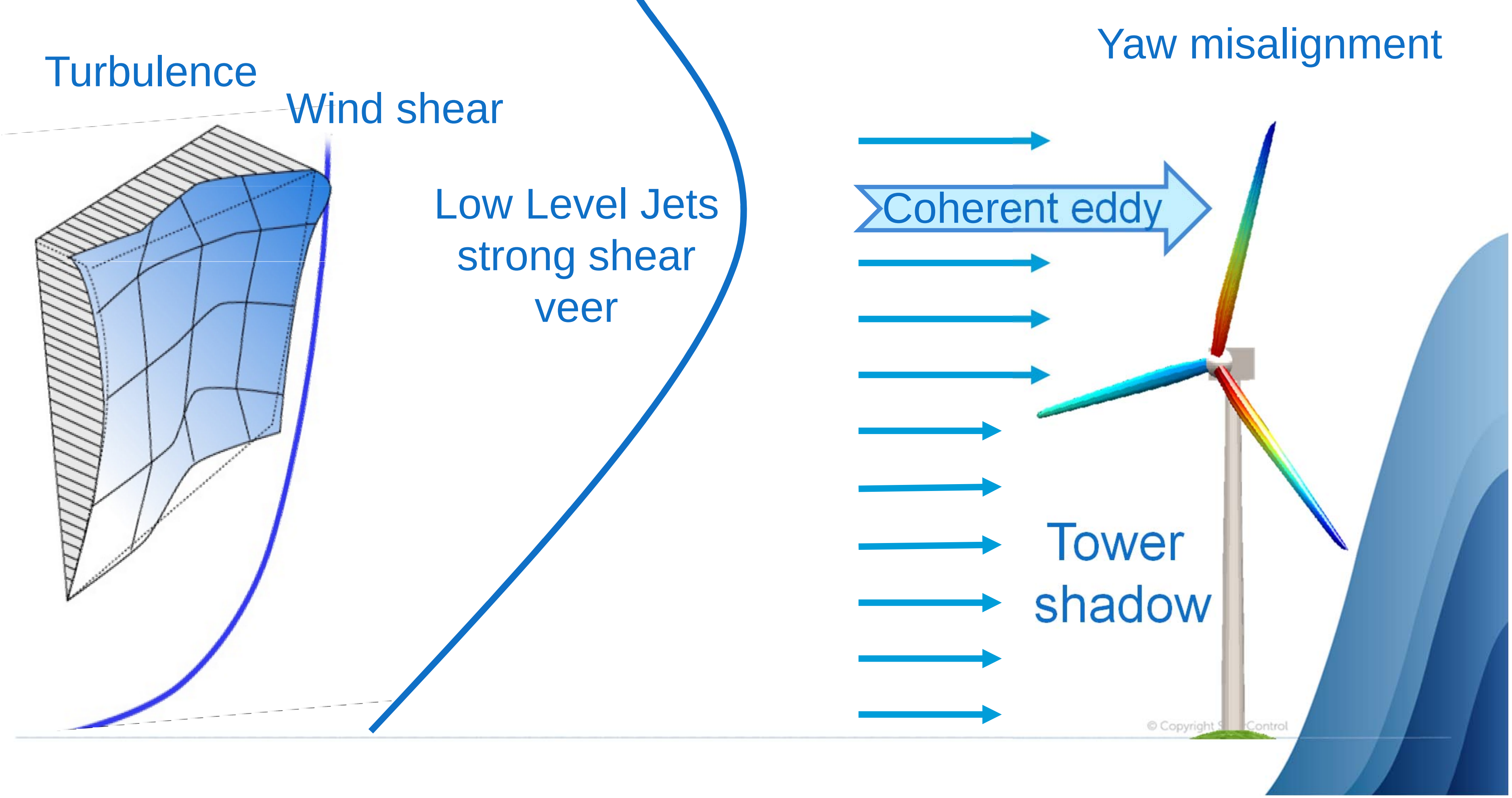
Importance of Control on Load Alleviation

- Increase in turbine size
  - Square-cube law between energy capture and material requirements
  - Size of wind field incident on the rotor
- Abnormal wind conditions
  - Low level jets
  - Sites with high shear, veer and turbulence

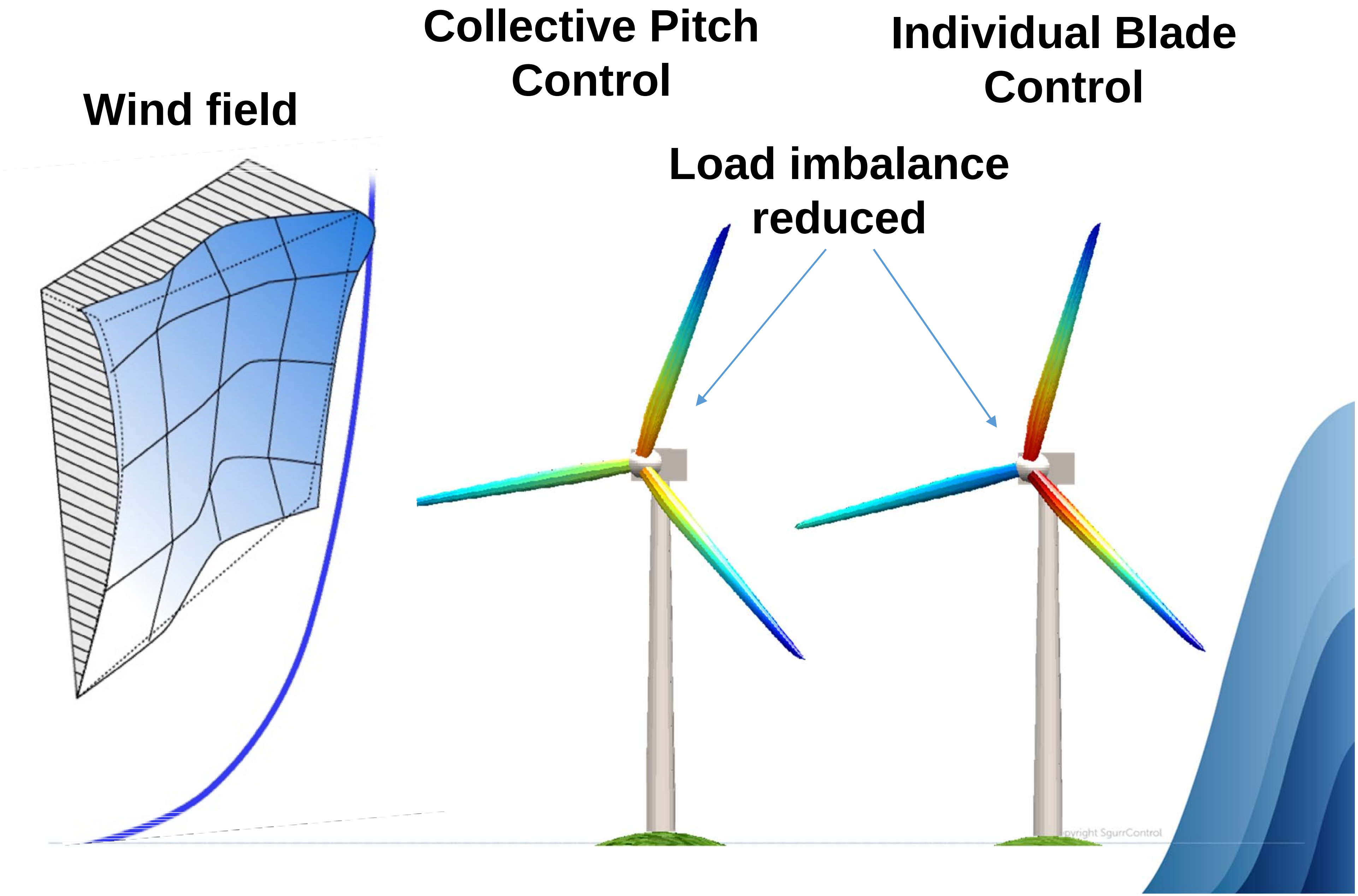


Underlying Cause of Loads

- Non-uniform wind fields damaging the turbine
  - Particularly at the harmonics of the rotational frequency of the rotor



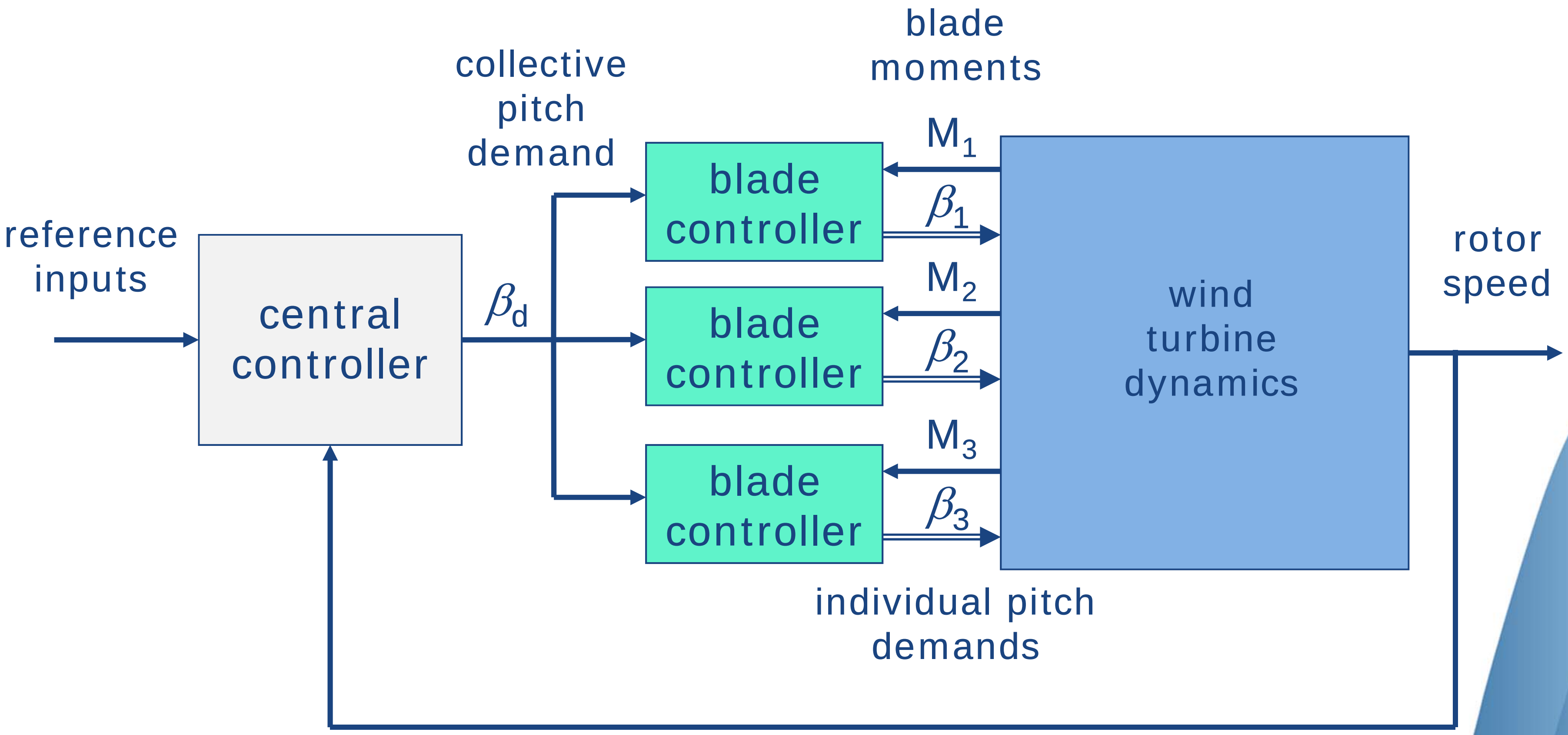
The Solution



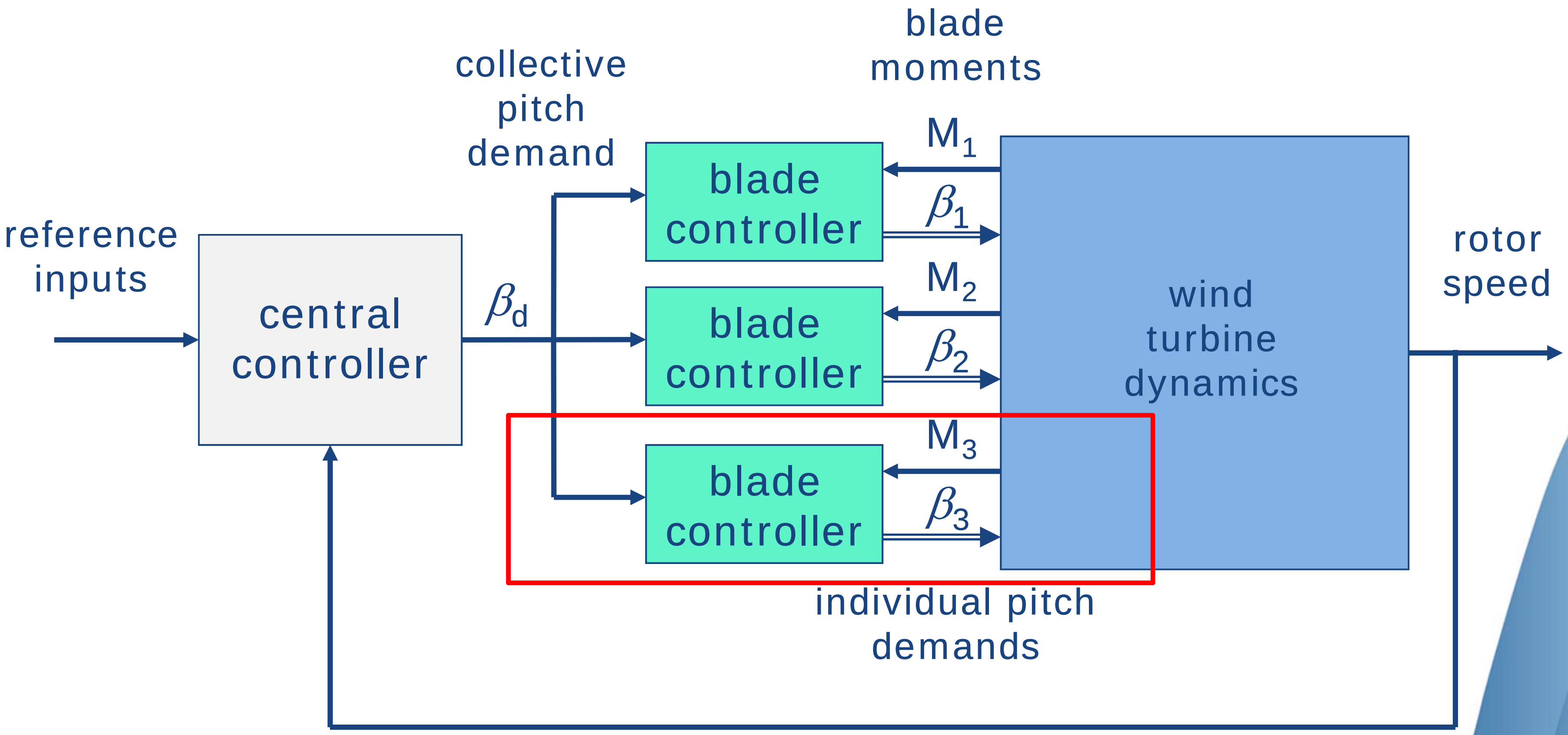
SUPERGEN Funding

- Individual Blade Control for Fatigue Load Reduction of Large-scaled Wind Turbines: Theory and Modelling (2010), Victoria Neilson

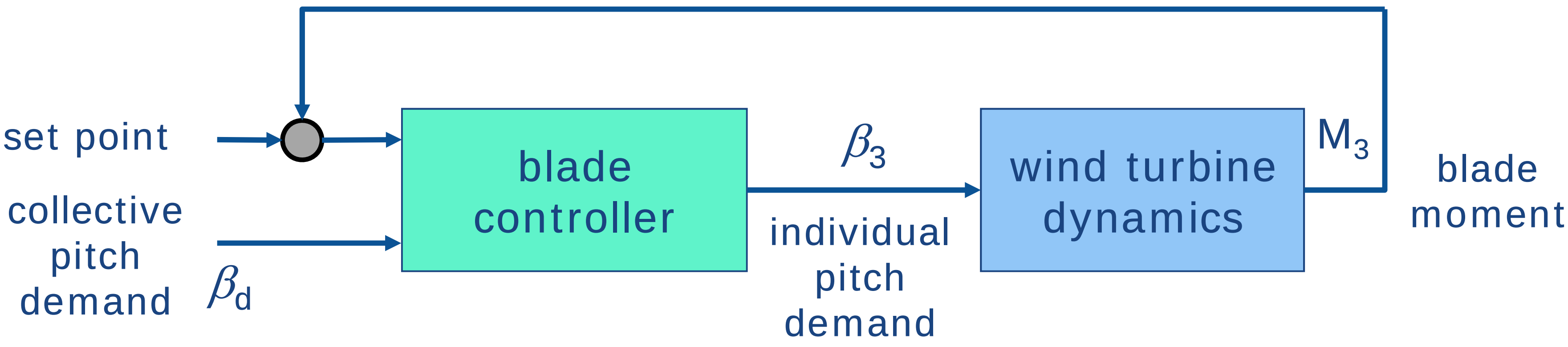
Turbine Control Structure

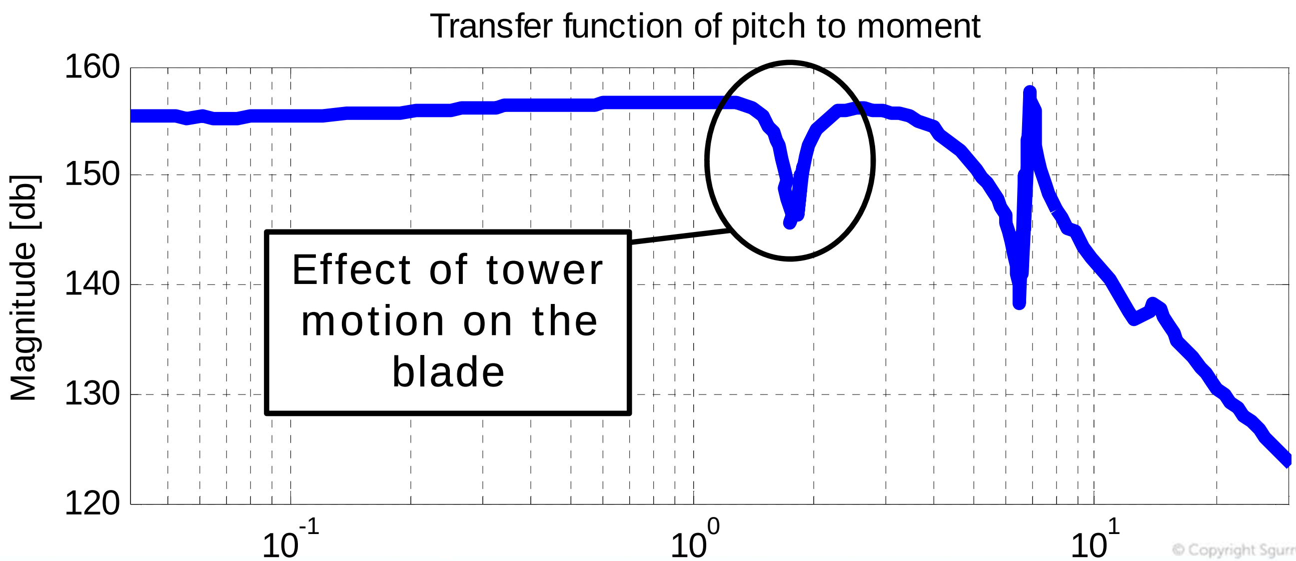


Turbine Control Structure

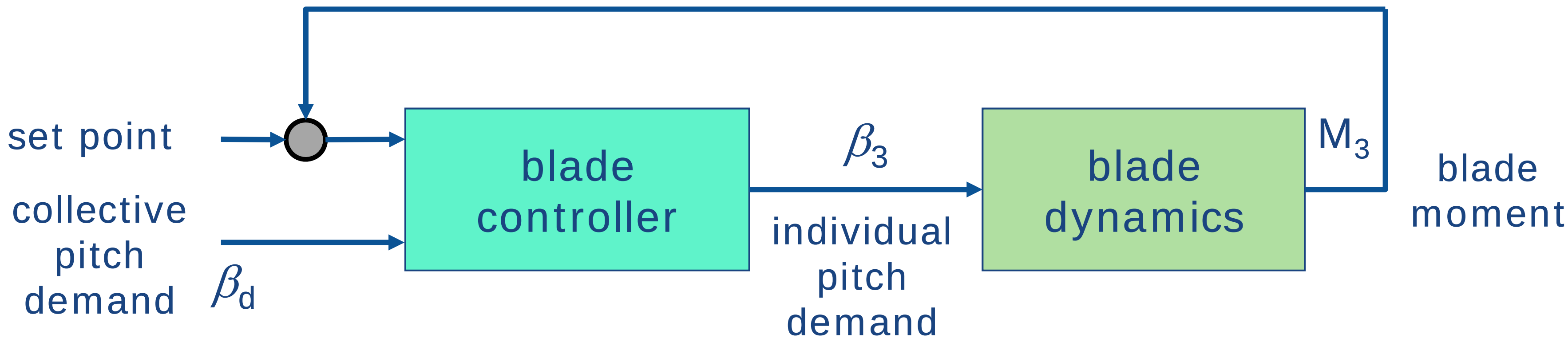


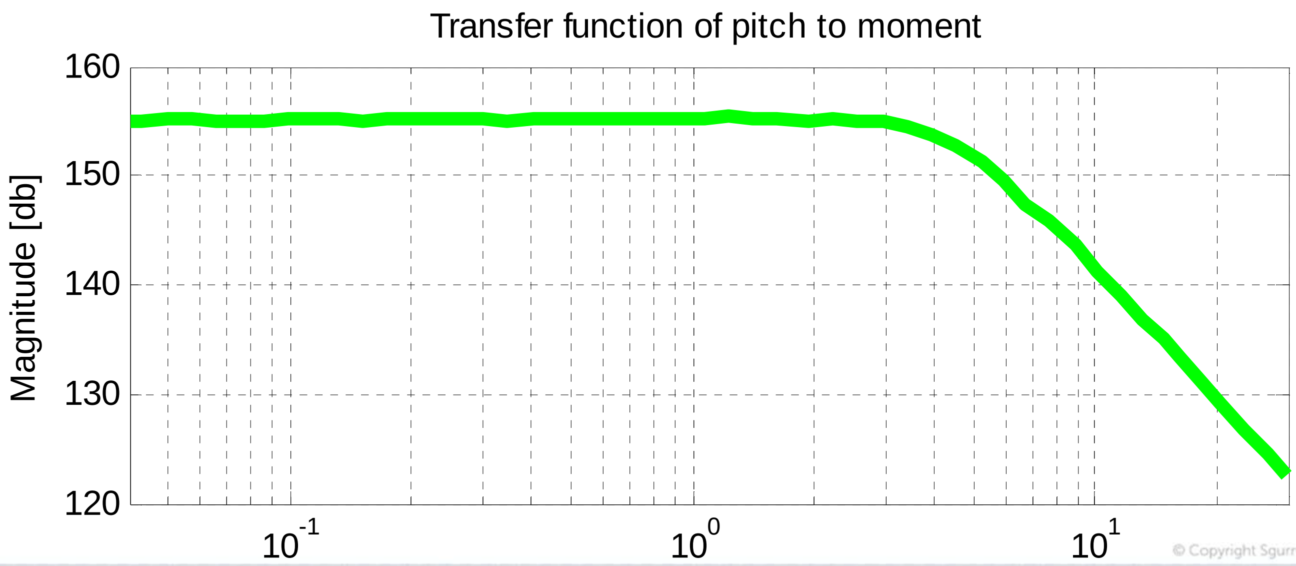
Blade Control Design





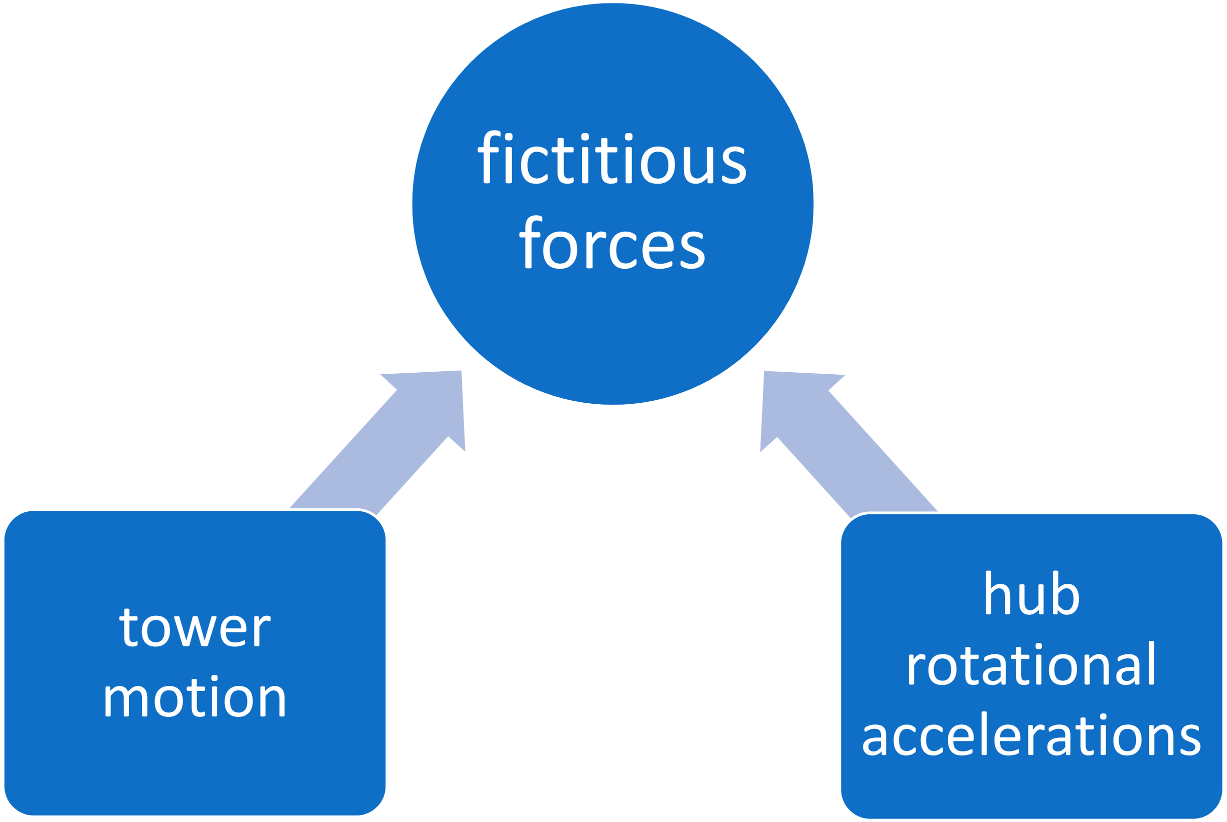
Blade Control Design





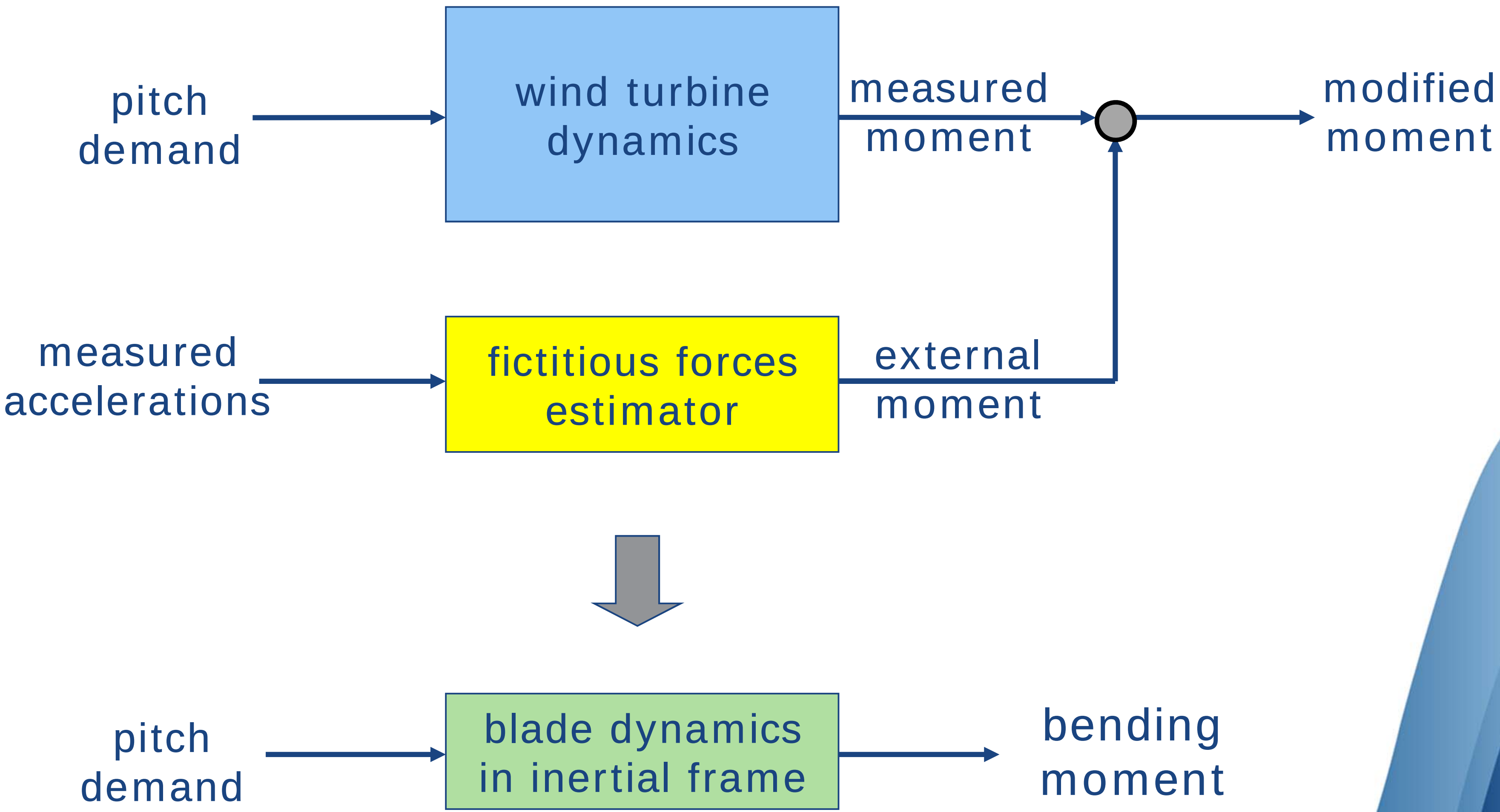
Fictitious Forces

- A **fictitious force** is an apparent **force** that acts on all masses whose motion is described using a non-inertial frame of reference, such as a rotating reference frame.

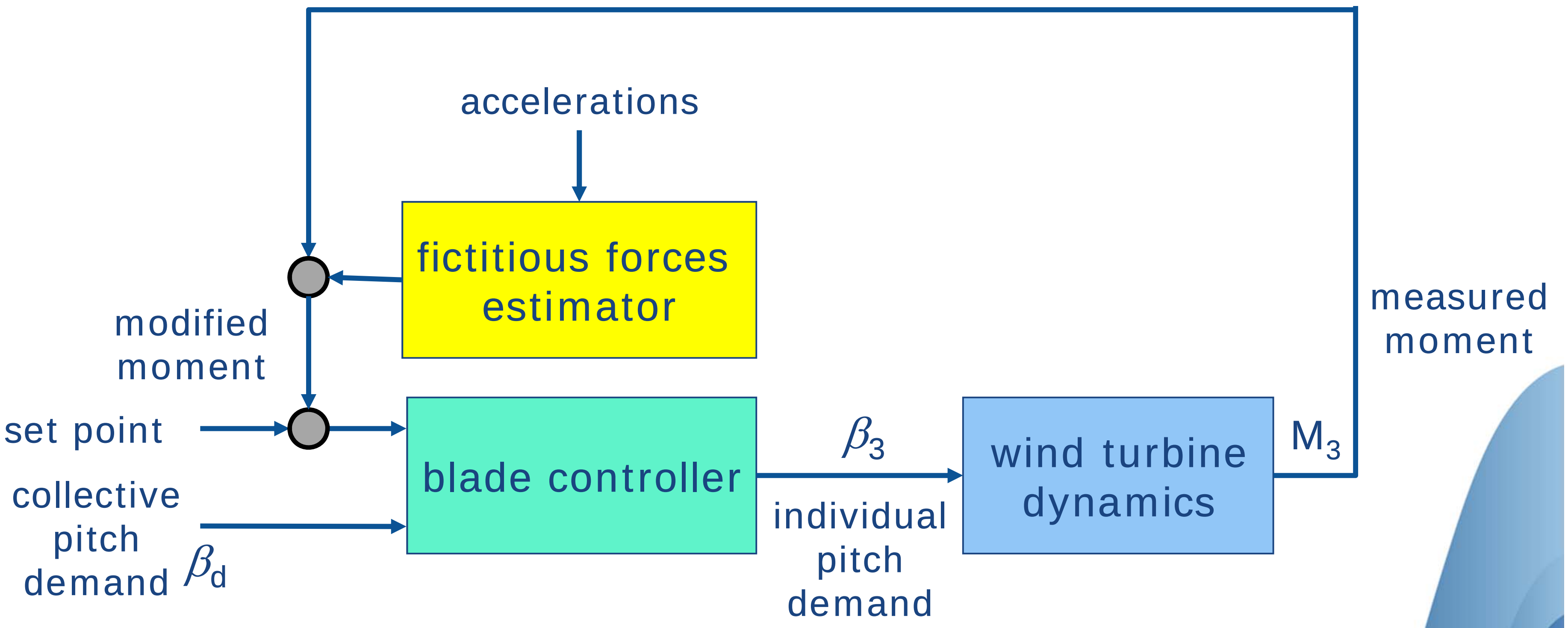


Simplifying the Dynamics

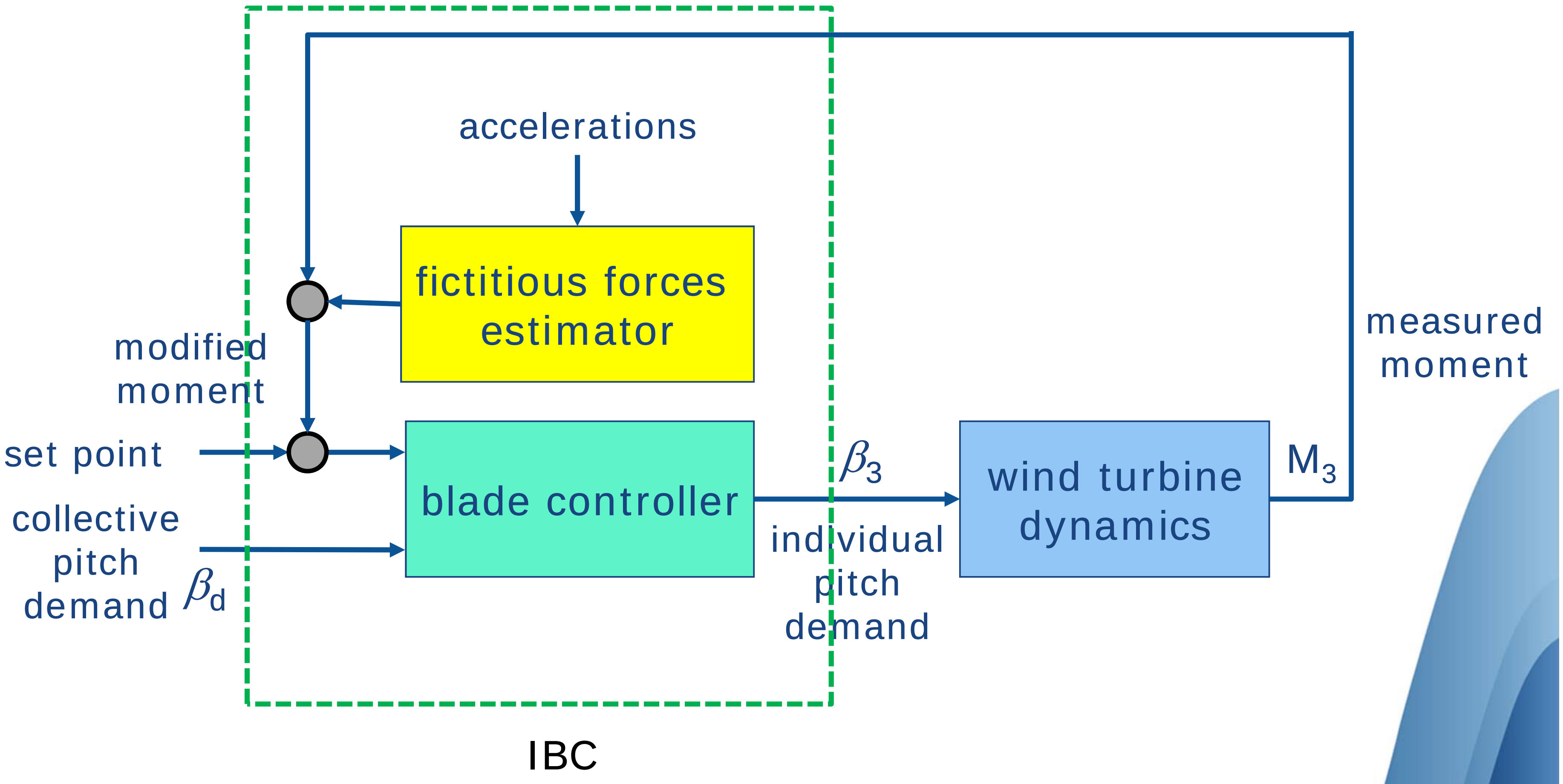
Simplifying the Dynamics



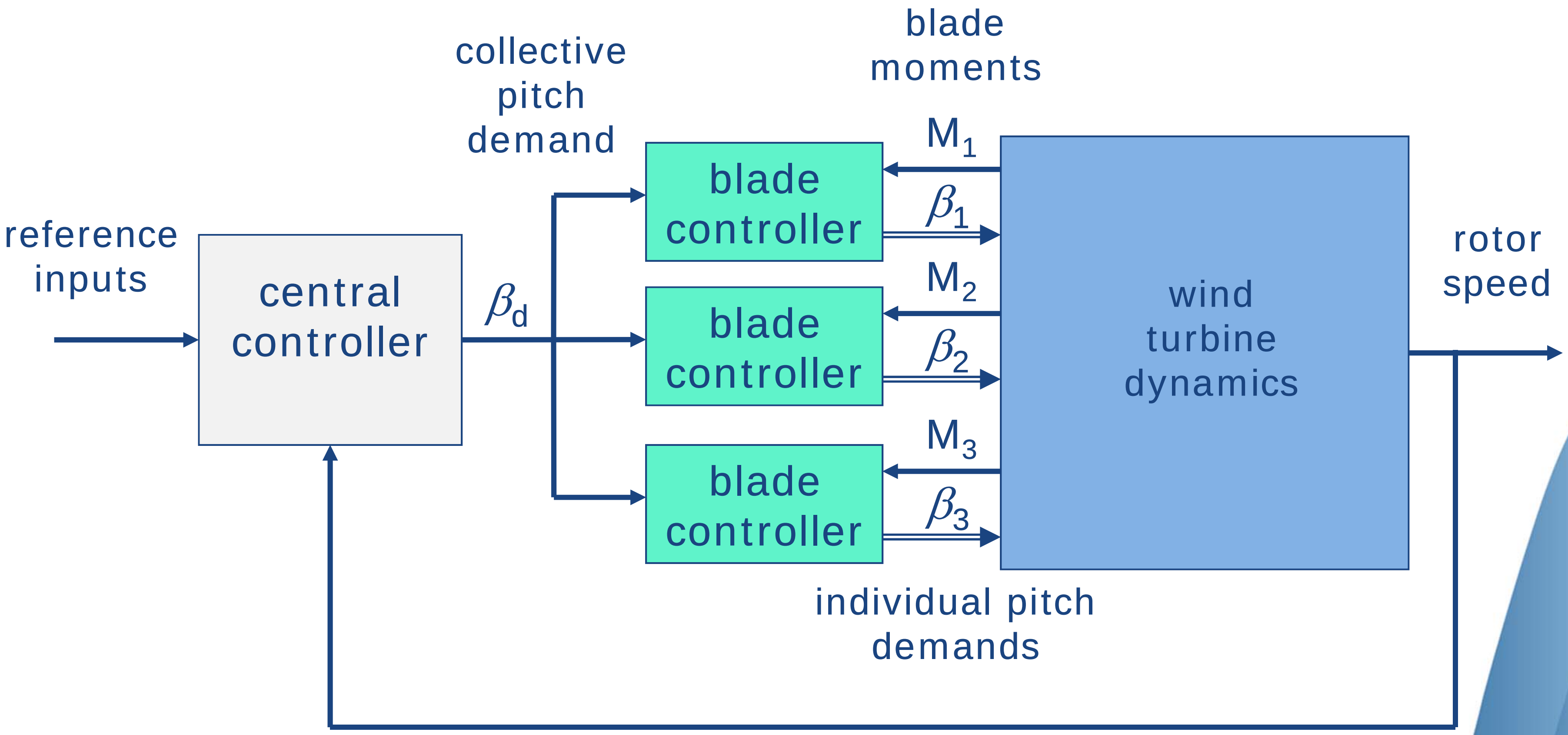
IBC Structure



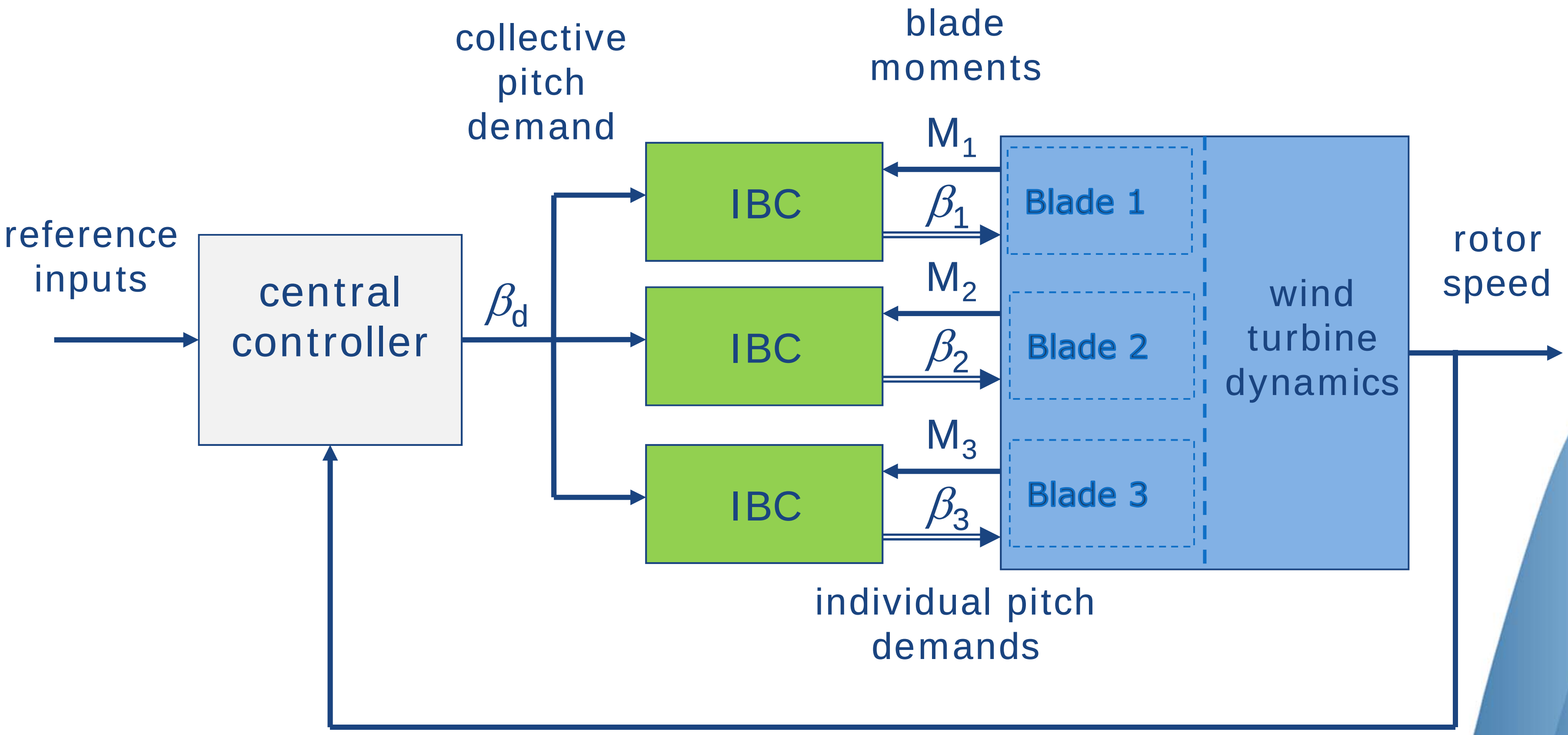
IBC Structure



Turbine Control Structure



Turbine Control Structure



Advantages of IBC

- Decoupled from turbine dynamics
- Decentralised control
- Transparent and straight forward to use
- No loss of information
- Has the flexibility to target critical loads
- Optimise trade-off between load reduction and pitch activity
- Target specific loadings at positions along the blades
- Simple structure to implement

The Product - ATLAS

Market

- Increased rotor diameter
- Rapid deployment of wind

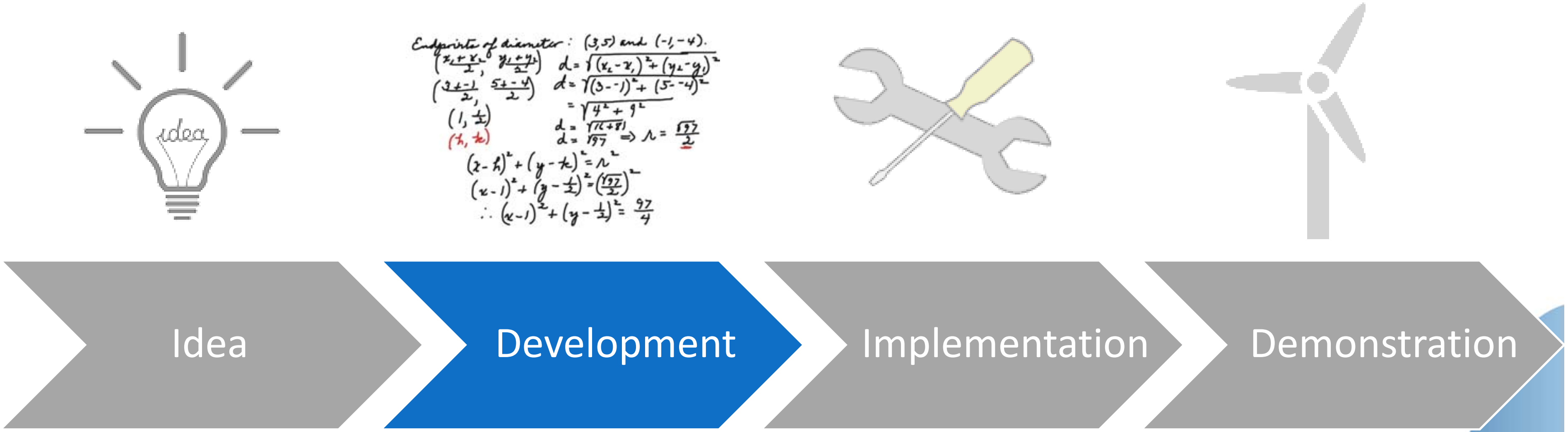
Problem

- Non-uniform wind
- Imbalanced rotor loads
- Damaging to turbine

Solution - IBC

- Control structure
  - Tuneable
  - Flexible

ATLAS


Idea
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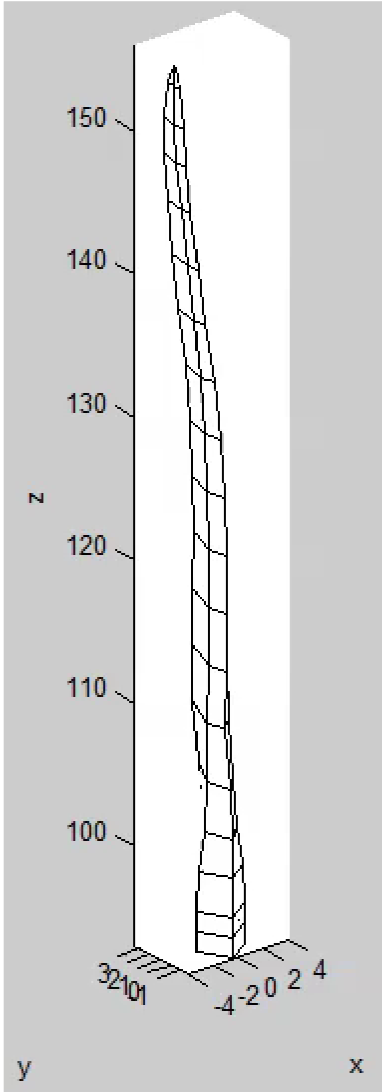
ATLAS™ Individual Blade Control

- Loads are the forces being applied onto the wind turbine component
- Fatigue load – the aggregate effect that the forces would have on the structure over the whole lifetime
- Extreme load – the abnormal and rare single event occurred at high level of force that the structure is generally designed to withstand

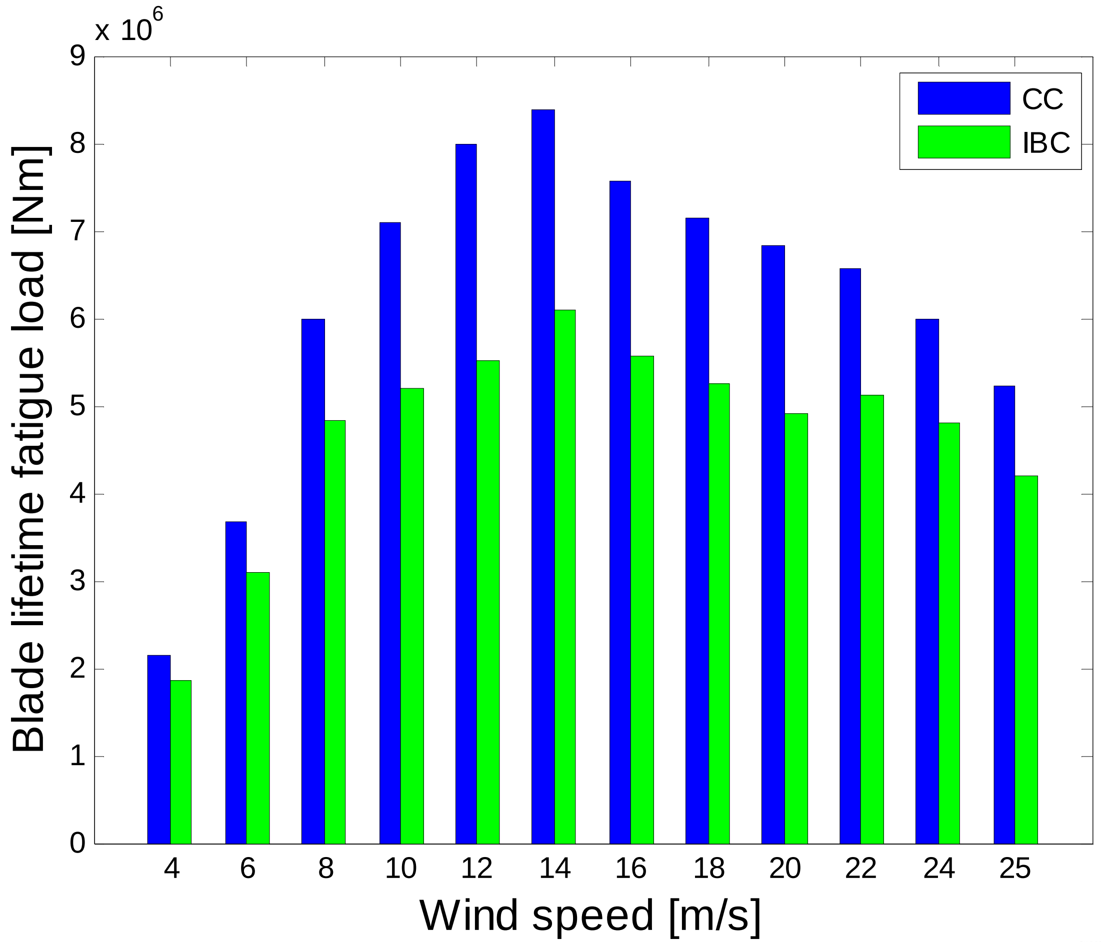


ATLAS™ - Reducing Fatigue Load

- Fatigue loads:
  - For the blades, the target component is out-of-plane bending moments
  - For the drive train, the target components are hub tilt and yaw moments
  - The main contribution is around the rated wind speed region where the wind turbine operates for most of the time
  - Assessed by lifetime (20 years) equivalent damage loads calculated through rain-flow counting

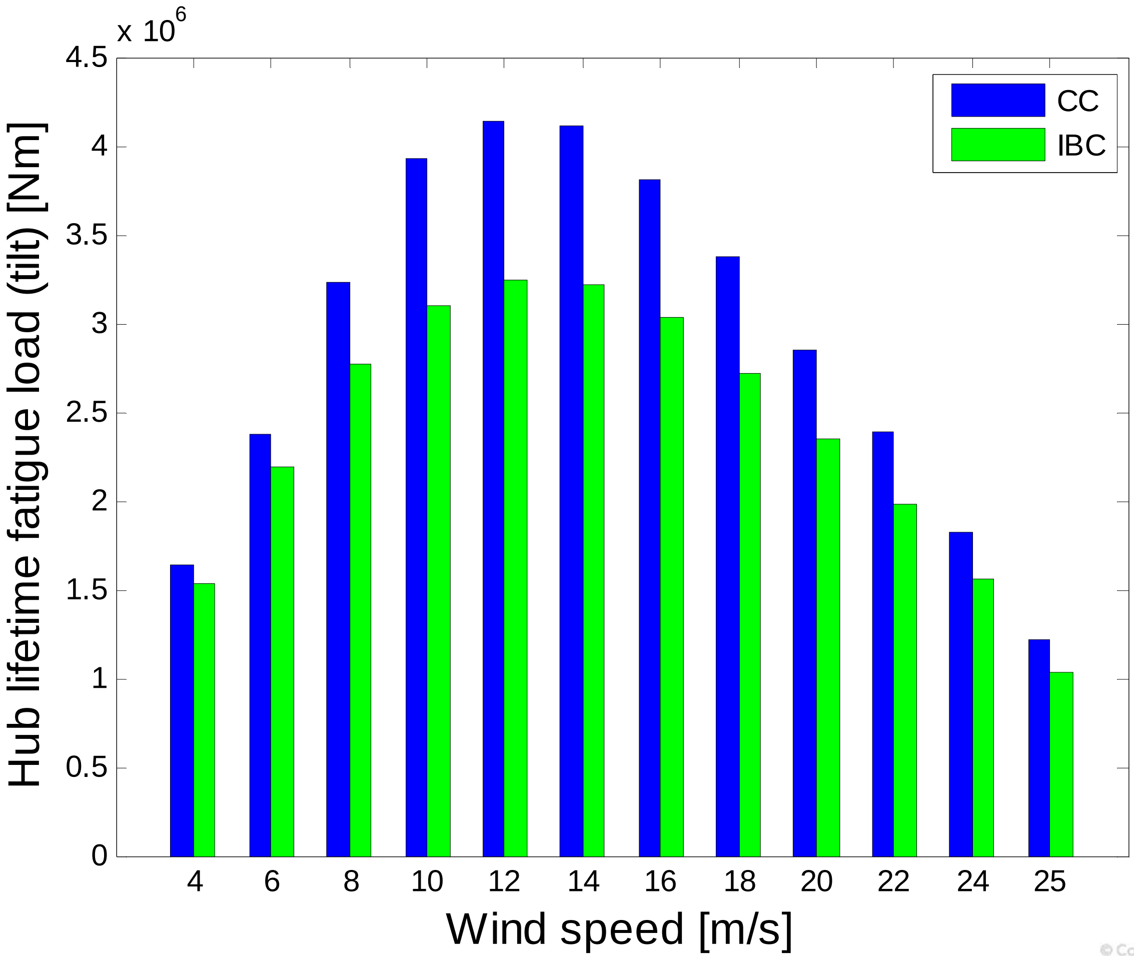
ATLAS™ - Reducing Fatigue Load

- Reduction (~25%) on the blade lifetime fatigue damage



ATLAS™ - Reducing Fatigue Load

- Reduction (~20%) on the hub lifetime fatigue damage

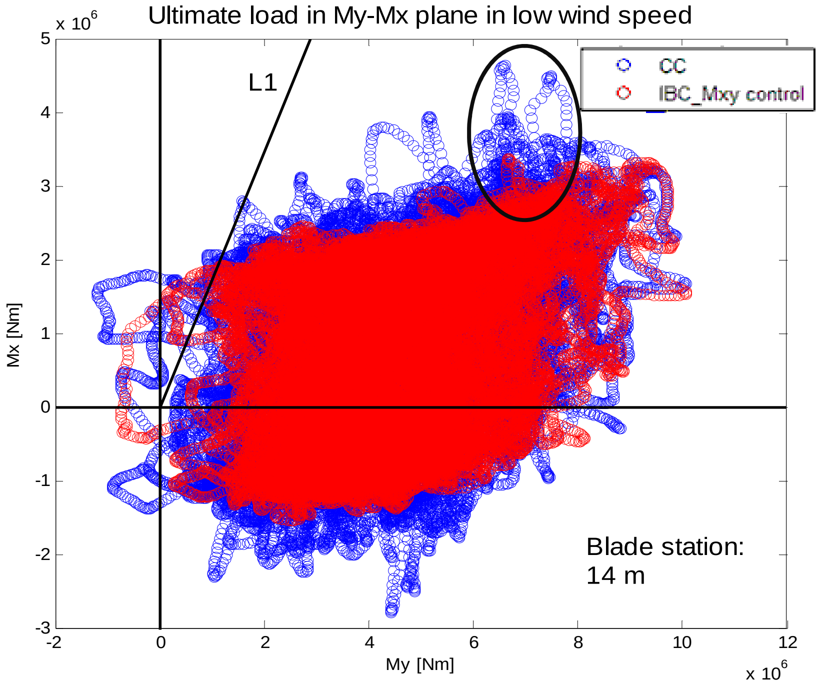


ATLAS™ - Reducing Blade Extreme Load

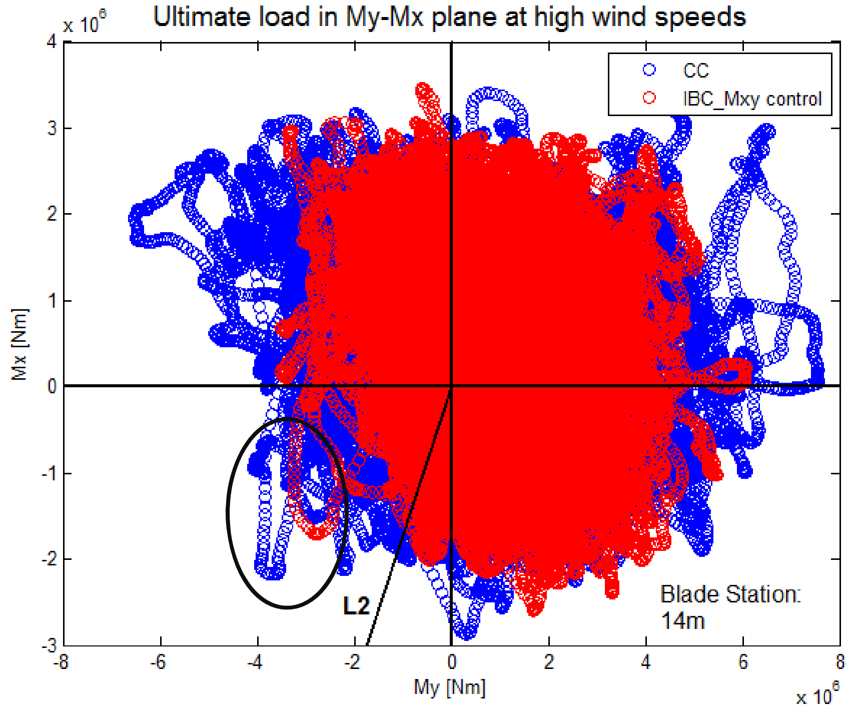
- Blade extreme loads:
  - Contributions from both blade in-plane (Mx) and out-of-plane (My) bending moments at various blade sections
  - Critical scenarios can occur at both low and high wind speeds
  - Assessed by projection of Mx and My onto specific directions in the (My,Mx) plane at the instance when the maximum load arises

ATLAS™ - Reducing Blade Extreme Load

- Reduction of extreme loads



Critical load L1
at low wind speed



Critical load L2
at high wind speed

ATLAS™ - Reducing the Load

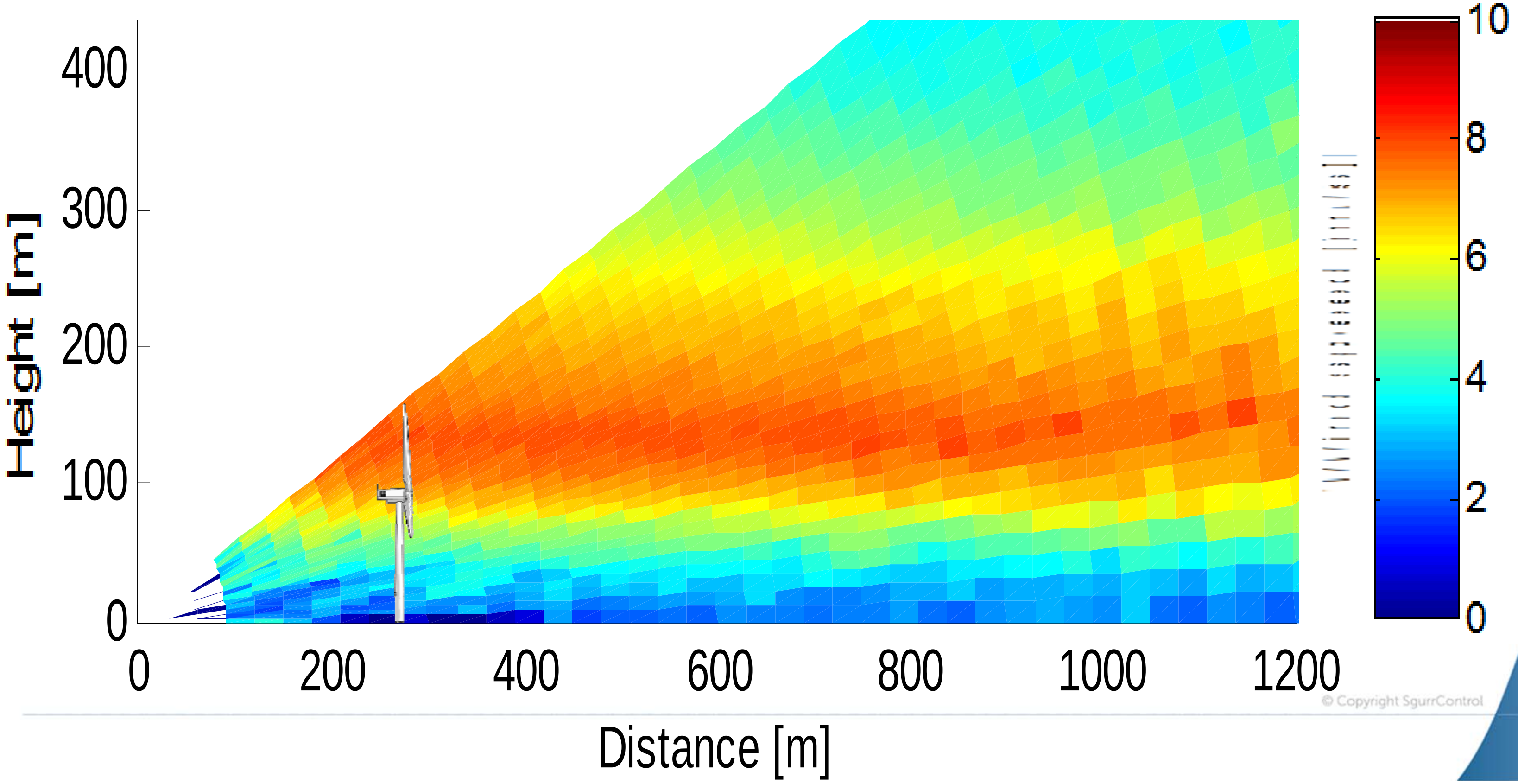
- ATLAS Fatigue
- ATLAS Extreme

→ ATLAS Combined

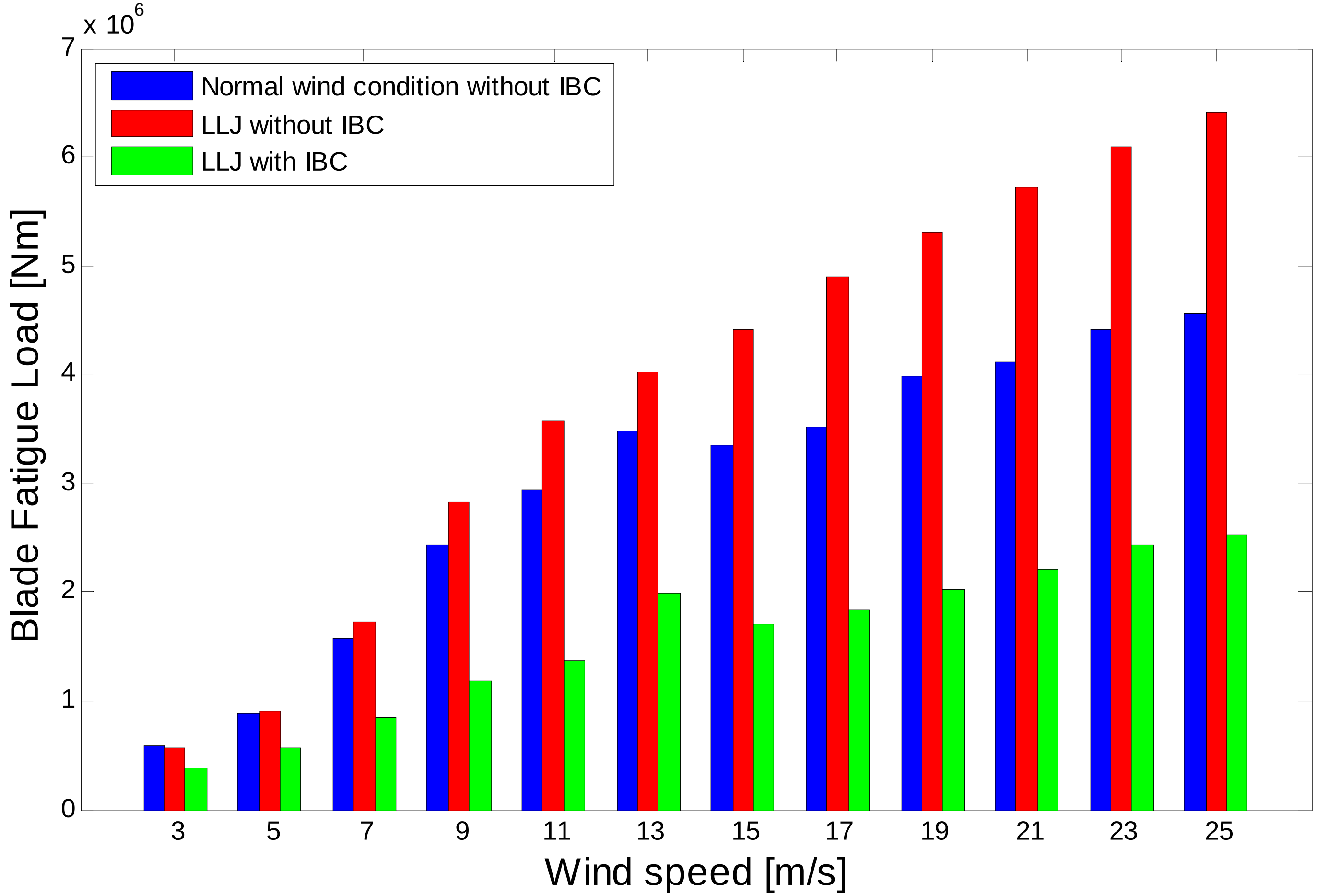
Controller Designs	ATLAS Fatigue		ATLAS Extreme		ATLAS Combined	
Blade fatigue load	-27%		0		-27%	
Hub fatigue load	-20%		0		-20%	
Tower fatigue load	-4%		0		-3%	
Blade extreme load	L1	L2	L1	L2	L1	L2
	0	-14%	-33%	-24%	-33%	-24%

ATLAS™ - Application for Low Level Jets

- Low Level Jet event – phenomenon observed shows the wind speed rising dramatically with the height
- Wind turbines have been experiencing higher loads and higher component failure rates



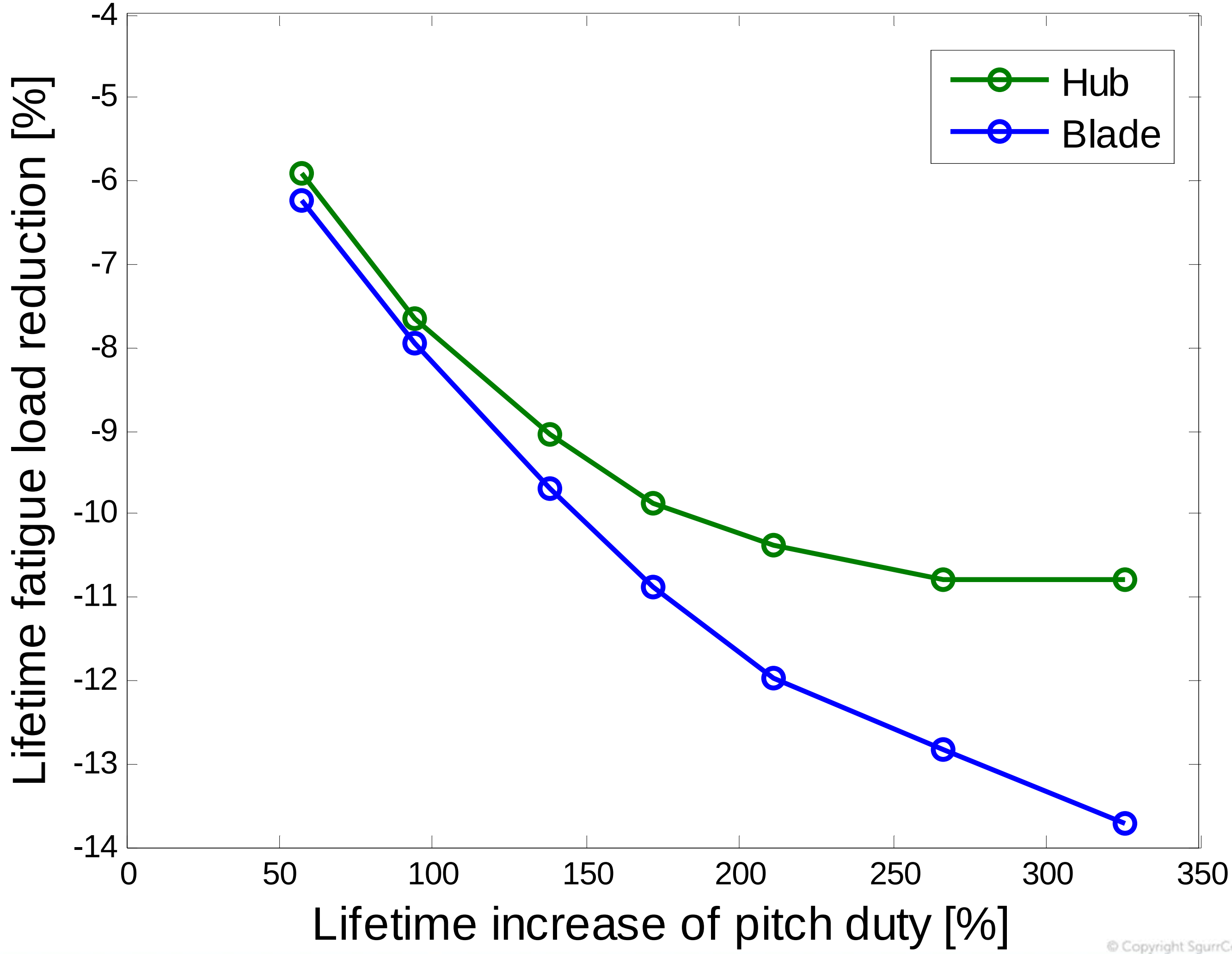
ATLAS™ - Application for Low Level Jets

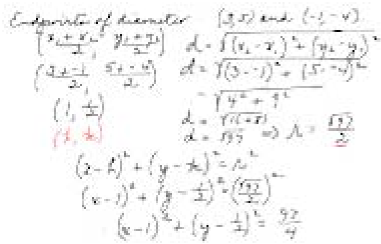


- Not only are the blade loads reduced, but also the loads on the hub and the shaft are reduced

ATLAS™ - Pitch Trade-off

- Investigation on pitch duty against load reduction





Idea → Development → **Implementation** → Demonstration

ATLAS™ - Field Demonstration

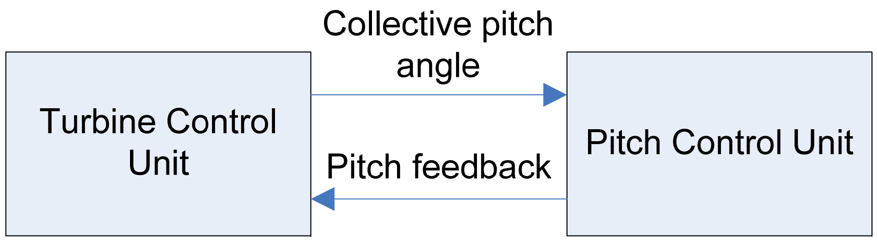
- Field demonstration funded by the Department of Energy and Climate Change (DECC)
- Partner with Romax as an independent third party for analysis
- Field test and assessment on a Clipper C96 2.5MW wind turbine owned by University of Minnesota

ATLAS™ - Field Demonstration

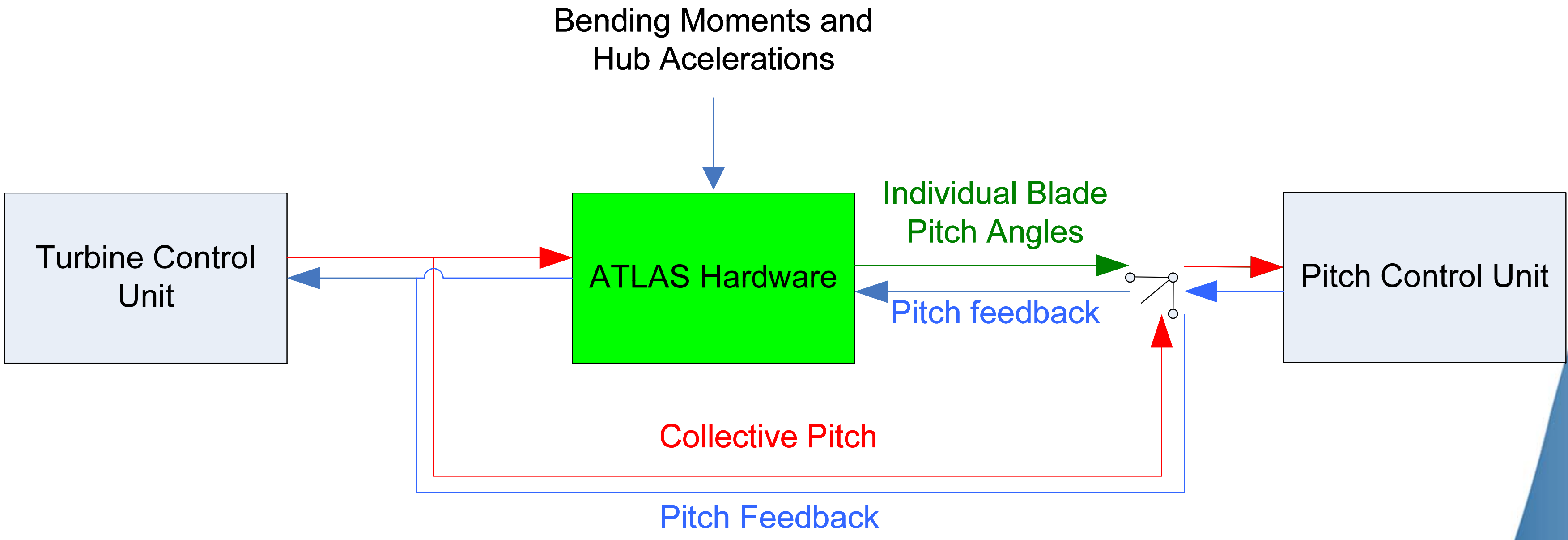
- Key aims:
  - Demonstration of the effectiveness of ATLAS in reducing the loads on a real turbine
  - Validation of the model and analysis and validation of the design process on a real turbine

Implementation Process

Original turbine layout

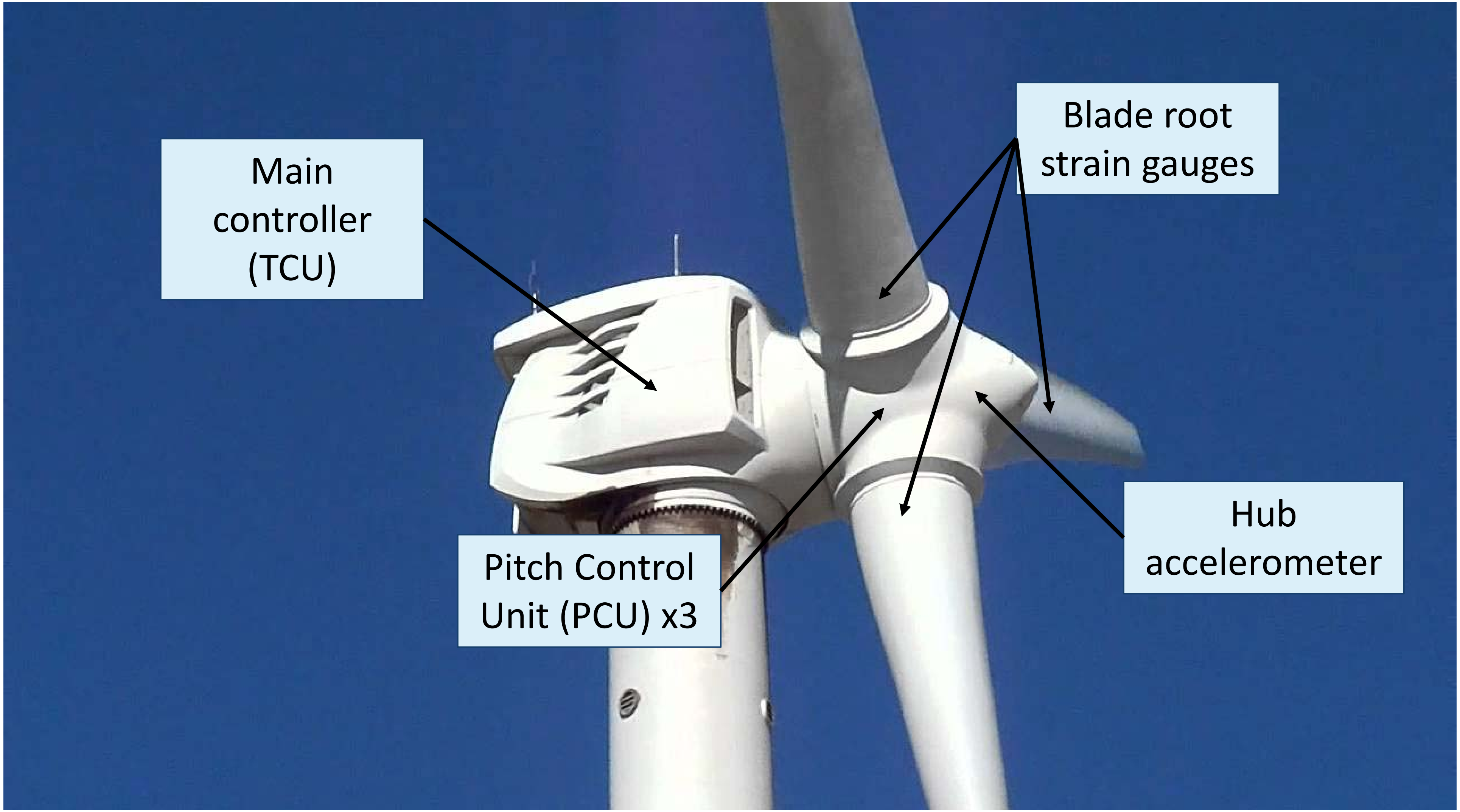


ATLAS layout



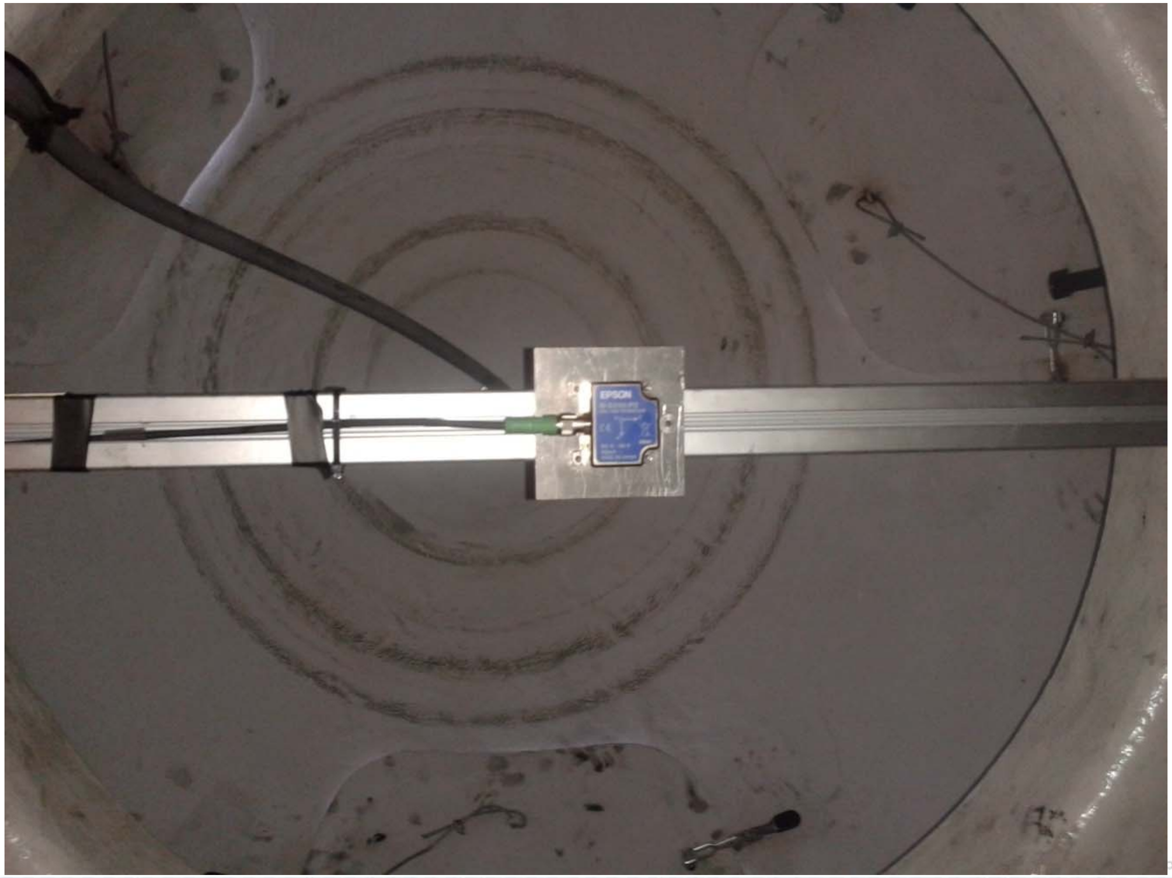
Implementation Process

- Location of strain gauges and hub accelerometer



Implementation Process

- Hardware configuration
  - Requirements for the extra measurements - bending moments and hub accelerations



Implementation Process

- Three triaxial accelerometers to calculate angular rates

Implementation Process

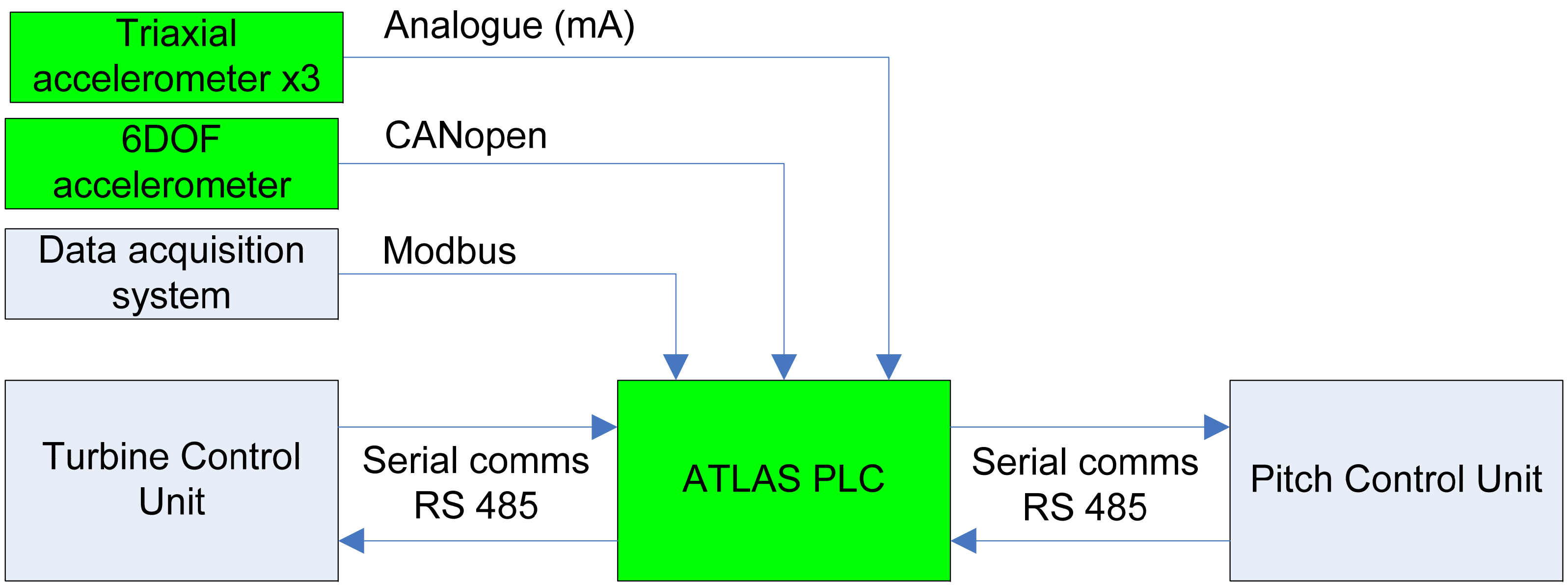
- Installing the three triaxial accelerometers

Implementation Process

- Identifying the environmental constrains
- IP rating, temperature range, vibrations, etc.

Implementation Process

- Turbine Control Unit (TCU) requirements
  - Identifying the communication protocols



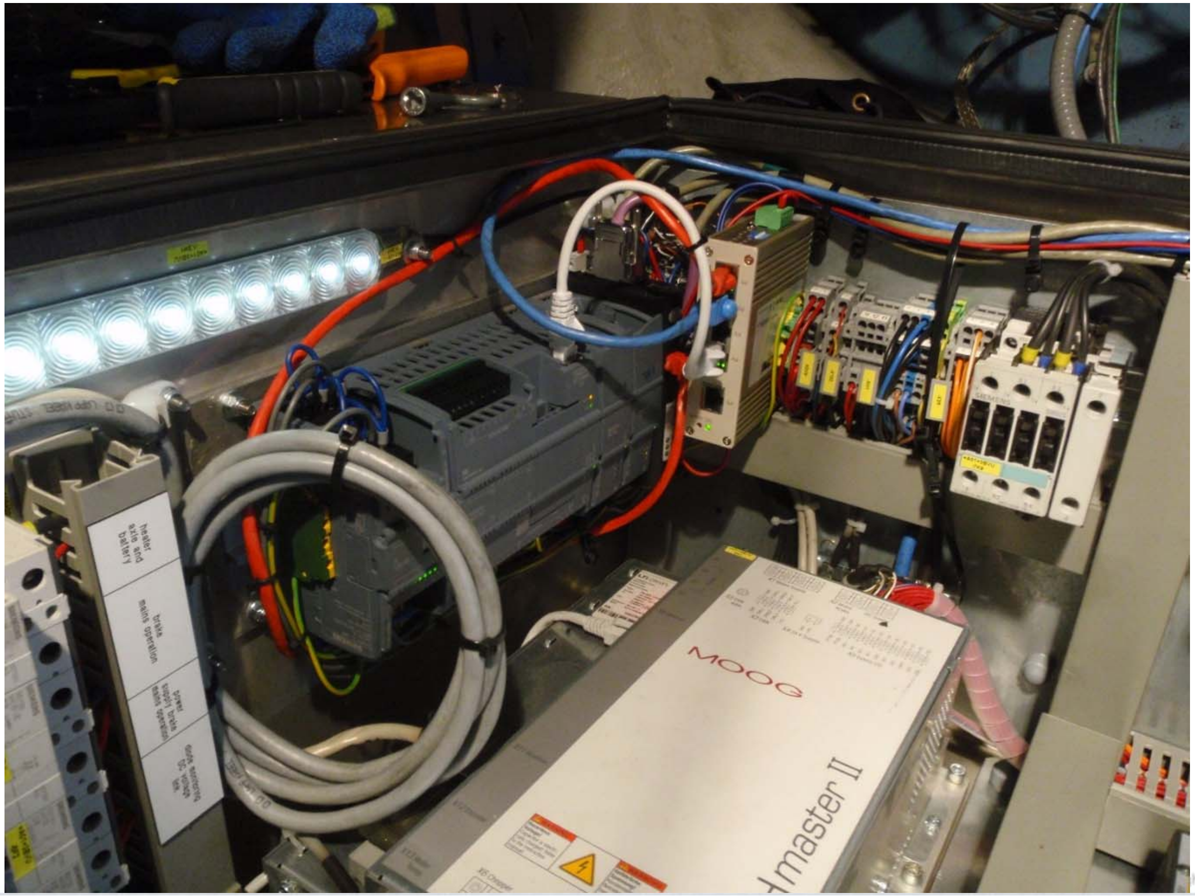
- Feedback required from Pitch Control Unit (PCU) according to the command issued in the same cycle
- The process of issuing commands and receiving an appropriate feed back should not take longer than 50ms

Implementation Process

- Testing before deployment:
  - Hardware in the loop (HiL)
  - Implementing extra alarms
  - Testing the communications with the spare parts available

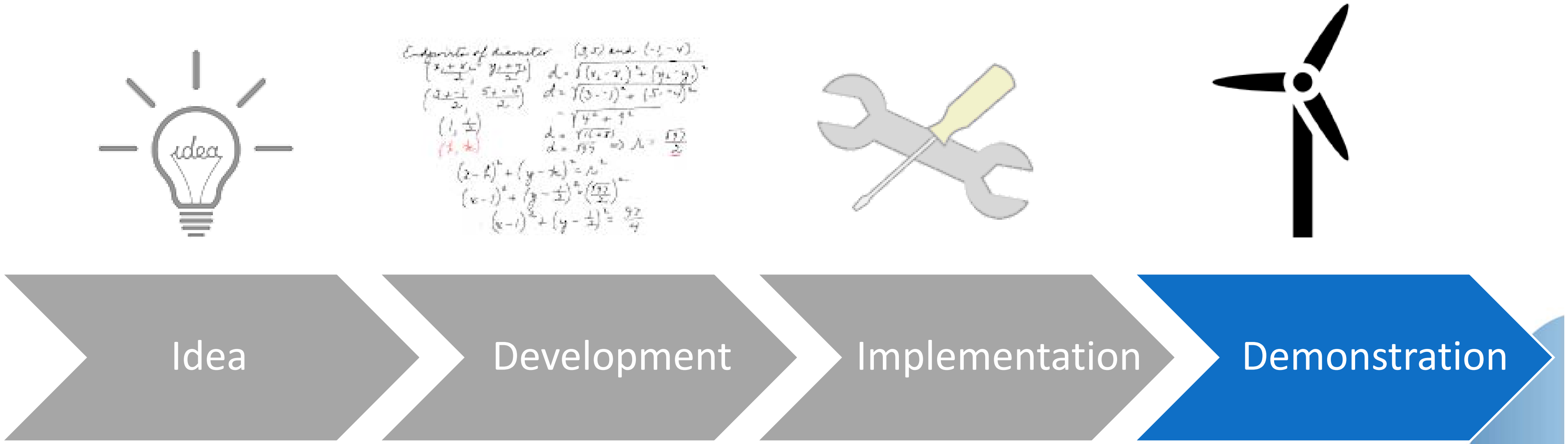
Implementation Process

- Deployment stages
  - ATLAS hardware mounted in the hub, tested to make sure it runs without any errors before connecting to TCU and PCU



Implementation Process

- Deployment stages
  - ATLAS hardware connected to TCU and PCU and run as a bypass
  - Human Machine Interface (HMI) changed to provide the capability to enable/disable ATLAS
  - ATLAS enabled, controlling each blade individually


idea
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Demonstration - Main Objectives:

- Test the effectiveness of ATLAS → Does it work ?
  - Reduce blade loads
  - Does not interfere with speed controller
  - Same energy capture

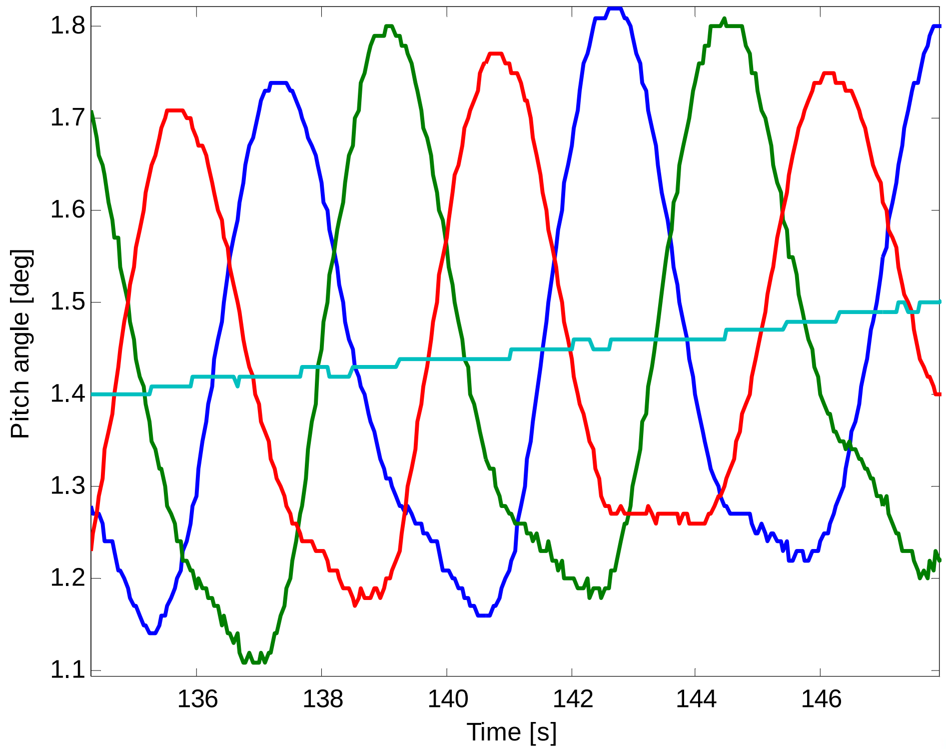
- Validate the model results → Does it work as supposed to?
  - Same blade load reduction
  - Same pitch activity

↓

- Predict the lifetime benefits of ATLAS on a wind turbine

Demonstration

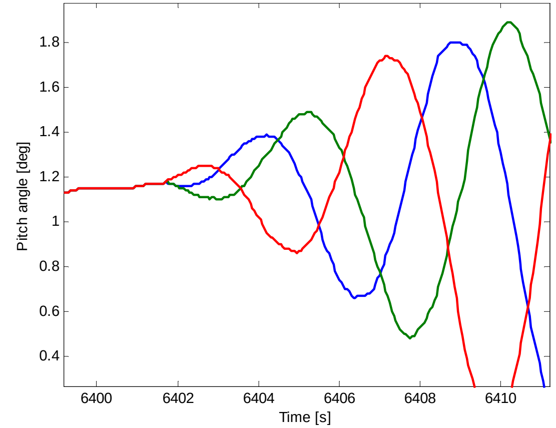
- Commissioning
  - What do I need to test ATLAS?
  - Reduced gain controller & running under safe conditions

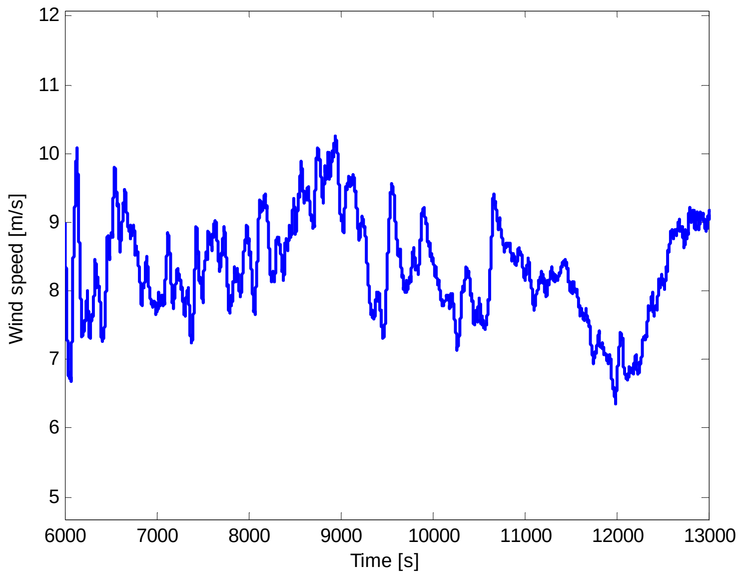


Experimental Campaign

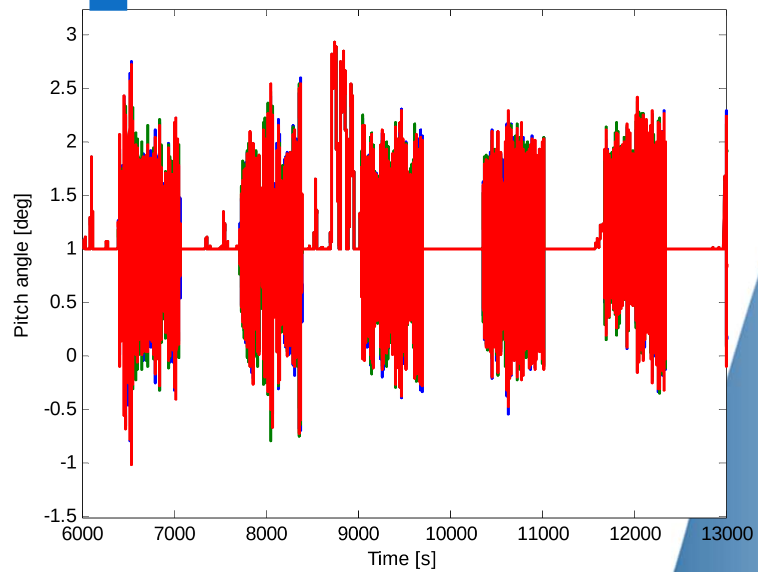
- Compare collective/ ATLAS
- Similar conditions
- 11 minutes on/off

Smooth switching





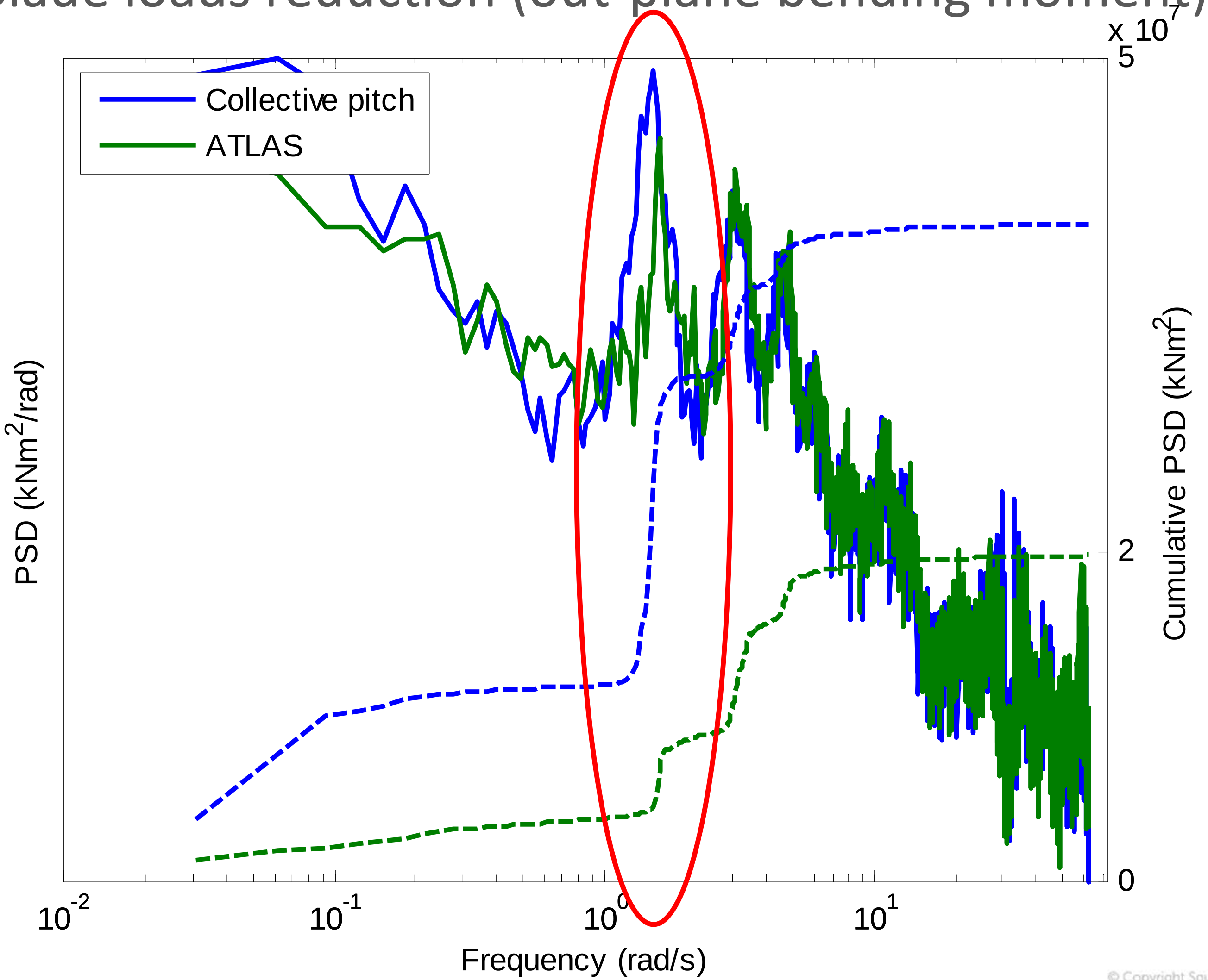
Wind Speed



Pitch Angles

Experimental Campaign - Results

- Blade loads reduction (out-plane bending moment)



Experimental Campaign - Results

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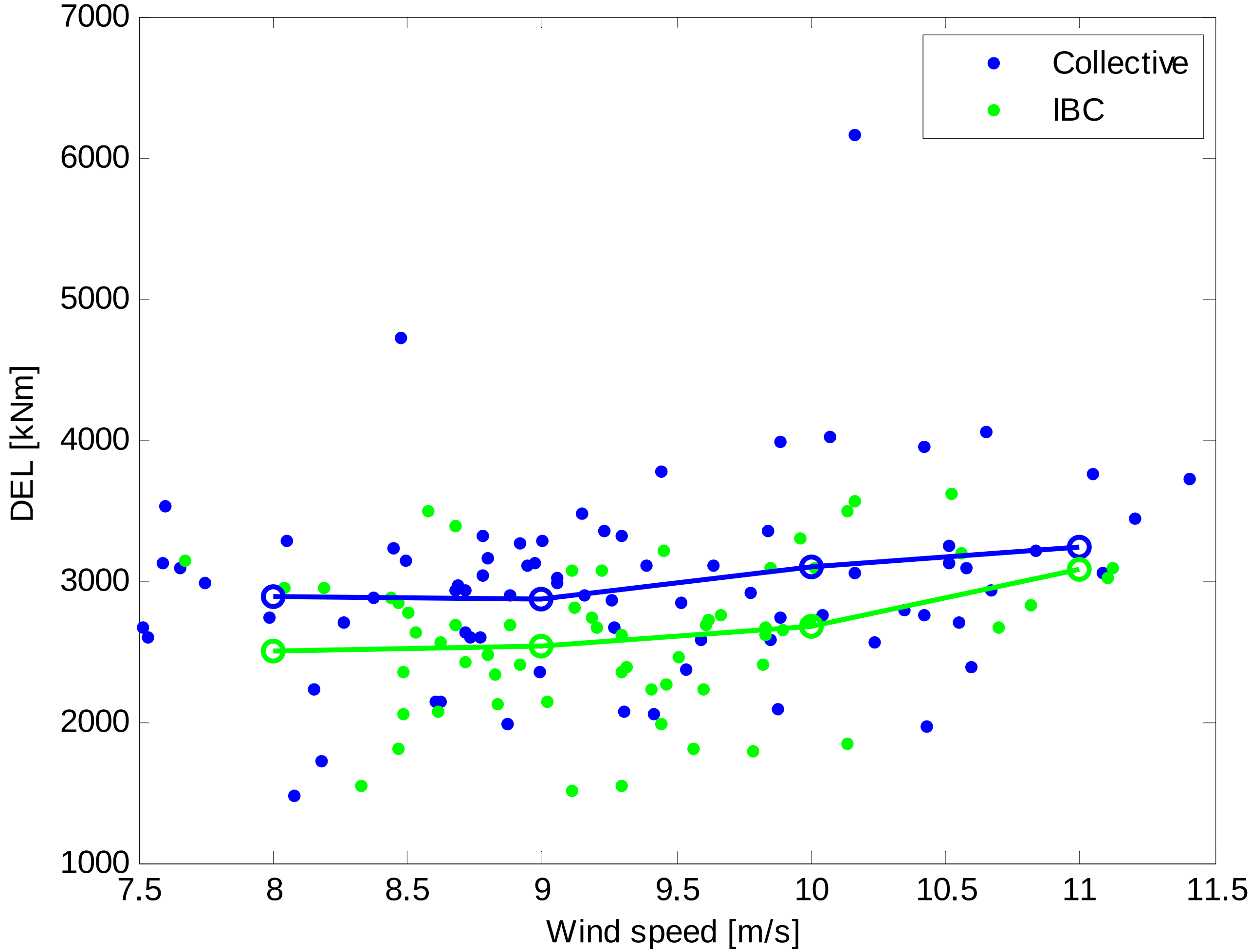
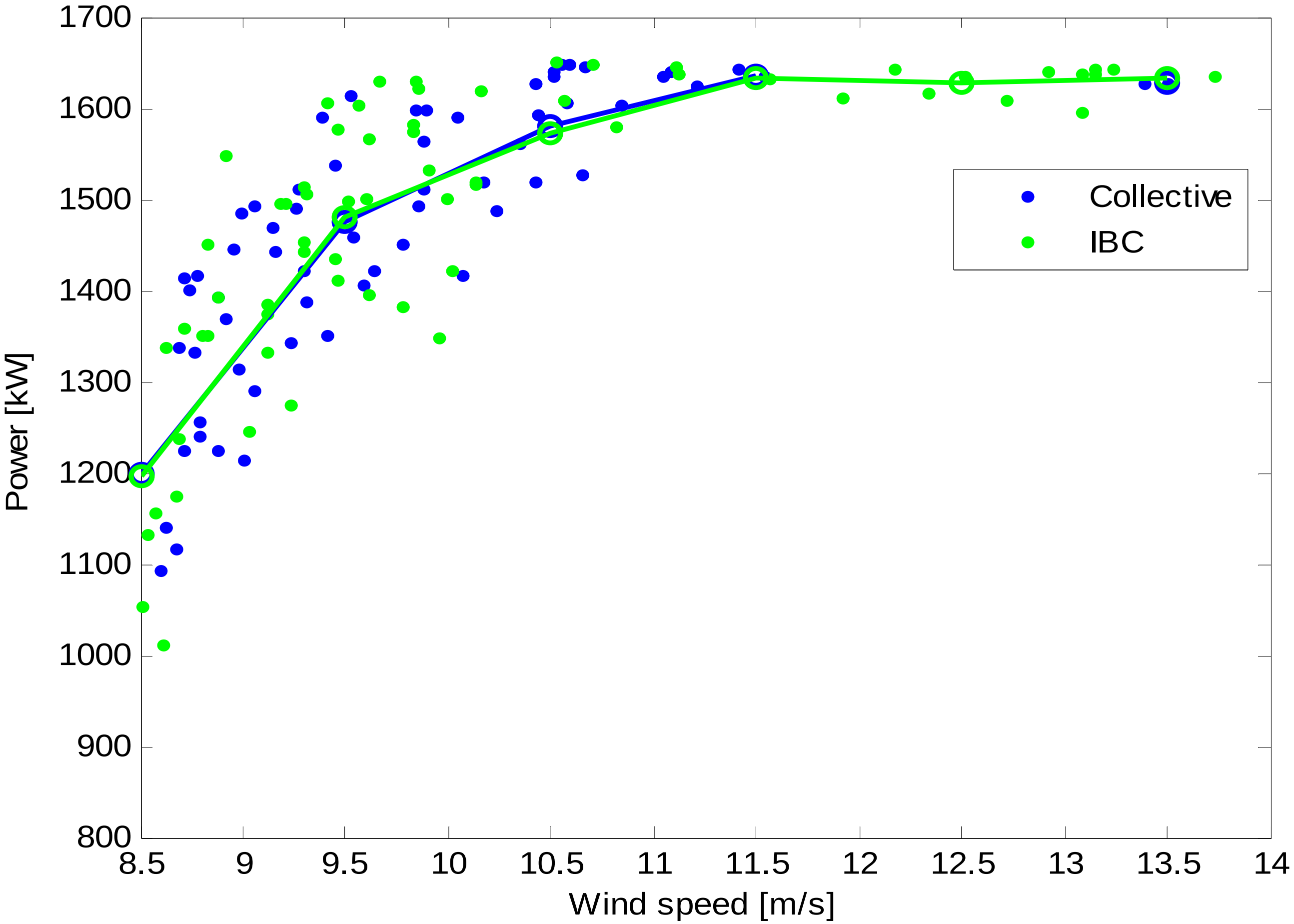


Experimental Campaign - Results

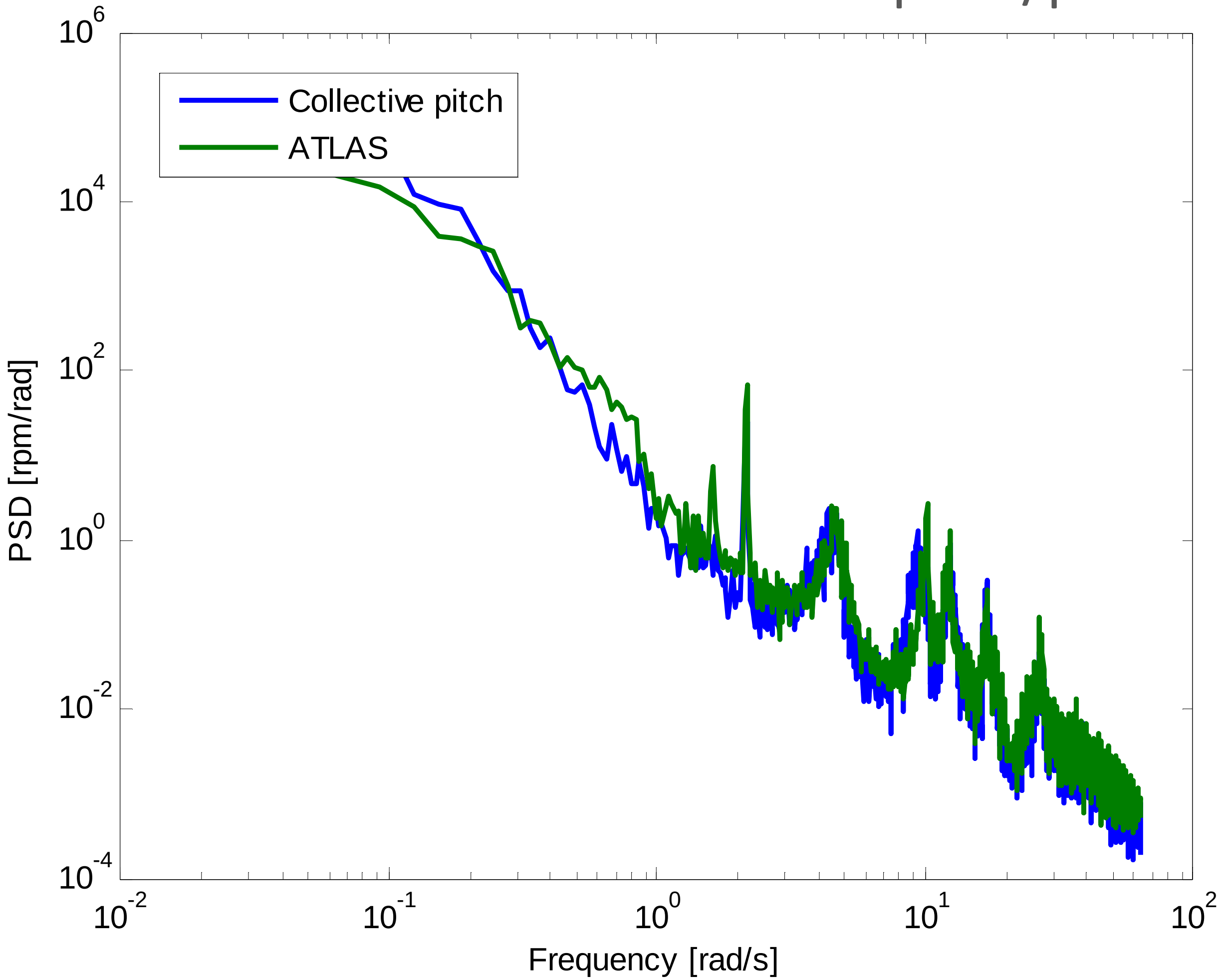
- ATLAS does not interfere with the speed/power control



Power curve

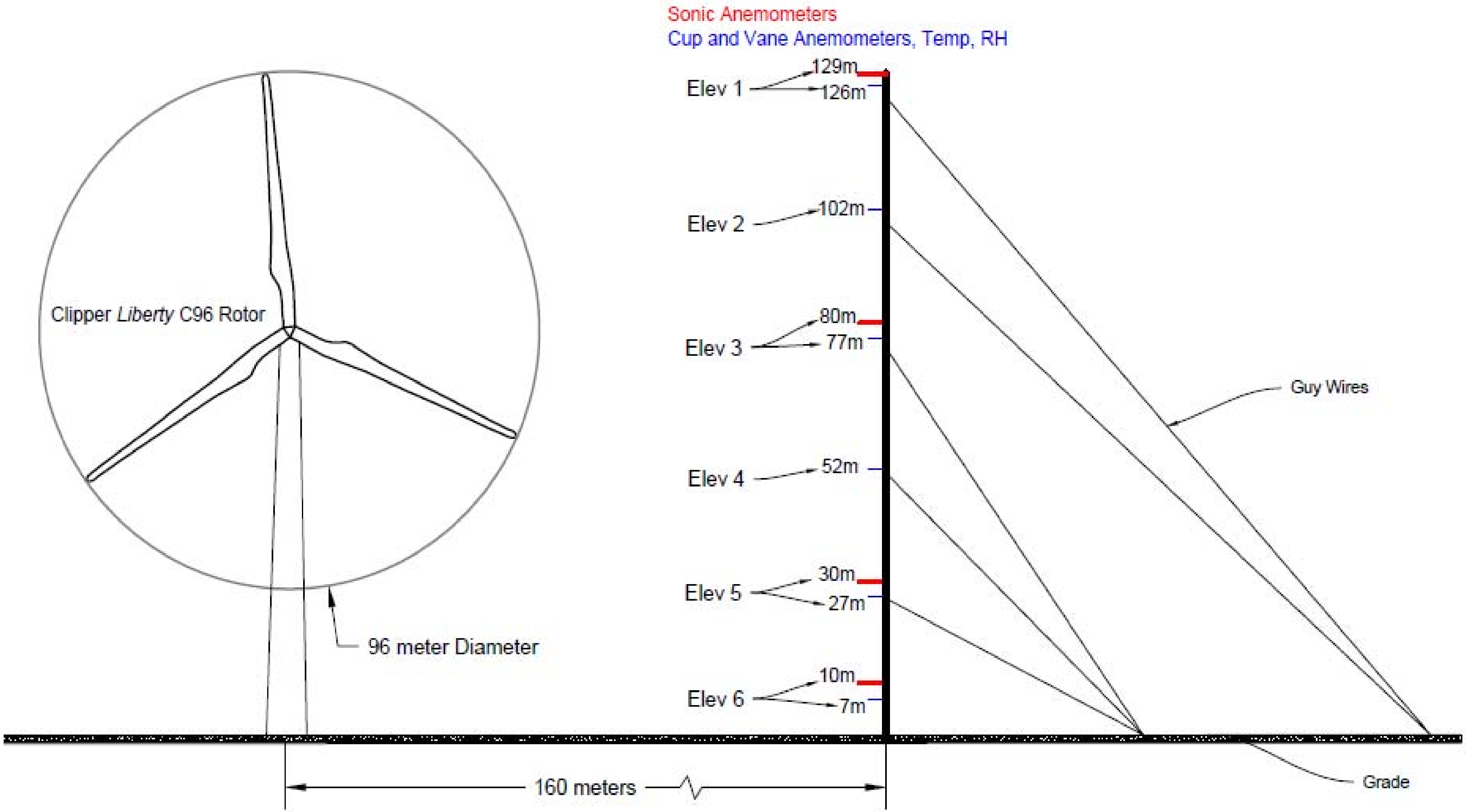
Experimental Campaign - Results

- ATLAS does not interfere with the speed/power control



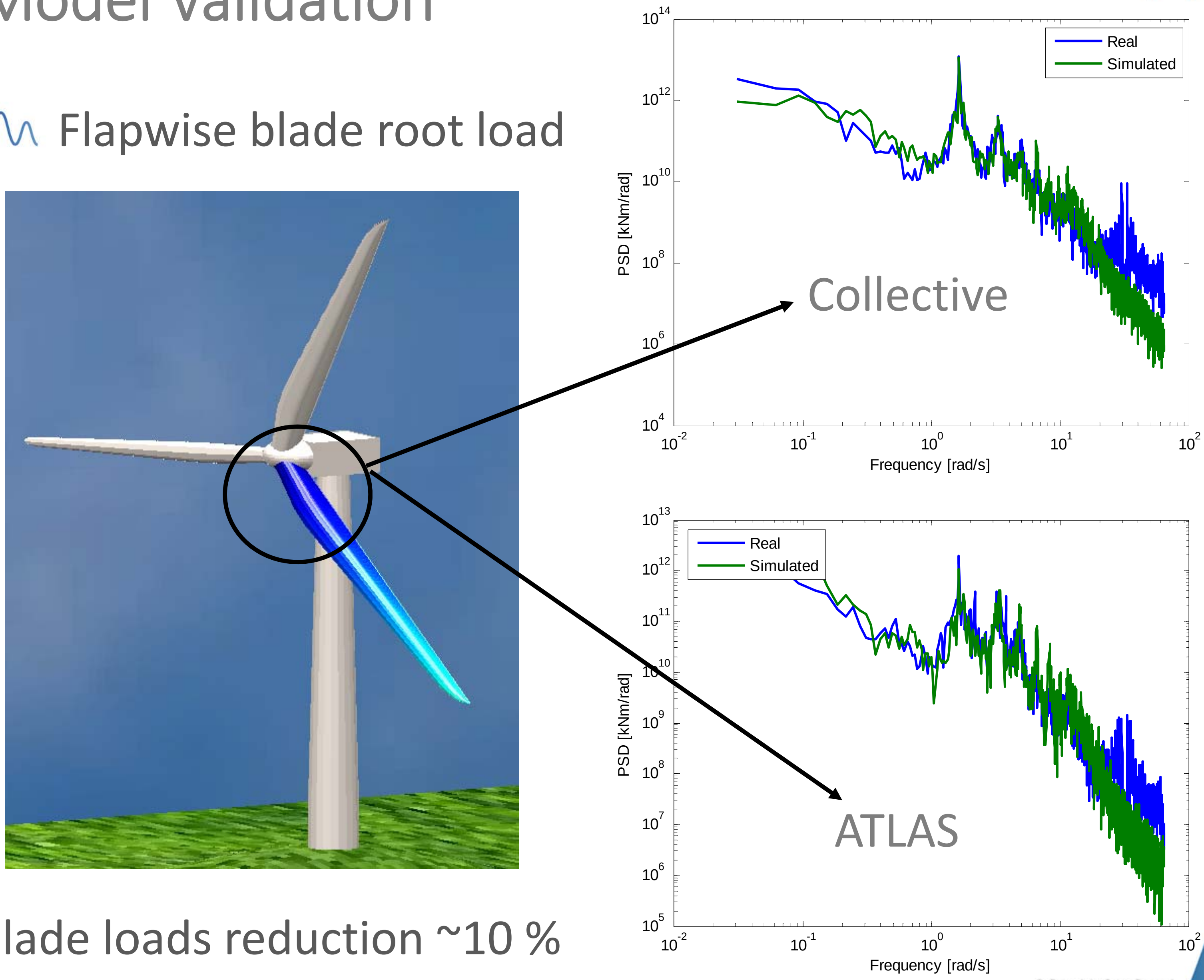
Generator speed spectrum

Model Validation



Model Validation

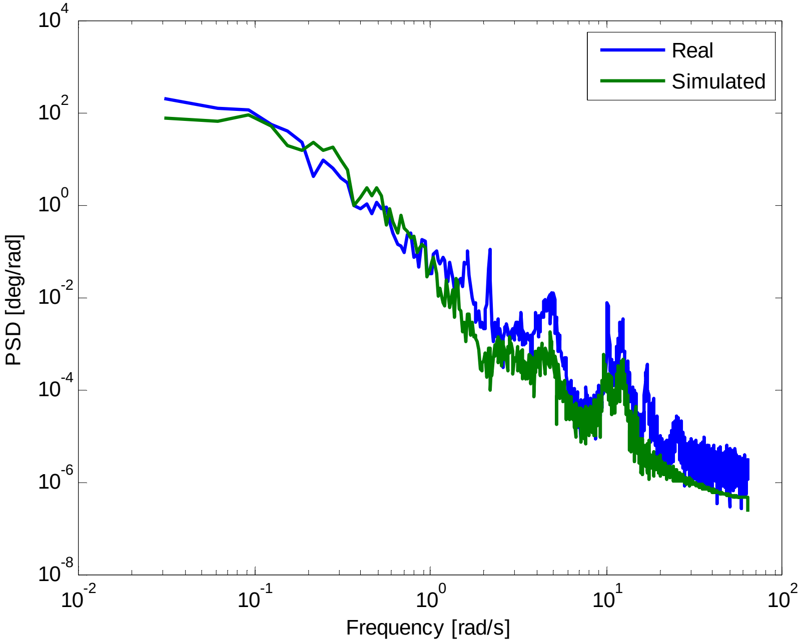
- Flapwise blade root load



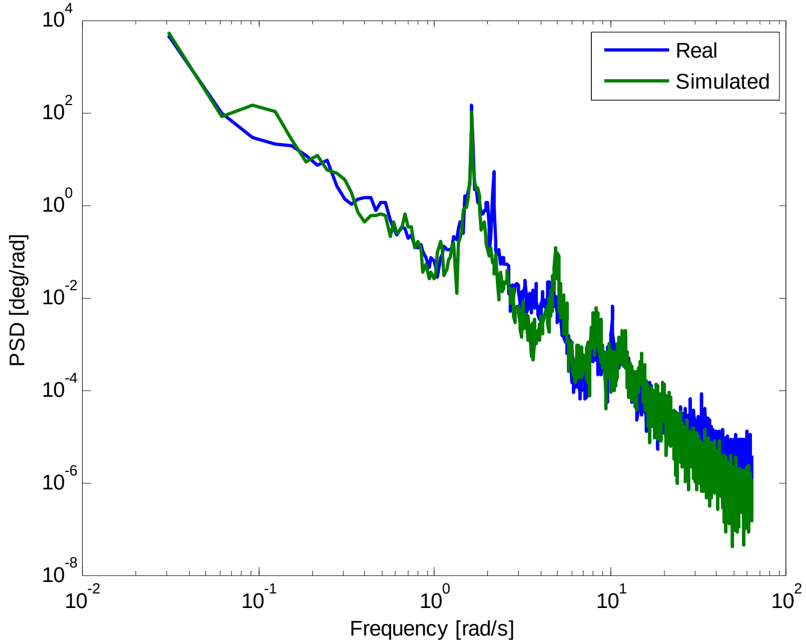
Blade loads reduction ~10 %

Model Validation

Pitch angle – real vs simulated



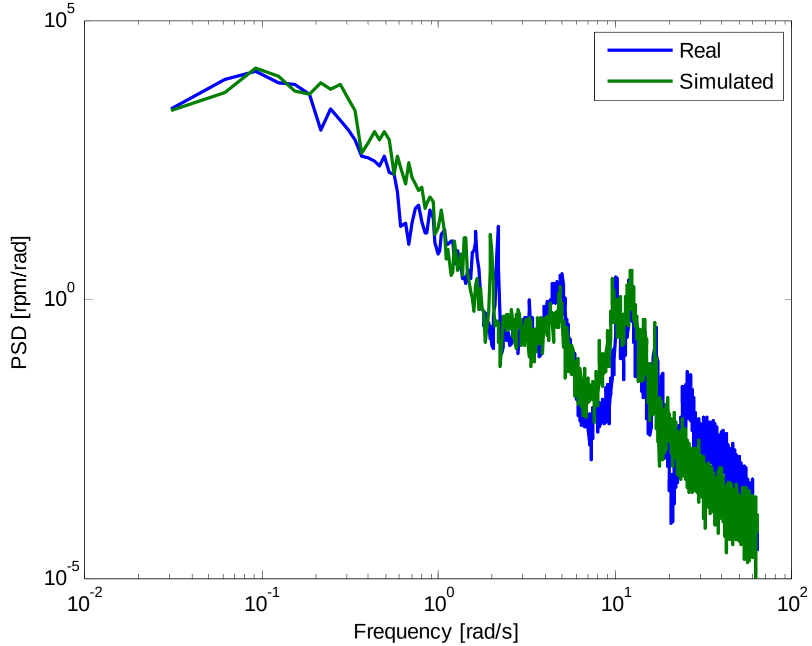
Collective



ATLAS

Model validation

Generator speed



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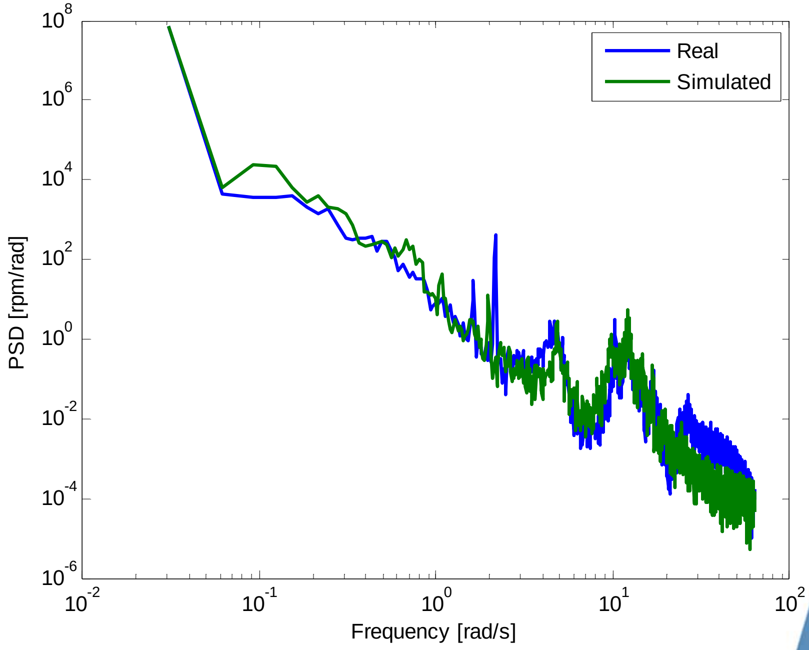
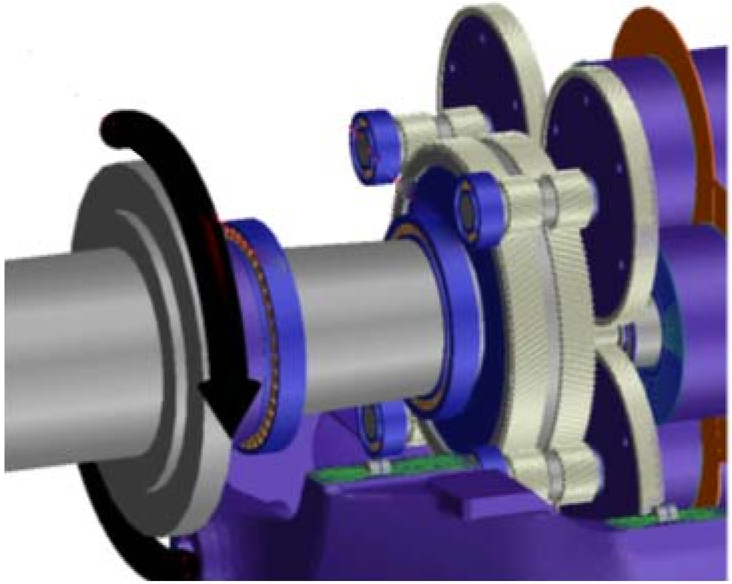
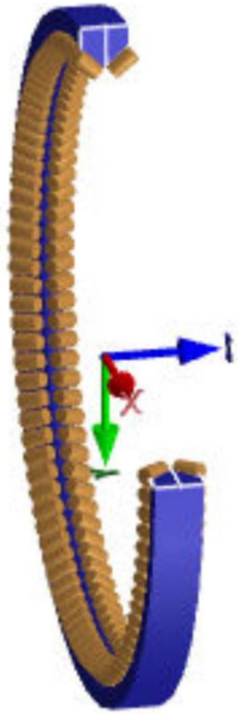


ATLAS

Independent 3rd Party Analysis

- Romax assessed lifetime of key components
- *RomaxWIND* - Detailed models of gearbox and bearings
- Standard and bespoke calculation methods



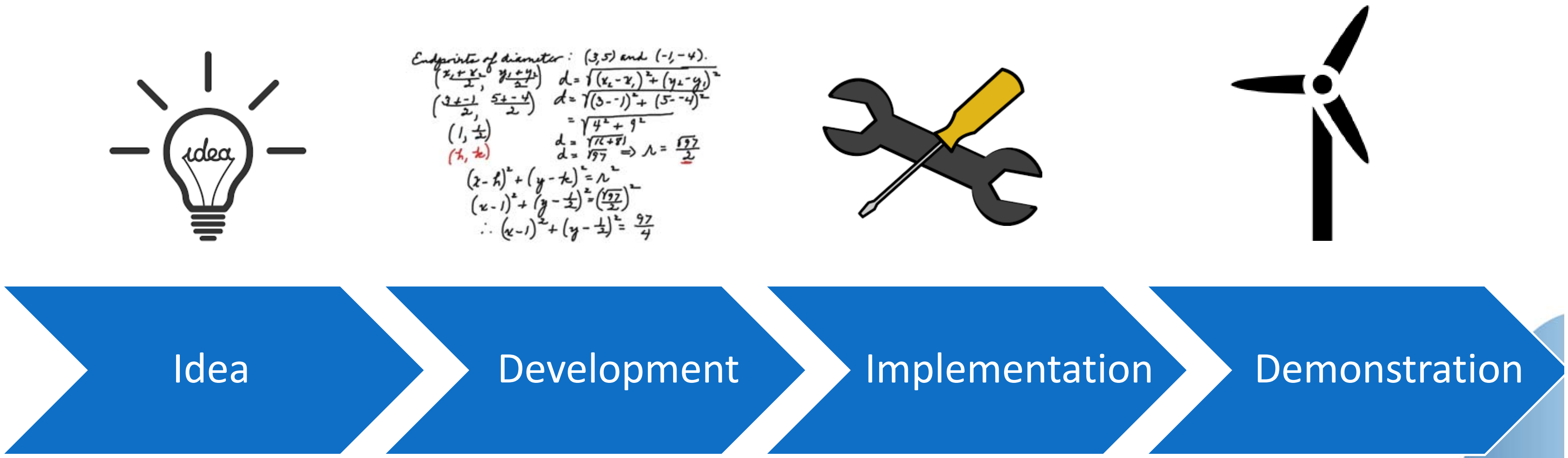


RomaxWIND models

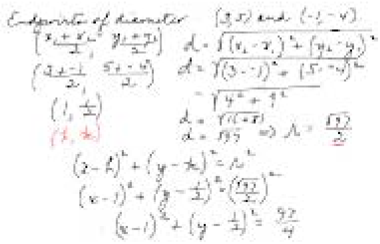
ATLAS – Main Benefits

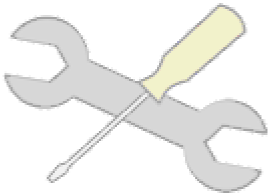
- Blade fatigue loads reduction (10-25 %)
- Alleviate gearbox loads
- Less risk of main bearing failures
- CAPEX and OPEX reduction
- Minimum pitch activity -> does not impact the pitch bearing life

End of the Story?



Next Steps





Idea → Development → Implementation → Demonstration

Commercialisation

Commercialisation

- Moving to TRL Levels 8-9
- Commercialisation and market ready
- Using experience from field demonstration to finalise product design, packaging, marketing
- Rollout to multiple sites and different wind turbine types
- Future development of product improvements to increase capability and performance

Target Markets

- Wind turbine manufacturers
  - Cost reduction of original design
  - Increased energy capture with longer blades
  - Essential for large wind turbines
  - Life extension

- Wind farm owners and operators
  - High wind shear, veer, turbulence
  - Low level jets
  - High failure rates of components
  - Life extension

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