Lidar–assisted model predictive turbine control

Challenges on the way to an industrial reality

Dr. Axel Schild, February 2023

IAV is More …

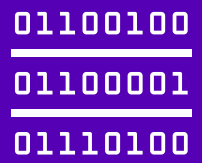
23
Locations worldwide

7,600
Employees

39
Years of Experience

863
Million Euros Annual Sales

What Can We Do for You?



Software Systems & Connectivity

Because connected mobility knows no boundaries.

Vehicle Solutions & Autonomous Driving

Because the vehicle must be thought of as a whole.

Future Powertrain

Because the powertrain of the future has more than one solution in store.

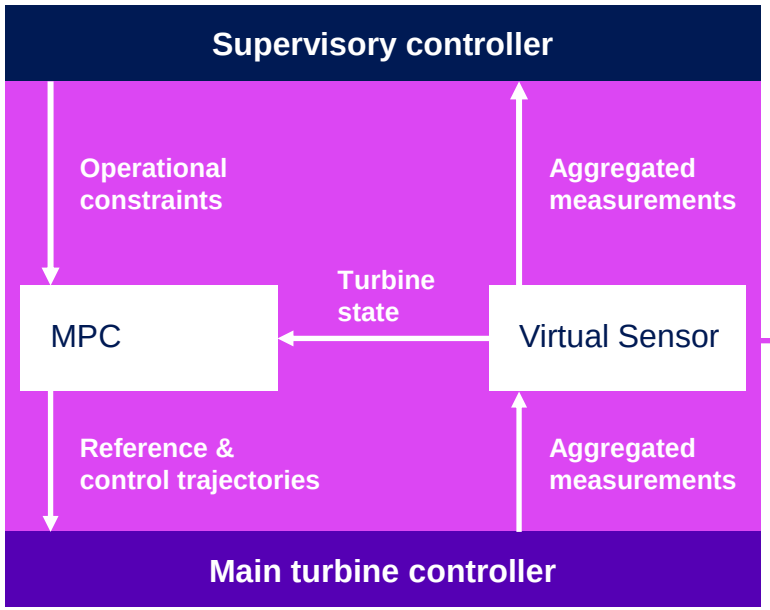
Solutions & Products

Because innovative solutions are in our blood – even beyond mobility.

That’s me

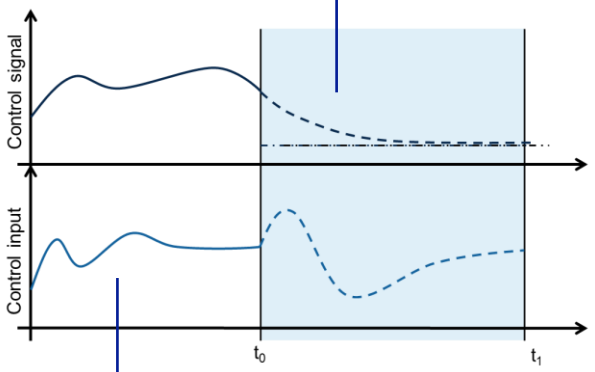
- Axel Schild, 45 years old
- Senior Technical Consultant, Automation Solutions Energy Sector @ IAV
- Phd. in control theory, Expert in nonlinear model predictive control (**nMPC**)
- >15 years of industrial experience in **nMPC** across diverse sectors
  - Chemical/process industry
  - Automotive
  - Wind Energy
  - Energy management / infrastructure

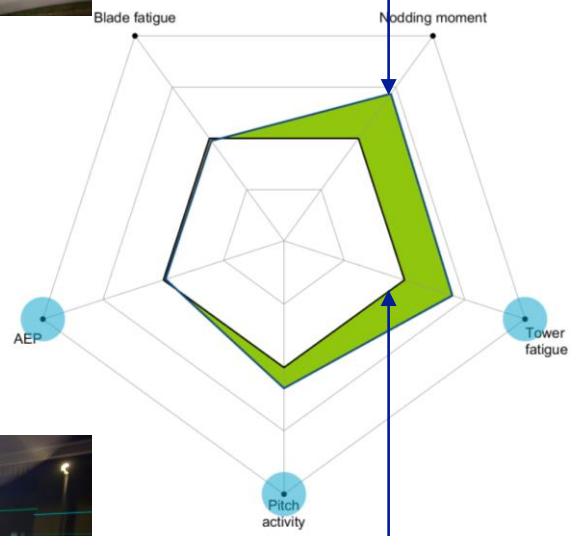
MPC vs. conventional control – a matter of performance



Model predictive control

Untapped potential





Conventional feedback control

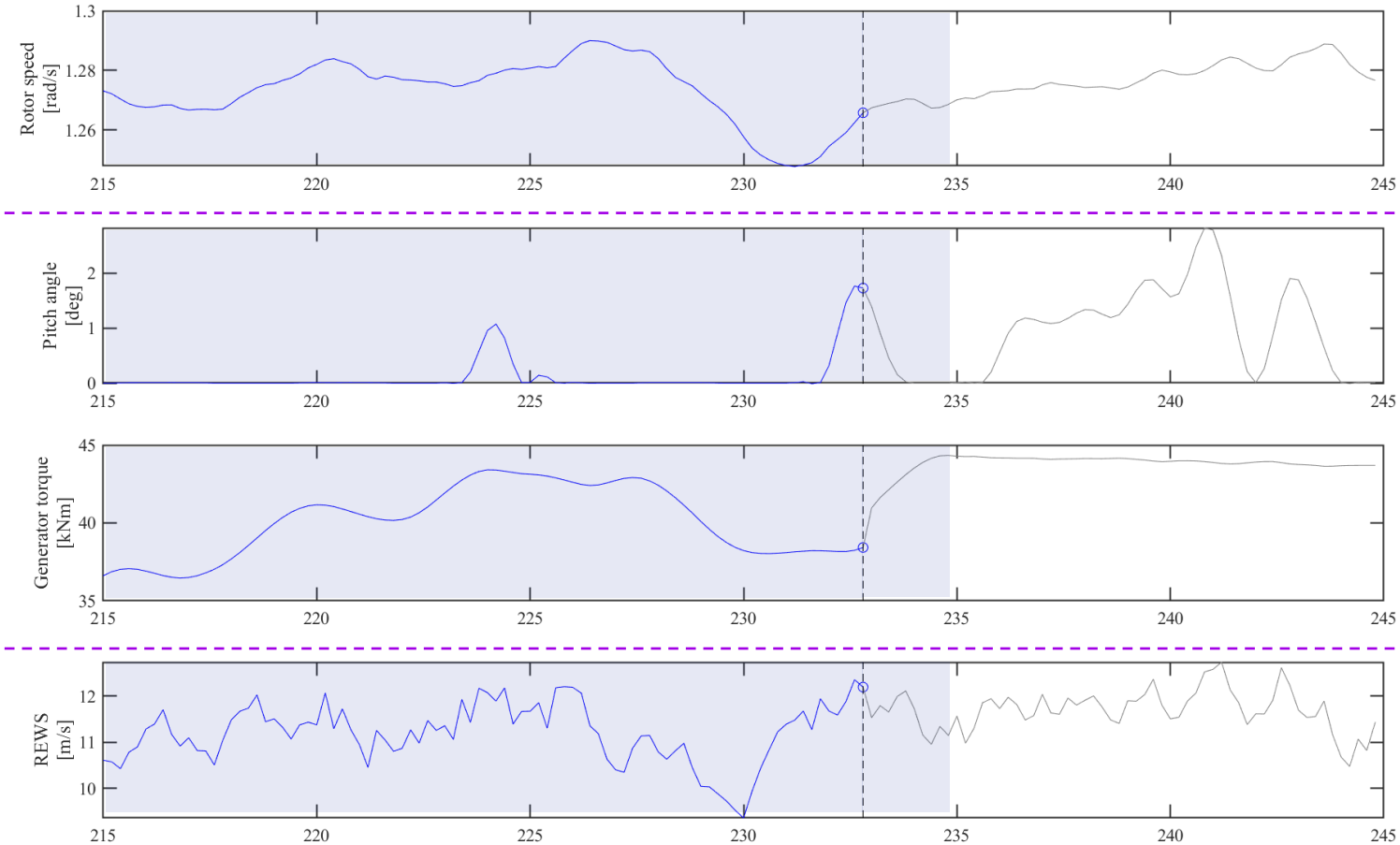
State-of-Art Performance

The MPC iteration illustrated at NREL 5MW turbine

State

Controls

Disturbance



“Technical ingredients” for formulating a model predictive controller

Performance metric

$$\min_{\boldsymbol{X},\boldsymbol{U}} J(\boldsymbol{X},\boldsymbol{U}) = \sum_{0}^{N-1} L\left(\boldsymbol{x}_k, \boldsymbol{u}_k, \boldsymbol{w}_k\right) + M\left(\boldsymbol{x}_N\right)$$

Formalizes an economically good system operation

Lidar-based rotor-effective wind speed prediction

Dynamic system model

$$\begin{aligned} \text{s.t.} \quad \boldsymbol{x}_{k+1} &= \boldsymbol{f}(\boldsymbol{x}_k, \boldsymbol{u}_k, \boldsymbol{d}_k) \\ \mathbf{x_0} &= \boldsymbol{x}(t_s) \end{aligned}$$

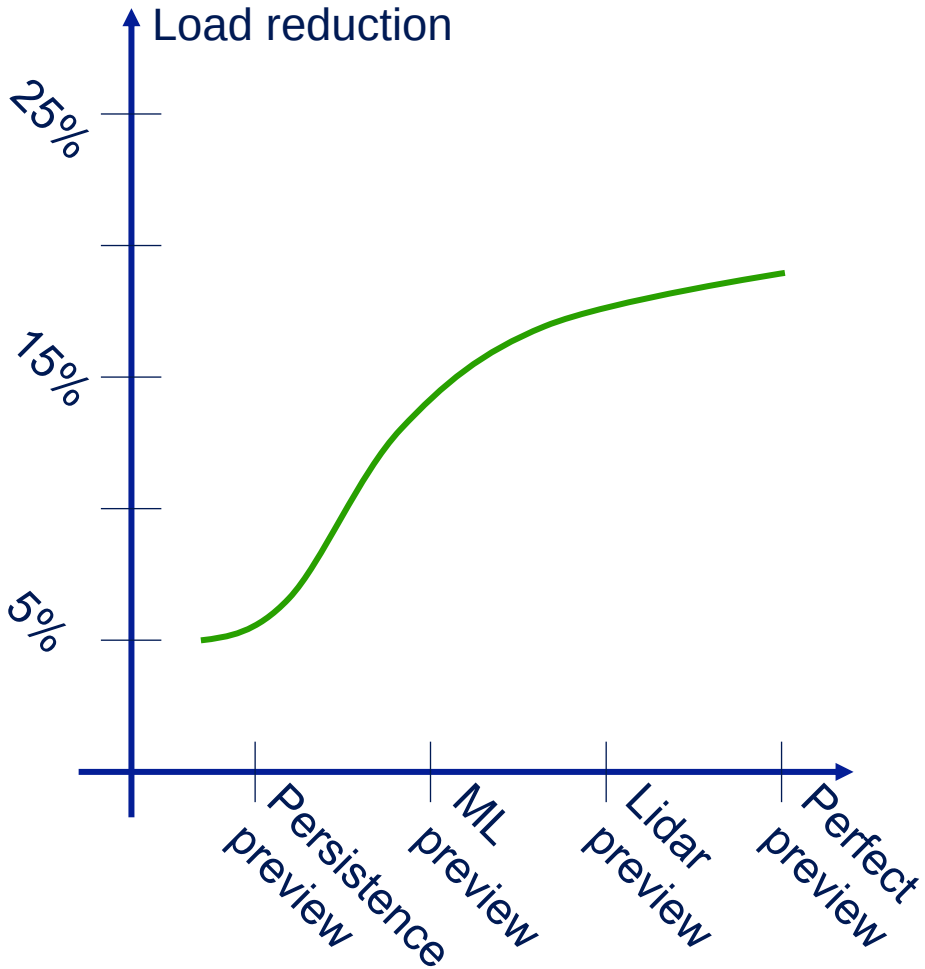
Captures relevant plant physics to forecast system behavior

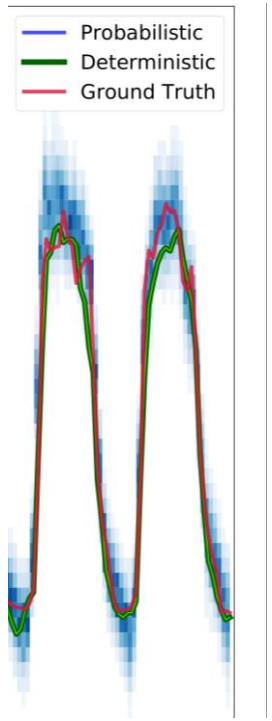
Safe operating regime

$$\begin{aligned} \underline{\boldsymbol{u}} \quad &\leq \quad \boldsymbol{u}_k \quad \leq \quad \overline{\boldsymbol{u}} \quad : \quad \forall k \\ \underline{\boldsymbol{x}} \quad &\leq \quad \boldsymbol{x}_k \quad \leq \quad \overline{\boldsymbol{x}} \quad : \quad \forall k \end{aligned}$$

Constrain admissible value ranges for relevant variables

Importance of preview knowledge





- Effective preventive control actions require a good short-term inflow preview
- At the upper quality-end, the performance improvement is limited by turbine equipment
- At the lower quality-end a predictive controller cannot outperform a conventional controller by far
- Aggressiveness of MPC should be scheduled according to certainty of preview information

Lidar data processing units should provide

→ Short-term REWS prediction

→ Certainty indicator, e.g. stochastic moments

One technology – different perspectives

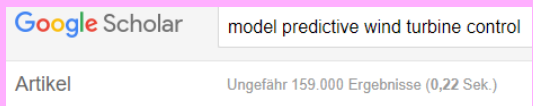
Academical focus

Objective formulation ✓

Modeling: accuracy vs. complexity ✓

Algorithms & numerics ✓

Potential assessment ✓



Industrial requirements

?

> 15 years of research, but no deployment at scale, yet…

Going beyond the 18MW threshold, MySE 18.X-28X is the epitome of Mingyang's consistent innovations and comprehensive upgrade on the proven hybrid-drive technology. The modular and lightweight design, as well as the use of holographic sensing MPC and digital twin DTC technology, serve as the basis for MySE1… …liable operations against the most extreme ocean conditions su… …>56.1 m/s.

With the new MySE 18.X-28X, Mingyang has taken a ma… energy transition by driving LCoE reductions and technolog… wind industry.

#offshorewind #HybridDrivestheWorld #myse18

= LA-MPC

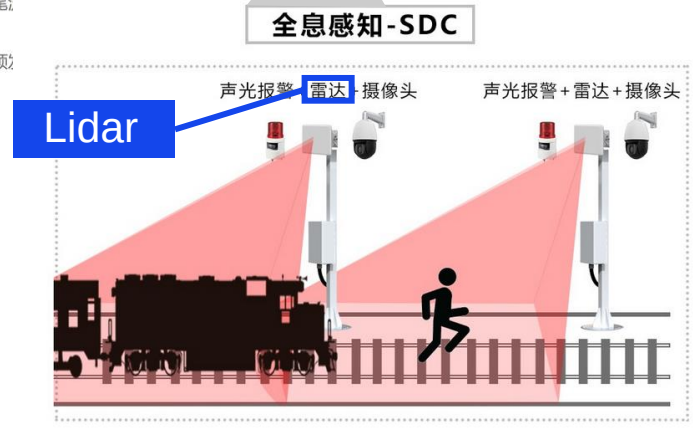
Milestone: Official press release on **January 13th, 2023**

- To personal knowledge, first time that lidar-assisted MPC is announced to be a standard turbine equipment

MySE18.X-28X机组在延续明阳半直驱技术路线的基础上进行了创新和突破，具有"模块化、轻量化、高效率、高可靠"的特点，使机组性能发挥到极致的同时降低了关键部件的重量、成本以及零部件制造工艺难度。研发团队采用基于跨领域融合叶片气动创新技术，使得该机组叶片可提升2%发电效率，还能避免失稳，且极端工况下可降低整机载荷。

全新发布的MySE18.X-28X机组继承了一系列智慧化的设计基因。该风电机组采用全息感知MPC技术和数字孪生DTC技术，可实现激光雷达感知超1000米、摄像头感知超… …使测量数据更精确，机组更安全。基于场群尾…

发布当天，鉴衡认证中心为明阳技术团队颁… 组设计方案已获得行业认可。



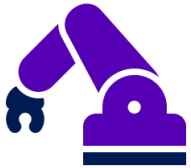
https://www.linkedin.com/posts/mingyangsmartenergy_offshorewind-hybriddrivestheworld-myse18-activity-7019568517867872256-YJ5x/

Question at hand

What are the main obstacles for an **introduction at scale**, if

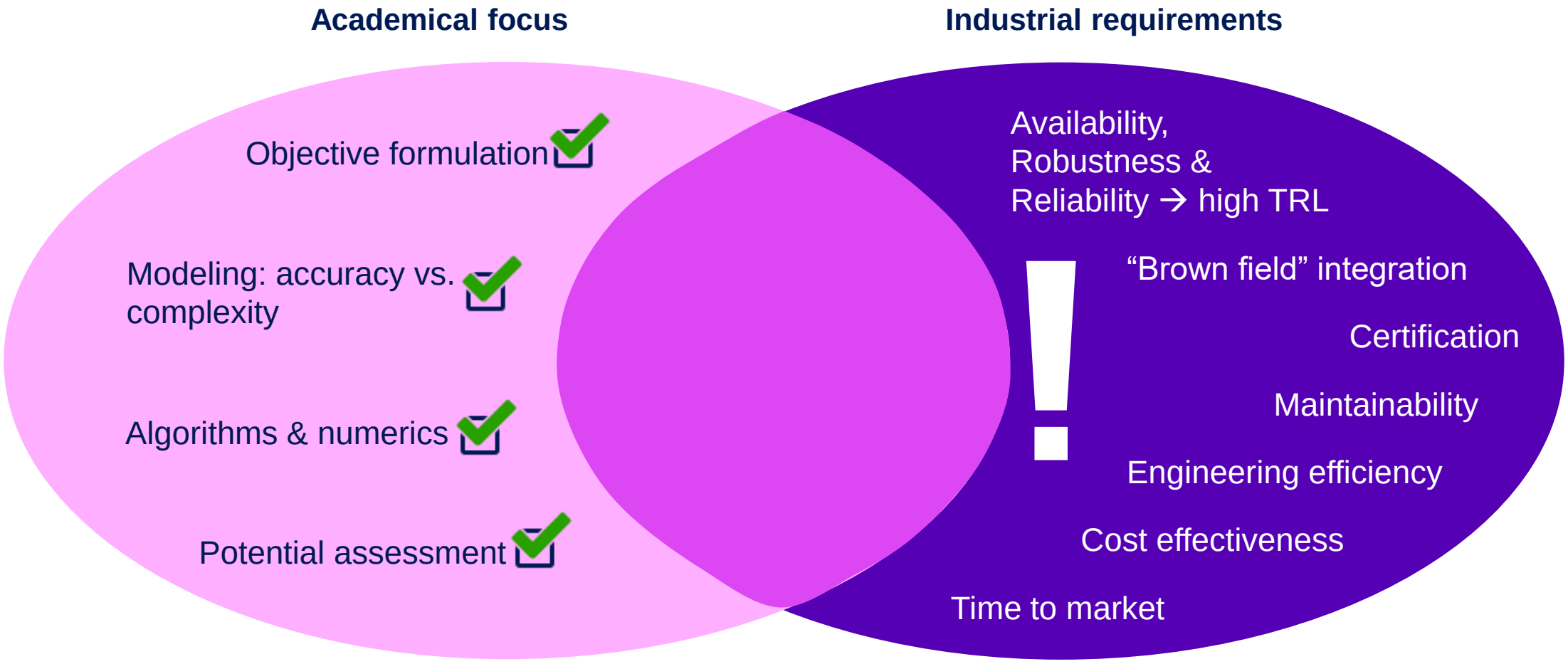
- MPC & Lidar processing theory are mature and publicly available
- MPC & Lidar are market-proven technologies
- Irrefutable benefits in terms of fatigue and ultimate loads are quantitatively known
- Hardware prices have dropped sharply

Turbine life-cycle



- Objective formulation
- Modeling: accuracy vs. complexity
- Algorithm & numerics
- Potential assessment

One technology – different perspectives

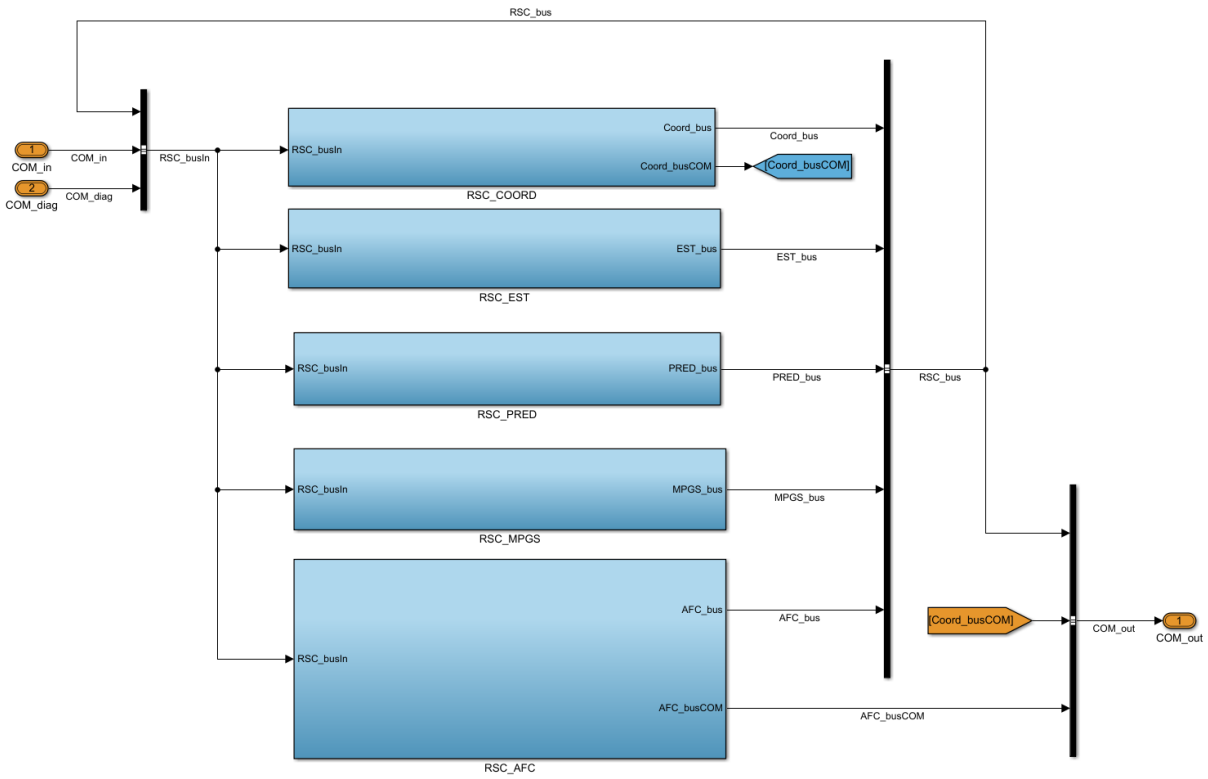


Turbine life-cycle




- Objective formulation
- Modeling: accuracy vs. complexity
- Algorithm & numerics
- Potential assessment
- Time to market
- Engineering efficiency
- Certification
- Maintainability
- Cost effectiveness
- “Brown field” integr.
- Availability, Robustness & Reliability → high TRL

“Brown-Field” integration by “adding” not “replacing” functionality

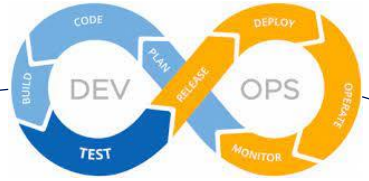


- **LA-MPC** design has to **assist** the conventional **MC** instead of substituting “its” decades of experience
  - Optimal gain scheduler approach
  - Optimal reference + FF generator approach
- Focus **LA-MPC** on operating modes with untapped potential

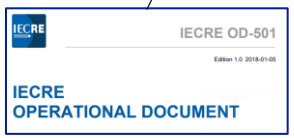
Certification requires more then certification rules

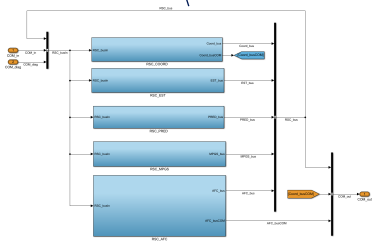
PDF

SW Engineering
Proc. & Arch.

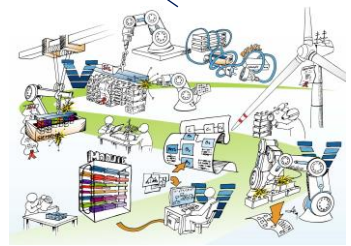


Testing & QA





Certification



Automotive diagnostics

Functionality

Fall-back strategies

Engineering efficiency & cost effectiveness demand for a highly automated Engineering Framework

CodeGenTool

Transcribe formal specification into executable code

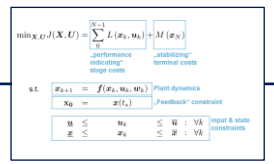
Config & CalibTool

Automated embedding of MPC SW-component into fully-fledged Turbine Controller

DeployTool

One-Click migration Engineering PC to target hardware

Operating strategy

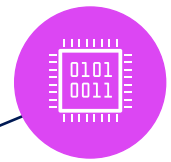


MATLAB / Python

Components for C-code generation

Platform-independent embedded SW

C/C++ IDE



Custom OEM tool-chain for code deployment

Control expertise

Translate into real-time feasible optimal control problem

Optimization Expertise & SW components

Engineering Expertise

- Efficient calibration
- Quality- & process standards
- Supporting Toolchain

Automation Expertise

Conclusions

- MPC and Lidar technology are mature and available on the market
- Making LA-MPC (holographic sensing) an industrial reality **goes beyond** mastering MPC and Lidar technology and just the R&D phase
- A good turbine operation starts with an excellent operating strategy → ability to implement is nice, but not differentiating
- Optimal results require “sufficiently good” preview information
- For complex technologies, cost-effectiveness requires to make use of every bit of synergy available

The way to success requires:

- Tech-solution components with open, standardized interfaces
- moving away from the lone warrior attitude
- bringing together strengths, expertise and experiences of many

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