



Pushing boundaries through model-based development

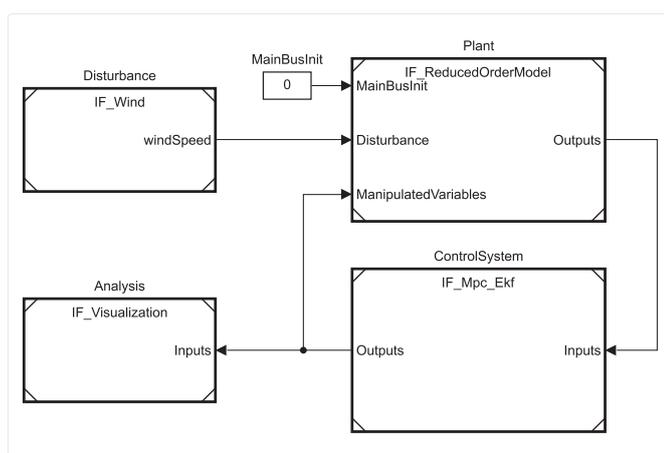
MPC for Wind Turbines



It goes without saying that wind turbine operators strive for the highest possible energy yields in order to achieve maximum financial returns. However, this demand is diametrically opposed to sustainable plant operation – at least in the short term. How can these two opposing goals be reconciled? The solution lies in innovative control concepts such as that developed by RWTH Aachen University: model-based predictive control for wind turbines. The concept, developed using a comprehensive, simulation-based development process, has now been field-tested for the first time on a multi-megawatt turbine operated by Rostock-based company W2E Wind to Energy GmbH (W2E).

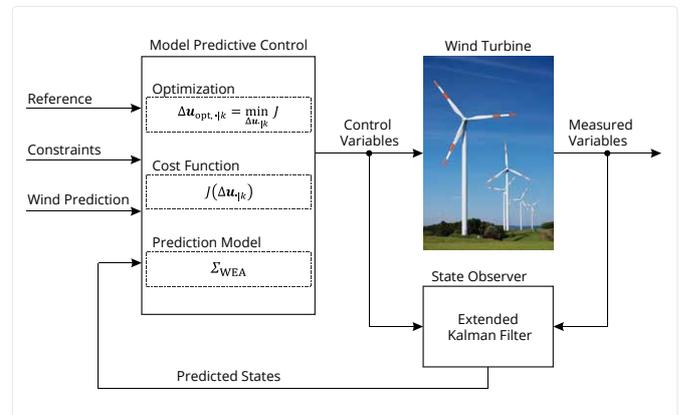
How it all began

The development process began with simulation models of the selected wind turbines. These models were then compared to real-world data – including the influence of wind, amount of power generated, and mechanical load on the tower – in order to provide an accurate representation of dynamic system behavior. "Using such simulation models, we developed model-based predictive controls. We tested the controls in system simulations, as well as with software- and hardware-in-the-loop testing with real control hardware," explains Thomas Konrad, Head of the Department for Energy Systems at the Institute of Automatic Control at RWTH Aachen. "As part of a joint research project with W2E, we recently had the chance to test the control system, developed purely using simulations, on a real turbine for the first time," adds Konrad. "Both RWTH Aachen and W2E are long-standing customers so we were involved in the project from the very beginning.



Simulink model of the simulative development environment with the subsystems of the controlled system of the wind turbine, the control system to be tested, and the simulative specification of the wind speed and analysis functions.

Dickler, S., Kallen, T., Zierath, J., & Abel, D. (2020). Rapid control prototyping of model predictive wind turbine control toward field testing. *Journal of Physics: Conference Series*, 1618, 22068. <https://doi.org/10.1088/1742-6596/1618/2/022068>



WT control structure with control system consisting of state observer and MPC (including optimization, cost function and prediction model modules).

Dickler S., Kallen T, Konrad T, Abel D. (2021). *Windenergieanlagen-Regelung: Ein Modell für die Zukunft. ATP!info, Artikelnummer: 03654_2021_05_05.*
<https://doi.org/10.17560/atp.v63i05.2536>

We were happy to support them with the necessary hardware, software and support know-how," says Ralf Becher, Key Account Manager at Bachmann electronic, of Bachmann's involvement.

Time for something new

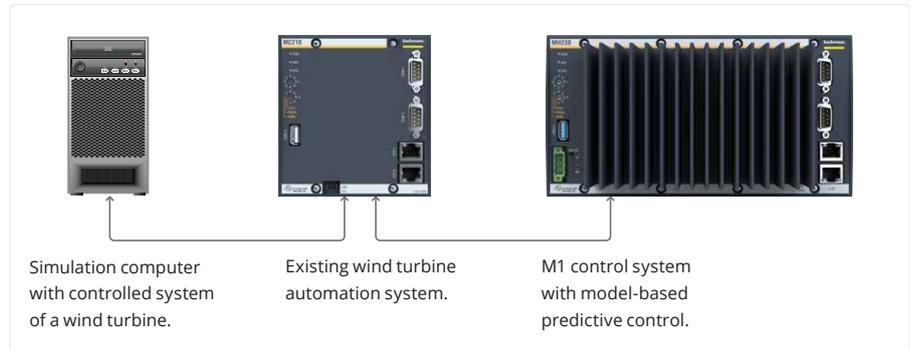
An extended Kalman filter is used to estimate relevant control system values, such as rotor-effective wind speed. Through cooperation between industry and academia a model-based predictive control was developed. It uses variables estimated by a state observer and a plant model to predict future behavior. "With this information, we can predict plant behavior up to around five seconds," explain project researchers and research associates Sebastian Dickler and Thorben Wintermeyer-Kallen. "In addition, several control objectives can be pursued simultaneously. The primary goal is to maximize power generation. The secondary goal is to reduce mechanical load changes in order to protect turbine components."

Another major focus of the research was the development of a test infrastructure for rapid control prototyping. "This is where M-Target for Simulink® shows its advantages, because it allows the M1 controller to be programmed directly with MATLAB®/Simulink®" explains Ralf Becher. Sebastian Dickler agrees, adding: "The seamless integration between MATLAB®/Simulink® and the M1 controller is an essential component for us. This enables us to validate the control algorithms through the different test stages – from simulation to real turbine".

Hardware-in-the-Loop(HiL)-Aufbau:

Hardware-in-the-loop (HiL) setup: Simulation computer simulates WT controlled system (left), MC210 PLC executes existing WT automation system (middle), MH230 PLC executes MPC system (right). PLC automation system from Bachmann electronic

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And the development begins ...

The project's control algorithm could be fully validated using existing simulation models. This is another major advantage of simulation-based, rapid control prototyping: it allows suitable controller parameters to be identified and optimized offsite. In addition, the behavior of the controlled system in simulated fault scenarios can be investigated without risk. Commissioning time and risk to the turbine are therefore reduced to a minimum.

Once system simulations had produced the desired results, the next step was software-in-the-loop (SiL) testing. "SiL testing is used to evaluate the robustness of the compiled controller code, and to test the interaction between closed loop control and operation control," says Sebastian Dickler. During this stage, the controller code was executed together with the turbine simulation on a development PC.

Subsequently, with the M1 controller as target hardware, the controls underwent hardware-in-the-loop testing to assess functionality and robustness. "We are able to implement the cross-controller signal exchange as a bus structure directly in the Simulink® model. Therefore, we use ready-made Simulink® blocks from the Bachmann library. This saves time and minimizes possible implementation errors," explains Thorben Wintermeyer-Kallen.

Testing on target hardware also revealed the actual CPU computing power required under real-world conditions. "However, the computationally intensive control algorithm used was no challenge for our new flagship CPU, the MH230 with 2 independent, real-time CPU cores" says Ralf Becher.

Real-world results

The field test was performed on a 3 MW wind turbine from W2E. "Based on simulations, the controller was already completely parameterized during our rapid control prototyping process. And so, we commissioned the turbine in just a few hours without

any further adjustments during field testing," explain Sebastian Dickler and Thorben Wintermeyer-Kallen. "Our model-based predictive control system took over the tasks of the standard control. During these tests, the new system delivered comparable control results for electrical power as well as mechanical loads. This result is remarkable as optimization based on the experiments has yet to be carried out. In future, the strengths of model-based predictive control to optimally achieve contradicting control goals are further exploited."

During testing, over 2000 signals were recorded with the Scope3 software oscilloscope directly on the M1 controller. This makes the algorithm's behavior transparent and, in addition, the data will be available for future developments.

What next?

"With the field test, we were able to bridge the gap between theory and practice," says Thomas Konrad. "We demonstrated both the basic function of model-based predictive control on a real turbine and the potential of our rapid control prototyping test infrastructure." The task now is to incorporate the knowledge gained from the field test into the control code as well as the simulation models. As Konrad explains, "In a follow-up project, we envisage further field tests up to the full-load operation of the turbine. However, we also see significant potential in the partial load range". Sounds like we'll soon have more news from the innovative research team from Aachen and Rostock.



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