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Provision of tertiary control reserve with large offshore wind farms

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Motivation

- Increasing need of renewable energy's contribution to grid stabilizing services due to continuous increase in power production fluctuation
- German Transmission System Operators initiated experimental phase in 2015 in order to gain knowledge and identify additional requirements (recently prolonged until the end of 2019)
- Chance for additional revenues for wind farm operators and therefore reducing the levelized cost of energy

Challenges

- Estimation of possible power production in real time and sufficient accuracy even during curtailment (dynamic calculation of wake effects)
- Identification and calculation of active power set points' optimal allocation, e.g. to minimize control error, reduce loads or increase control stability
- Consideration of changing wind farm topology, e.g. changes in WEC's operational mode

Modular Wind Farm Controller

Total control structure

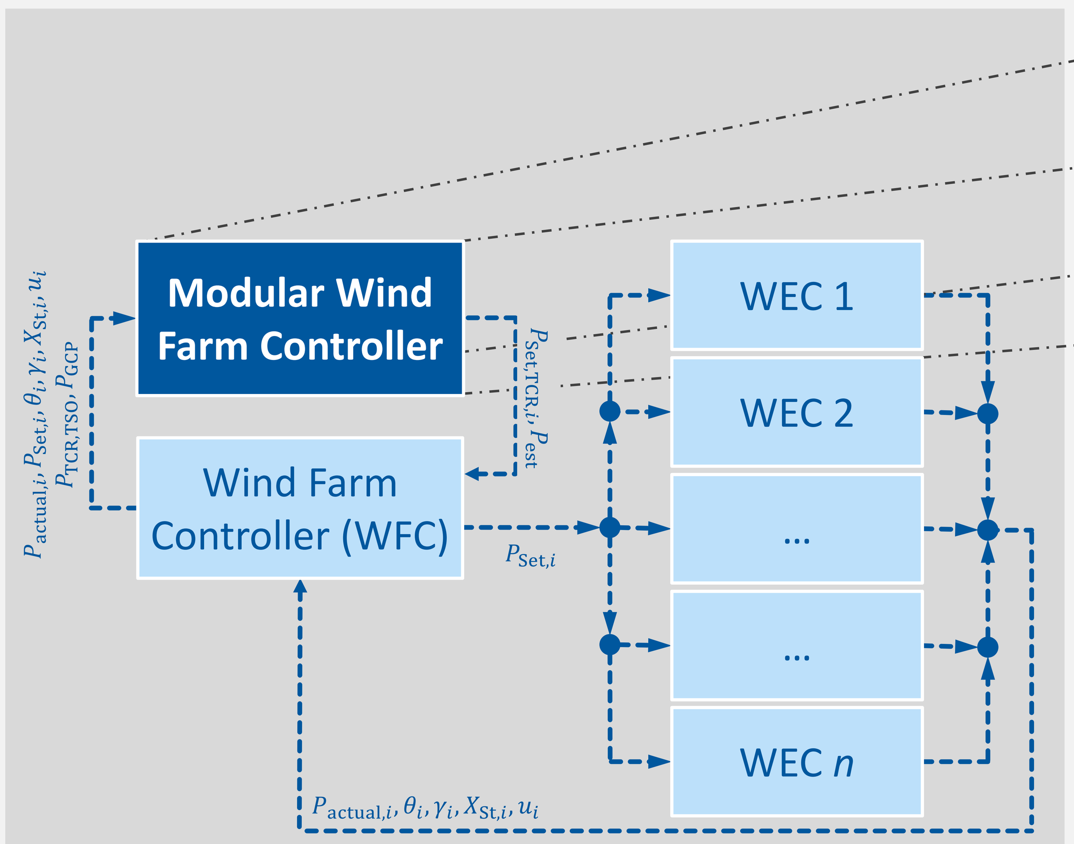


Fig. 1: Representation of the total control structure for the wind farm, WFC and Modular Wind Farm Controller

- Modular concept, which is generally applicable to most wind farm control architectures by using active power set points $P_{\mathrm{Set},i}$ of the WEC as the interface to WFC
- High variety of possibilities to calculate and allocate active power set points $P_{\mathrm{Set},i}$ to WEC
- Feedback of measurements to modular WFC to consider for operational modes, curtailments, environmental conditions, wake effects and wind direction

Modular Wind Farm Controller – details

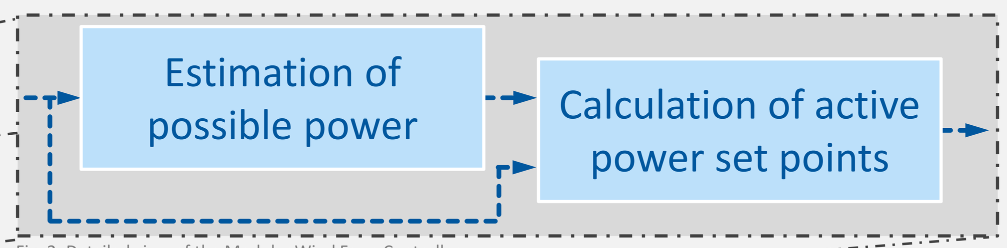


Fig. 2: Detailed view of the Modular Wind Farm Controller

- Estimation of possible power P_{est} with static wake model even during curtailment of wind farm
- Control strategies for calculation of active power set points developed

Parametric wake model for estimation of wind farm effects

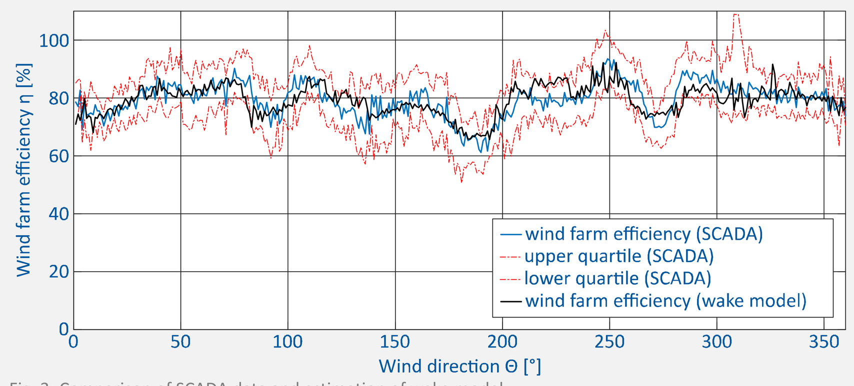


Fig. 3: Comparison of SCADA data and estimation of wake model

- Static wake model used
- Data acquisition, plausibility check and data correction (10min SCADA data)
- Optimization of model parameters to meet dynamic effects by making use of 10min SCADA data's stochastic properties
- Good agreement of the model with the measured values

Calculation and allocation of active power set points

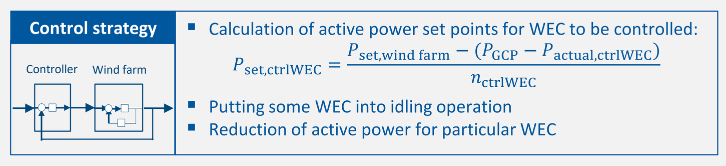
- Power set point for the whole wind farm:

$$P_{\mathrm{set,wind\ farm}} = P_{\mathrm{est}} - P_{\mathrm{TCR,TSO}}$$

- Power set points for WEC:

$$\Sigma_{i=1}^{n} P_{\mathrm{set},i} \coloneqq P_{\mathrm{set,wind\ farm}}$$

- Control strategies developed and benchmarked according to assessment criteria of interest to wind farm and grid operators
- Optimal solution (feedback control):



- Solution leads to reduction of pitch actuation for all WEC of the wind farm
- Changing dynamics due to changes in WEC's operational status are considered

Simulation results

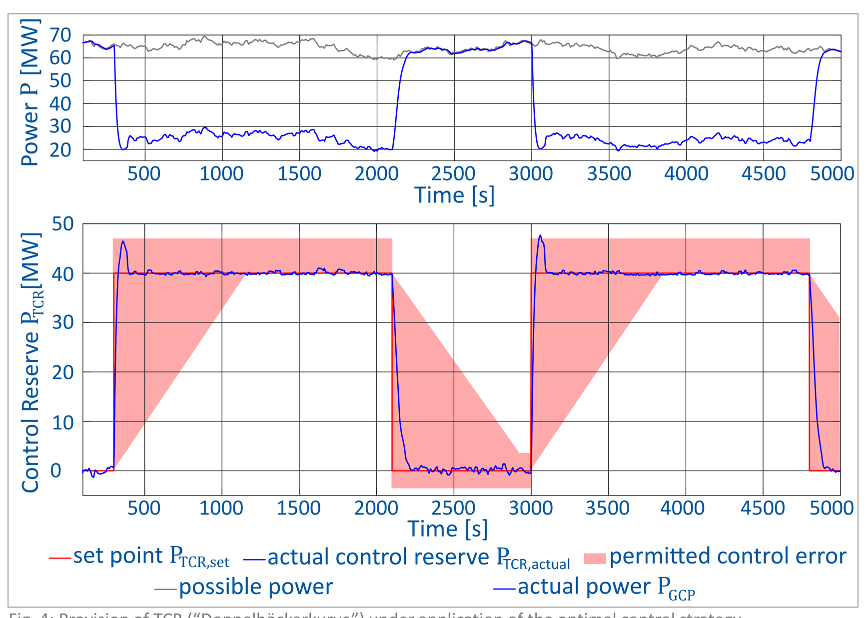


Fig. 4: Provision of TCR ("Doppelhöckerkurve") under application of the optimal control strategy

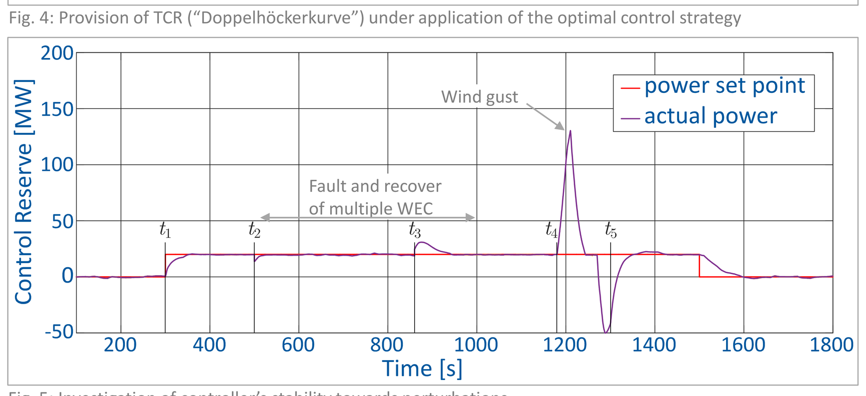


Fig. 5: Investigation of controller's stability towards perturbations

- Simulation of "Doppelhöckerkurve", which describes mandatory requirements for the prequalification, in testing environment
- Verification of wind farm's and controller's dynamic behavior
- Mandatory requirements as possible power's estimation accuracy, settling time and permitted control error are met with optimal control strategy
- Additional simulations prove the controller's stability towards perturbations as simultaneous fault of multiple WEC and wind gusts

Conclusion

- Environment developed to analyze and verify control strategy
- Compliance with TSO requirements
- Reduction of pitch actuation during curtailment
- Reliable inflow conditions and high temporal resolution needed for accurate estimation of possible power
- Complex terrain needs to be considered for onshore wind farms
- Wind farm to wind farm interaction could not be analyzed due to lack of operational data from adjacent wind farms

Outlook

- Development of a dynamic real-time wake model with consideration of atmospheric stability's influence on wind farm effects
- Analysis of wind farm to wind farm interactions
- Technical-ecological assessment for wind farm operator
- Development, simulation and analysis of fault scenarios
- Gaining knowledge through further research with dynamic wake model, test environment and adapting modern control strategies (MPC)

OWP-Control: Adaptive Operational Management and Control of Offshore Wind Farms Based on Specific Operational Strategies for the Optimization of Energy Yield, Loads and Grid Stability

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