IEC Work on modelling – Generic Model development
IEC 61400-27 – expected outcome & timeline

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Overview

- IEC 61400-27: Scope, Timeline
- IEC 61400-27: Validation based on IEC 61400-21
- Three Examples of Type III / IV model development (still work in progress)
  - Reactive Power Control
  - Generator Model
  - Aerodynamic Model

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IEC TC 88 (Technical Committee for wind power) - list of working groups

- 61400-1 Design requirements for wind turbines
- 61400-2 Safety for small wind turbines
- 61400-3 Design requirements for offshore wind turbines
- 61400-4 Wind turbine gearboxes
- 61400-5 Wind turbine rotor blades
- 61400-11 Acoustic niose measurement techniques
- 61400-12 Power performance
- 61400-13 Measurement of mechanical loads
- **61400-21 Measurement and assessment of power quality ...**
- 61400-22 Conformity testing and certification – rules and procedures
- 61400-23 Full scale structural testing of rotor blades
- 61400-24 Lightning protection of wind turbines
- **61400-25 Communication ...**
- 61400-26 Availability
- **61400-27 Electrical simulation models for wind power generation**

Part 1 – wind turbines

- Definition of generic terms and parameters for wind turbine models
- Specification of **dynamic simulation models**:
  - Standard models for generic wind turbine topologies/ concepts / configurations on the market.
  - A method to create models for future wind turbine concepts.
- Specification of a **method for validation** of wind turbine simulation models

Part 2 – wind power plants

- Definition of generic terms and parameters for wind power plant models
- Specification a method to create **models for wind power plants** including wind turbines, auxiliary equipment and wind power plant controller.
- Specification of a **method for validation** of wind power plant simulation models

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Potential users of the standard

- **TSOs and DSOs are end users** of the models, performing power system stability studies as part of the planning as well as the operation of the power systems,
- wind plant owners are typically responsible to provide the wind power plant models to TSO and/or DSO prior to plant commissioning,
- **wind turbine manufacturers** will typically provide the wind turbine models to the owner,
- **developers of software for power system simulation** tools will use the standard to implement standard wind power models as part of the software library, and
- education and research communities, who can also benefit from the generic models, as the manufacturer specific models are typically confidential.

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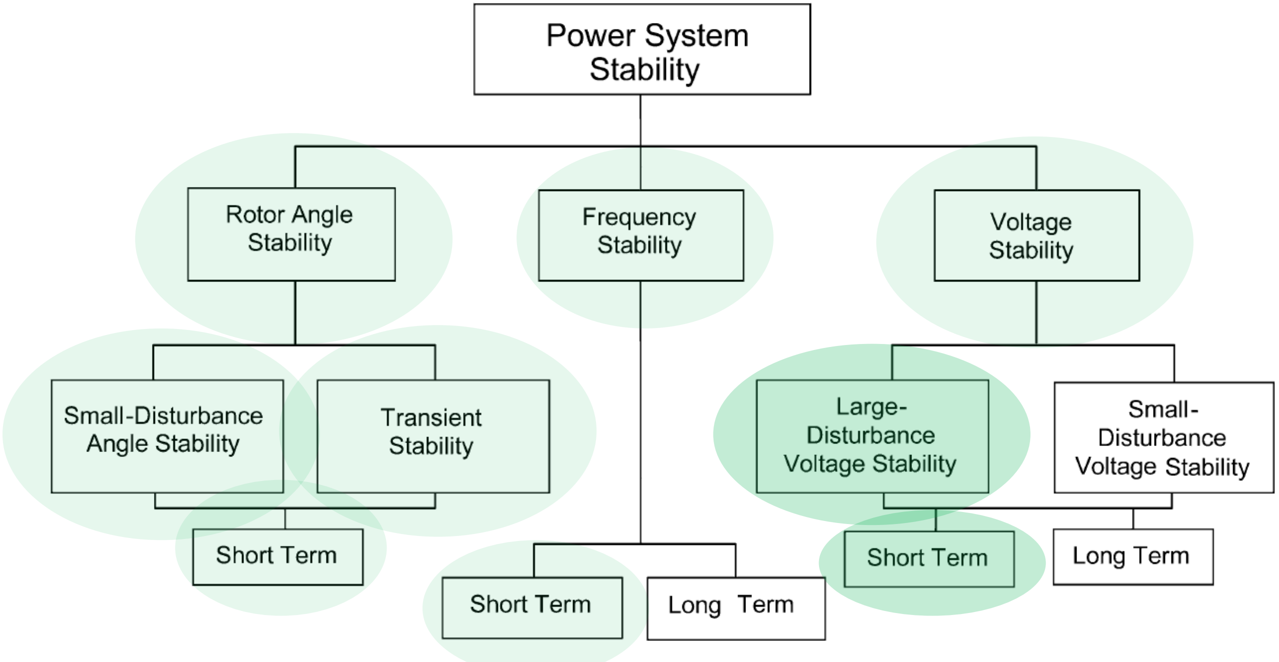
Purpose of models

- IEC 61400-27 models are developed to represent wind power generation in studies of large-disturbance short term voltage stability phenomena, but they will also be applicable to study other dynamic short term phenomena:



Classification of power system stability according to IEEE/CIGRE Joint Task Force on Stability Terms and Definitions. (© IEEE 2004)

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Validation procedure limitations

- The validation is limited by the available tests defined by IEC 61400-21 . These include
    - FRT
    - Active power setpoint control (including response to frequency-changes)
    - Reactive power setpoint control (including voltage control)
- The test and measurement procedures introduce errors which limit the possible accuracy as specified in the validation procedure
- Validation of steady state reactive power capability is not included

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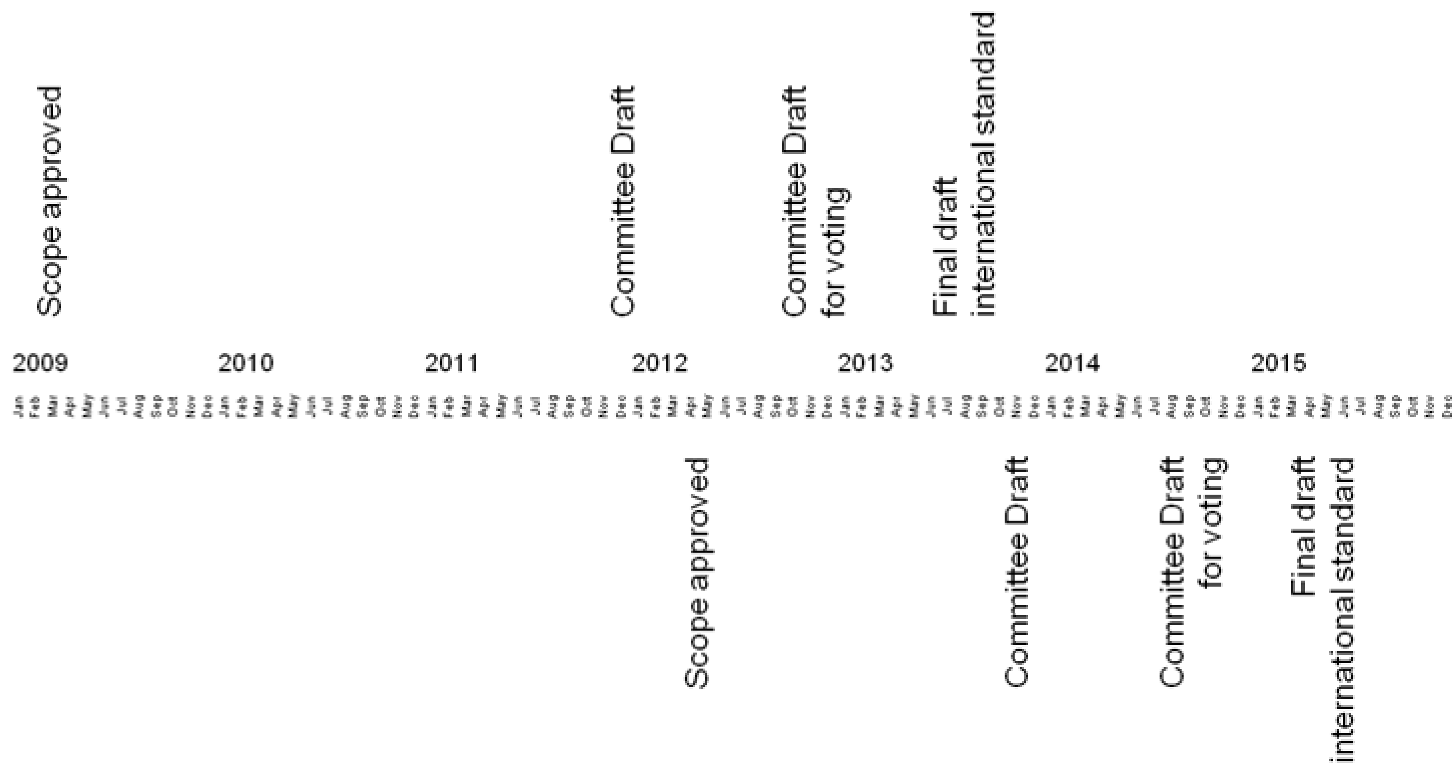
IEC 61400-27 – timeline

Part 1



Part 2

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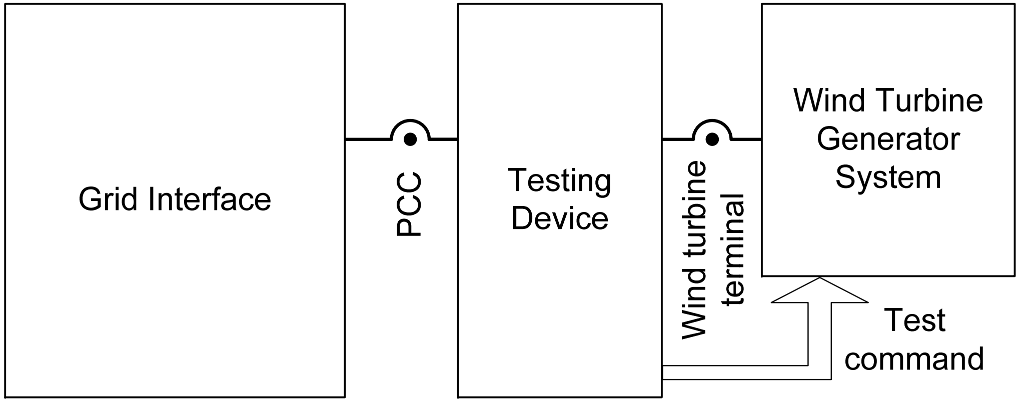
Validation: FRT Measurement setup according to IEC 61400-21



- 3-phase measurement @ 2 kHz or higher according to IEC 61400-21
- Calculation of positive sequenc eaccording to IEC 61400-21

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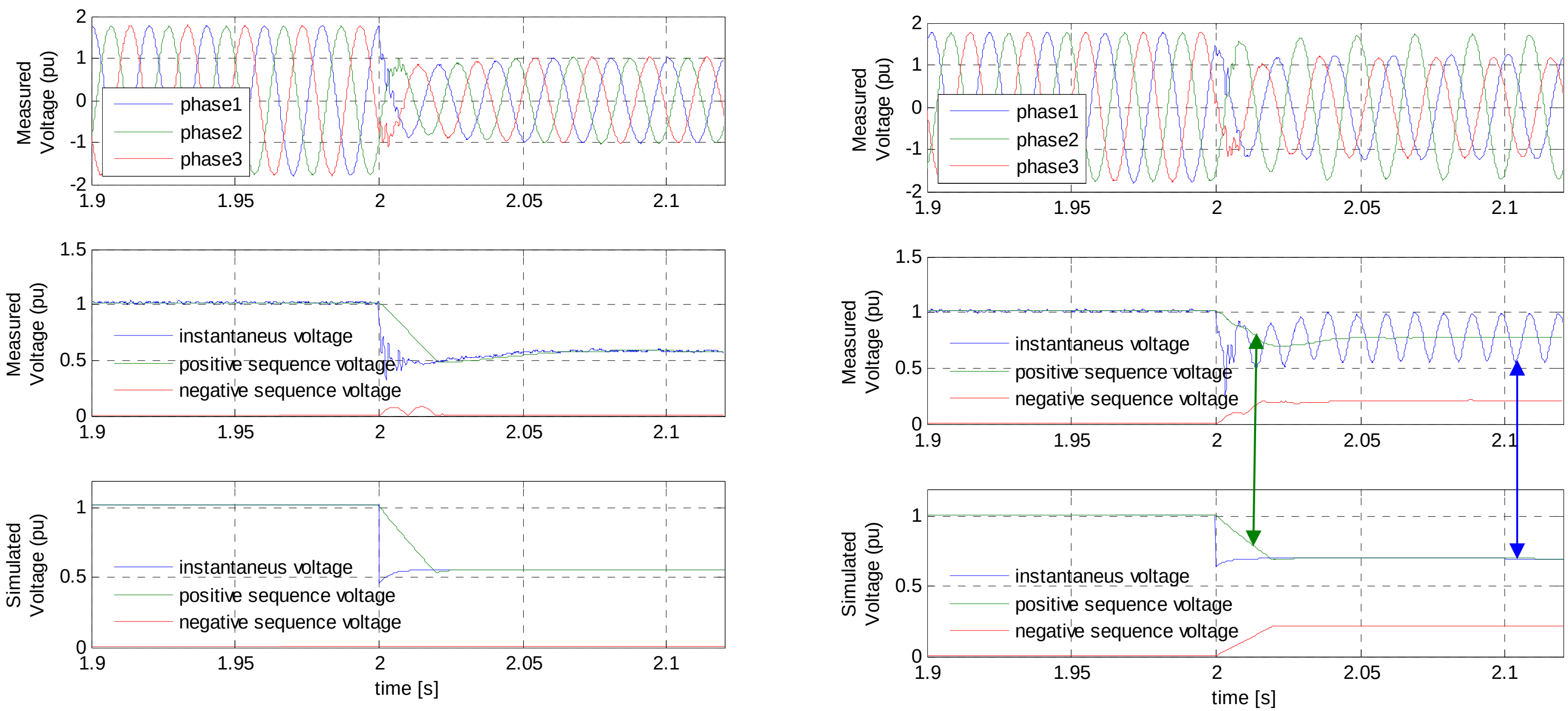
Validation: Filtering of measurment and simulation



- Both measurement <u>and</u> simulation have to be filtered
- 10 Hz filter limit proposed as best compromise (models are not expected to be accurate beyond 10 Hz)

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Why generic Models

Generic models :

- ‘open’ model structure
- only parameters are manufacturer dependent

Advantages of generic models for the user

+ Fully documented model
+ All model components have been thoroughly tested
+ Clear (although not simple!), logically designed model structure
+ physical relationships clearly visible
+ Implementations available in many simulation environments
+ User does not have to rely on manufacturer support if
    - the simulation system is updated to a newer version
    - the simulation environment is replaced/extended

Limits of generic models for the user

– Compromise between different implementations, no exact fit possible

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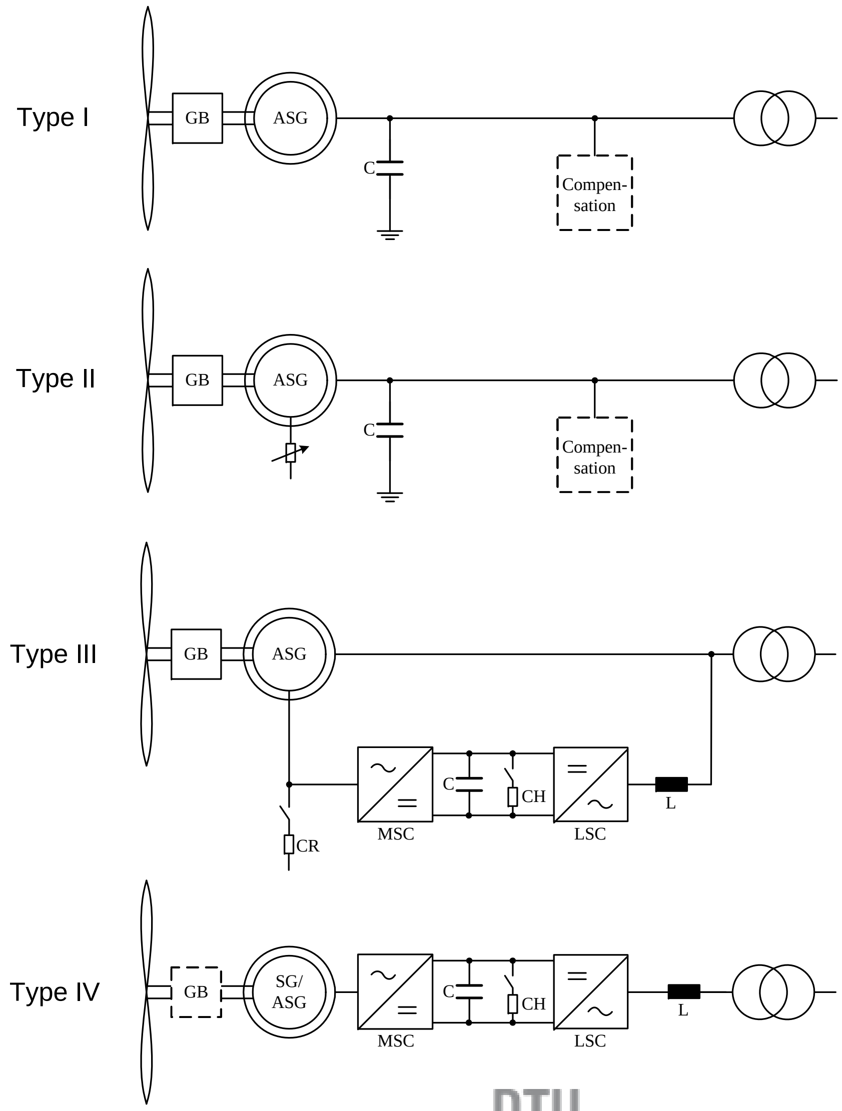
Classification of Generic Models according to electrical system



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Modeling – three examples of structure and physical model background

Three examples:

Reactive power setpoints – several options

DFG Generator Model - physics and Parameter calculation from data sheet

Aerodynamic Model – good accuracy and transparent physical structure

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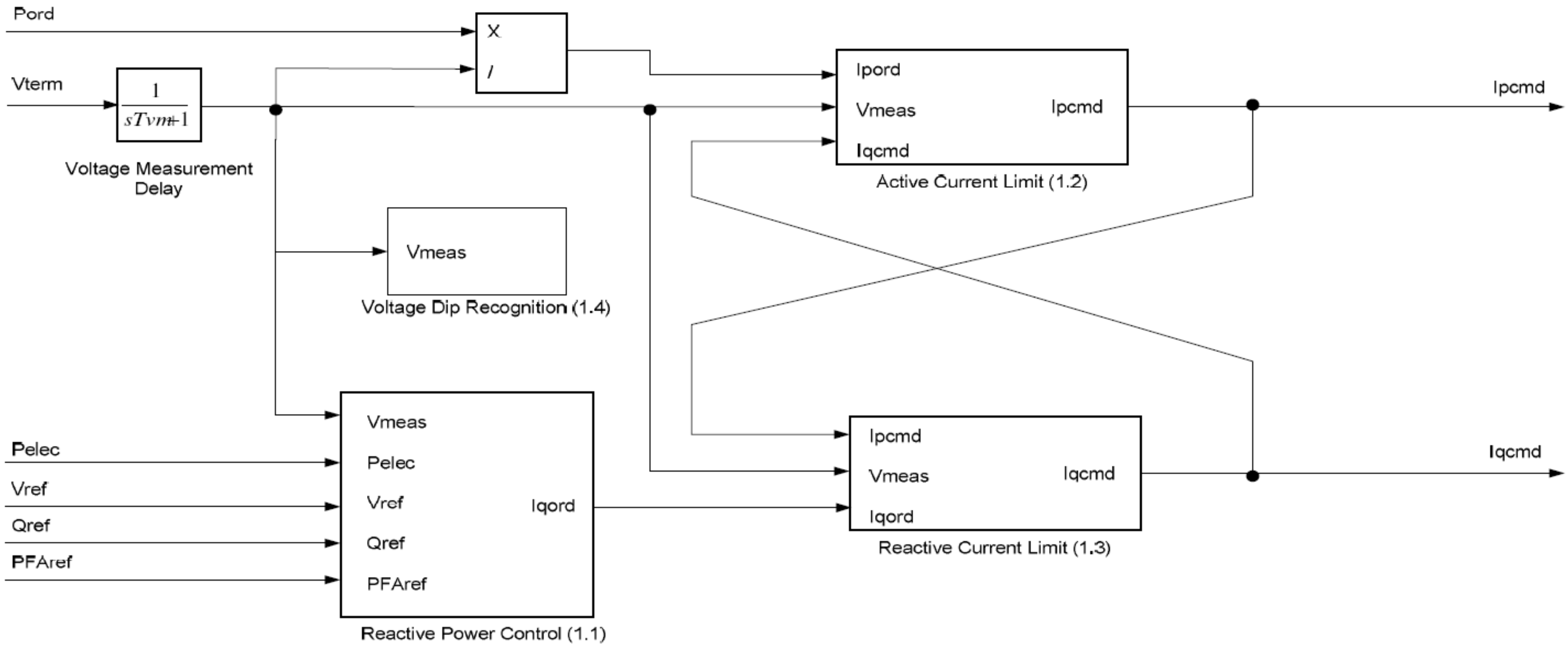
Control Representation for Type III and IV : power control



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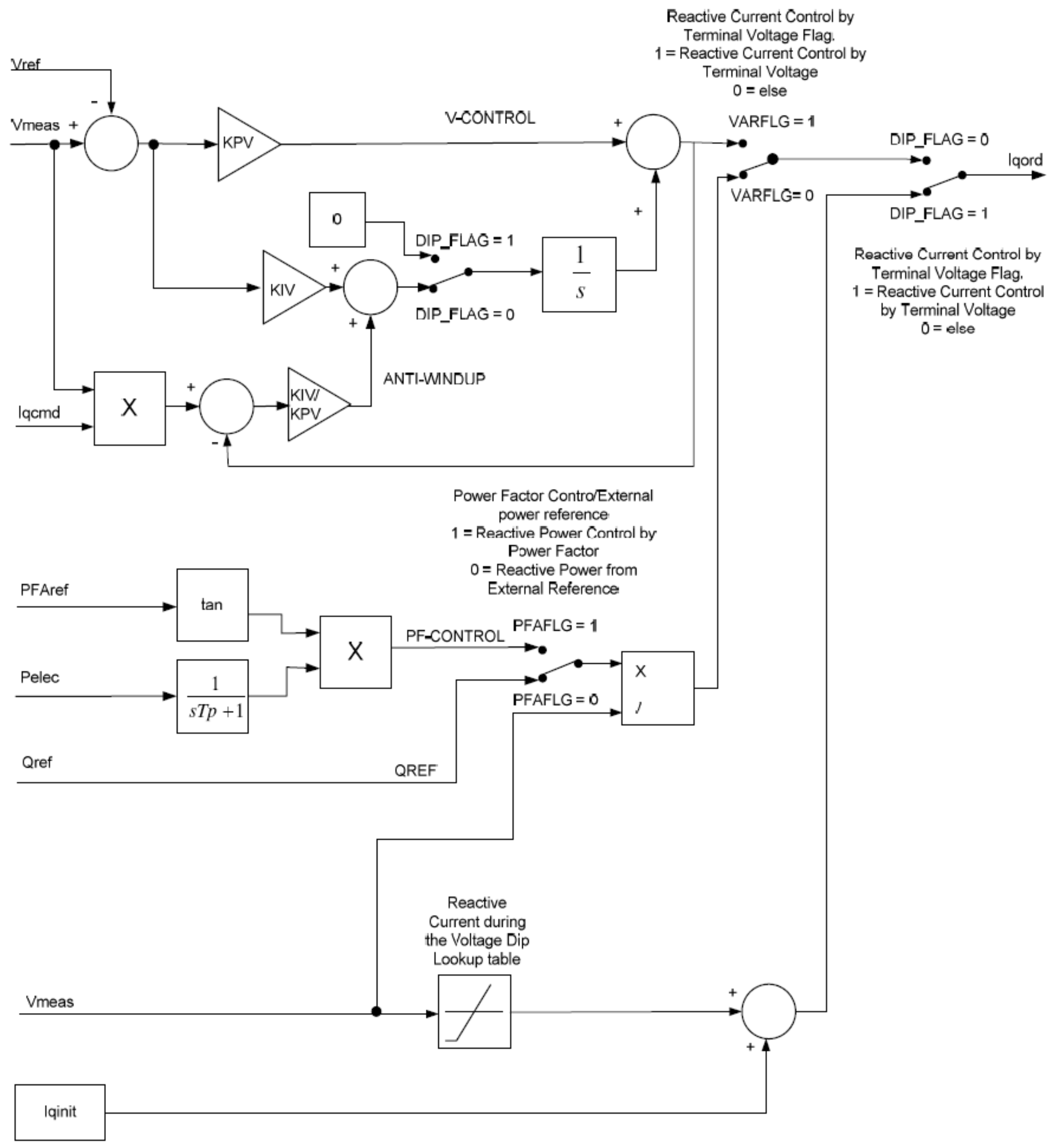
Control Representation for Type III and IV : reactive power control

Options for normal operation

- voltage setpoint
- Power factor setpoint
- reactive power setpoint

Options during FRT

- voltage control using table
- active or reactive current priorit
- voltage dependant limitation of active and reactive current



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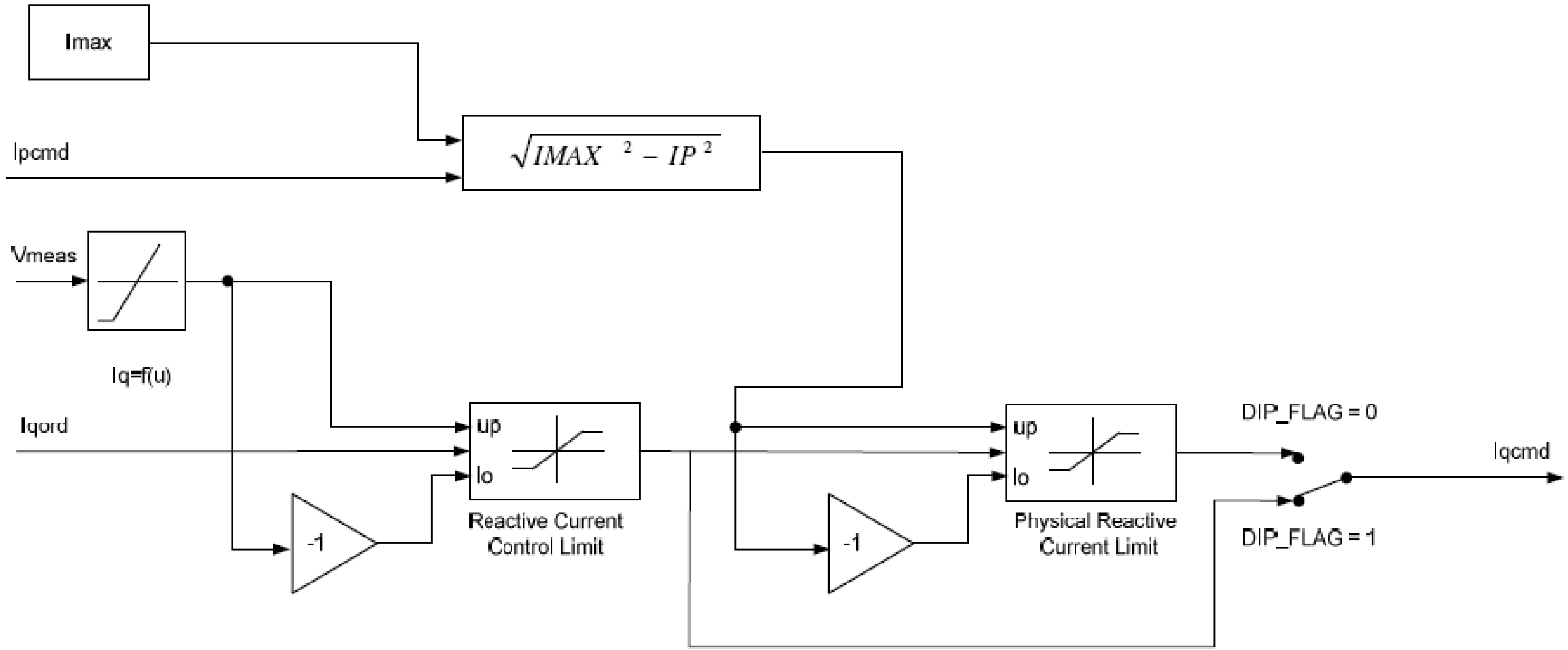
Control Representation: current limitation

Reactive current limitation

- as function of voltage
- total turbine current limit (reactive power priority)



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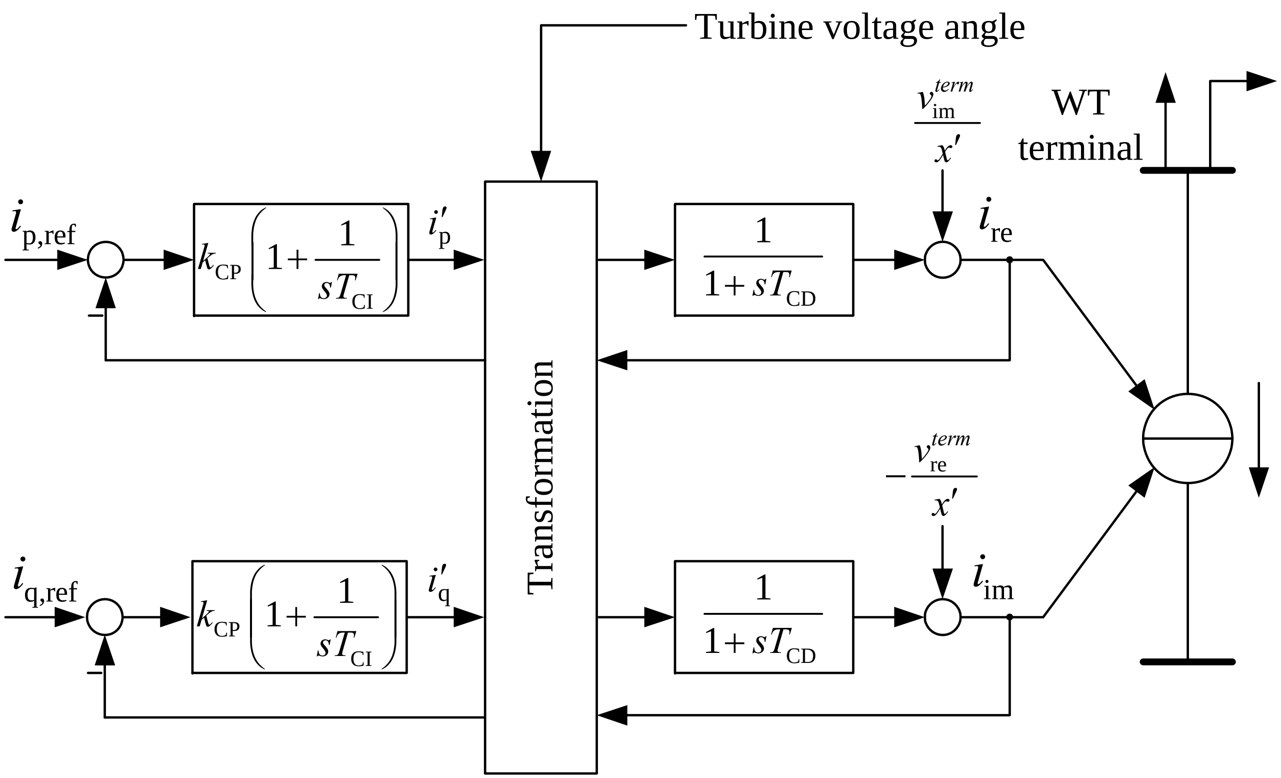
DFG Generator model: general form



|-- Converter --||-- rotor equations --||-- stator equations --|

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DFG Generator Model: calculation of Parameter <u>z</u>’ from data sheet

DFG voltage and flux equations

(1) $\underline{v}_S = r_S \underline{i}_S + \cancel{\frac{d\underline{\psi}_S}{dt}} + j\omega_0 \underline{\psi}_S$

(2) $\underline{v}_R = r_R \underline{i}_R + \frac{d\underline{\psi}_R}{dt} + j(\omega_0 - \omega_R)\underline{\psi}_R$

(3) $\underline{\psi}_S = l_S \underline{i}_S + l_h \underline{i}_R$

(4) $\underline{\psi}_R = l_h \underline{i}_S + l_R \underline{i}_R$

with

$$l_S = l_h + l_{\sigma S}$$
$$l_R = l_h + l_{\sigma R}$$

The 3rd order model for the positive sequence model is derived by setting the stator flux derivate to zero.

Description using current source/Norton equivalent for simulation implementation by inserting (3) and (4) in (1)

$$\underline{v}_S = \underline{z}' \underline{i}_S + \underline{v}'$$

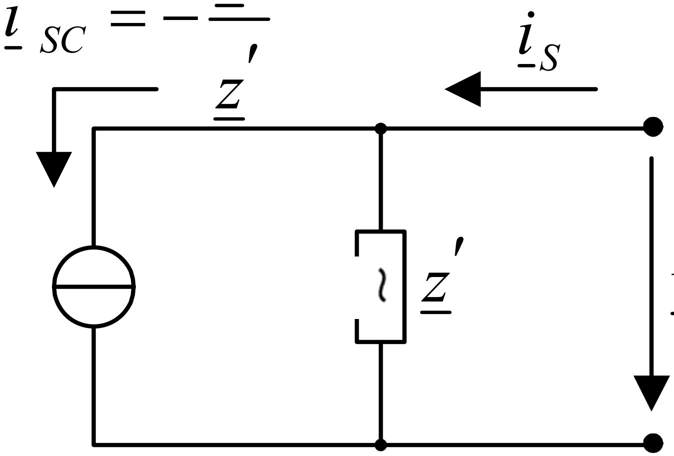
$$\underline{z}' = r_S + j\omega_0 l' \qquad \underline{v}' = j\omega_0 \frac{l_h}{l_R} \underline{\psi}_R = j\omega_0 k_R \underline{\psi}_R$$

with

$$l' = l_s - \frac{l_h^2}{l_R}$$

$$k_R = \frac{l_h}{l_R}$$

$$\underline{i}'_{SC} = -\frac{\underline{v}'}{\underline{z}'}$$



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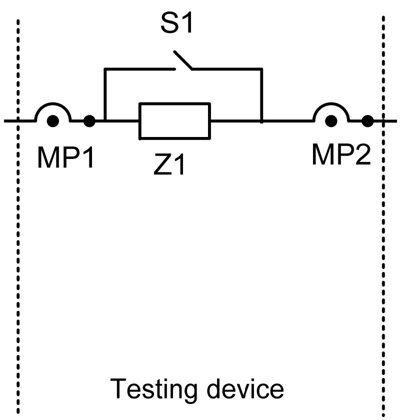
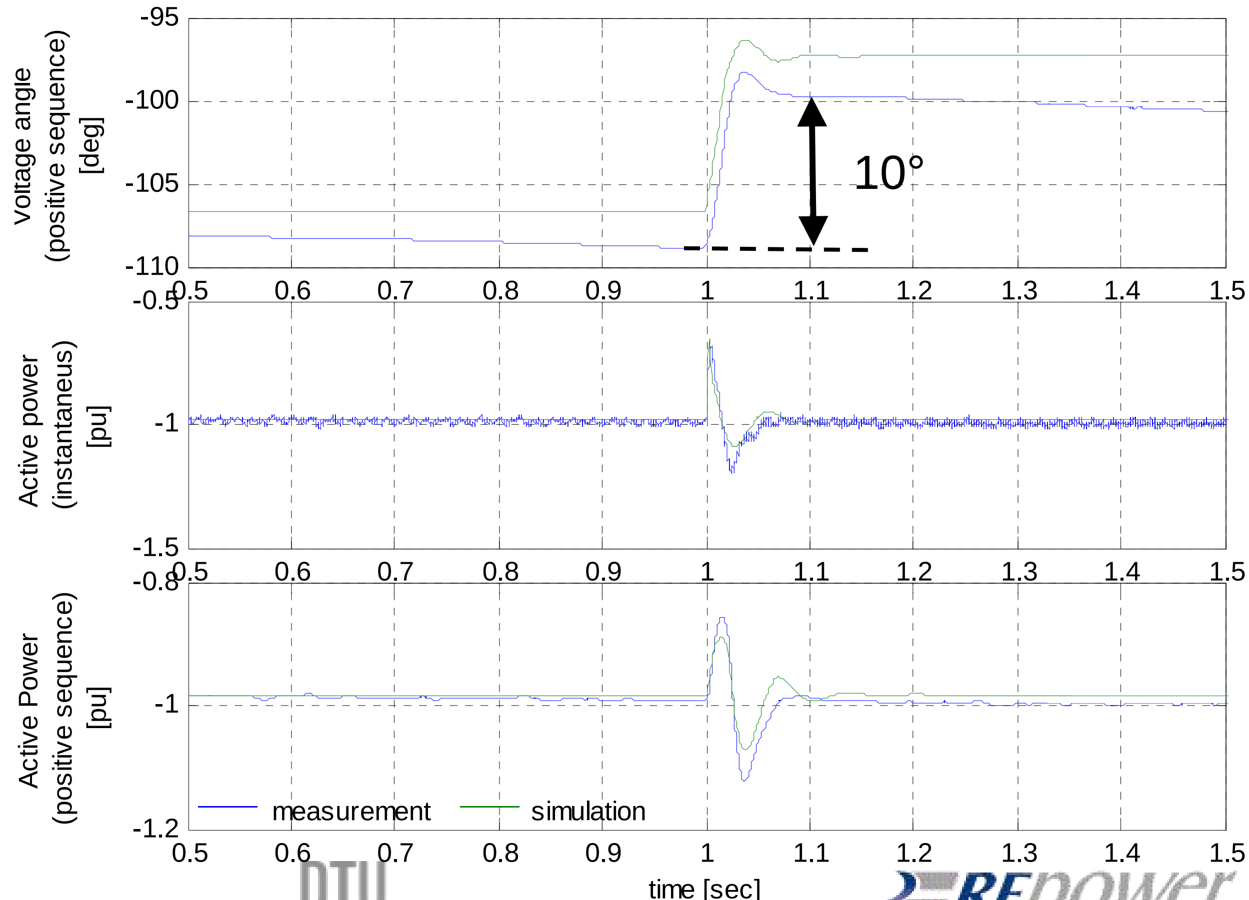
DFG Generator Model: Example of Validation– phase angle change

Measurement and simulation of fast phase angle change





Physical representation: Aerodynamic Model based on partial derivatives

Aerodynamic model

+ Suitable for partial load and full load

+ Allows active power reduction at higher wind speeds

+ Supports speed variation following grid faults and programmed inertia

+ Clear physical background with very limited number of parameters

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Aerodynamic Model: Model reduction using Taylor series

$$cp_{aero} = f(\underset{\text{Blade angle}}{\Theta}, \underset{\text{Tip-speed ratio}}{\lambda})$$

$$\lambda = \frac{v_r}{v_w} = \frac{\Omega_r \cdot r}{v_w}$$

Taylor-series:

$$f(x) = f(a) + \frac{f'(a)}{1!}(x-a) + \frac{f''(a)}{2!}(x-a)^2 + \ldots$$

$$cp_{aero} = cp_0 + \left.\frac{\partial cp}{\partial \Theta}\right|_{\lambda=const} \Delta\Theta + \left.\frac{\partial cp}{\partial \lambda}\right|_{\Theta=const} \Delta\lambda$$

with $\Delta\Theta = \Theta_0 - \Theta$

and $\Delta\lambda = \lambda_0 - \lambda$

with $P_{Aero} = \frac{1}{2}\rho\pi R^2 v_{w1}^3 \cdot cp$

$$\boxed{P_{aero} = P_0 + \left.\frac{\partial P}{\partial \Theta}\right|_{\lambda,n=const} \Delta\Theta + \left.\frac{\partial P}{\partial n}\right|_{\Theta,v=const} \Delta n} + \cancel{\left.\frac{\partial P}{\partial v}\right|_{\Theta,n=const}} \Delta v$$

Change of wind speed modeled by changing P_0

$$P_{aero} = P_0 + P_\Theta + P_n$$

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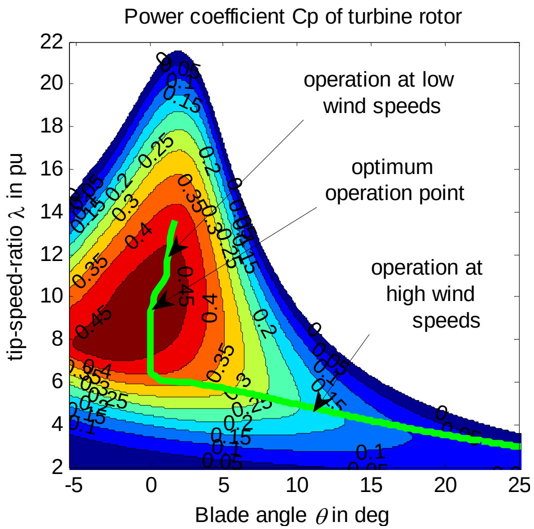
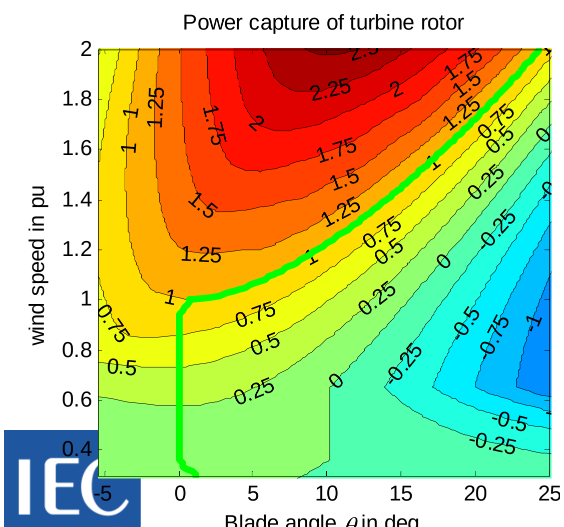
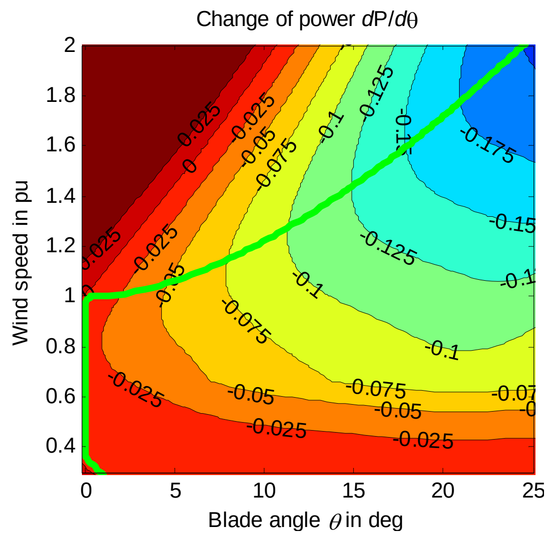
Aerodynamic Model: Model reduction using Taylor series

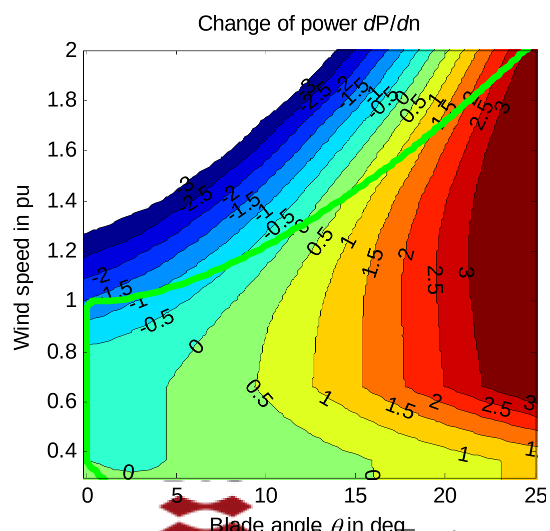
1. Static representation



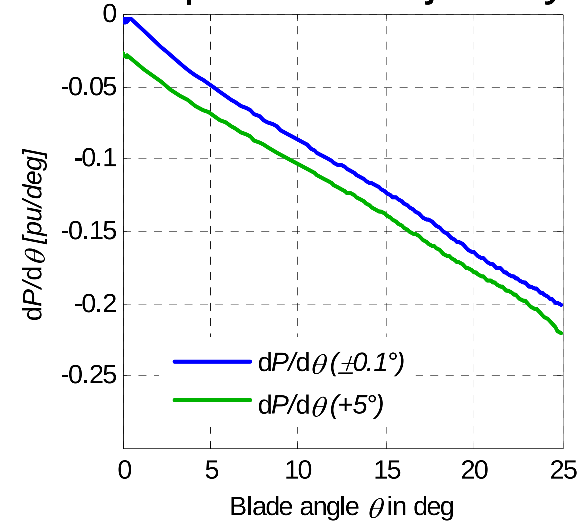


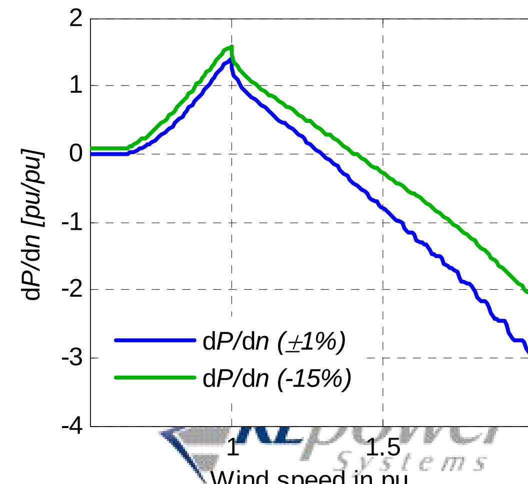
2. Partial derivatives





3. Partial derivatives along operation trajectory





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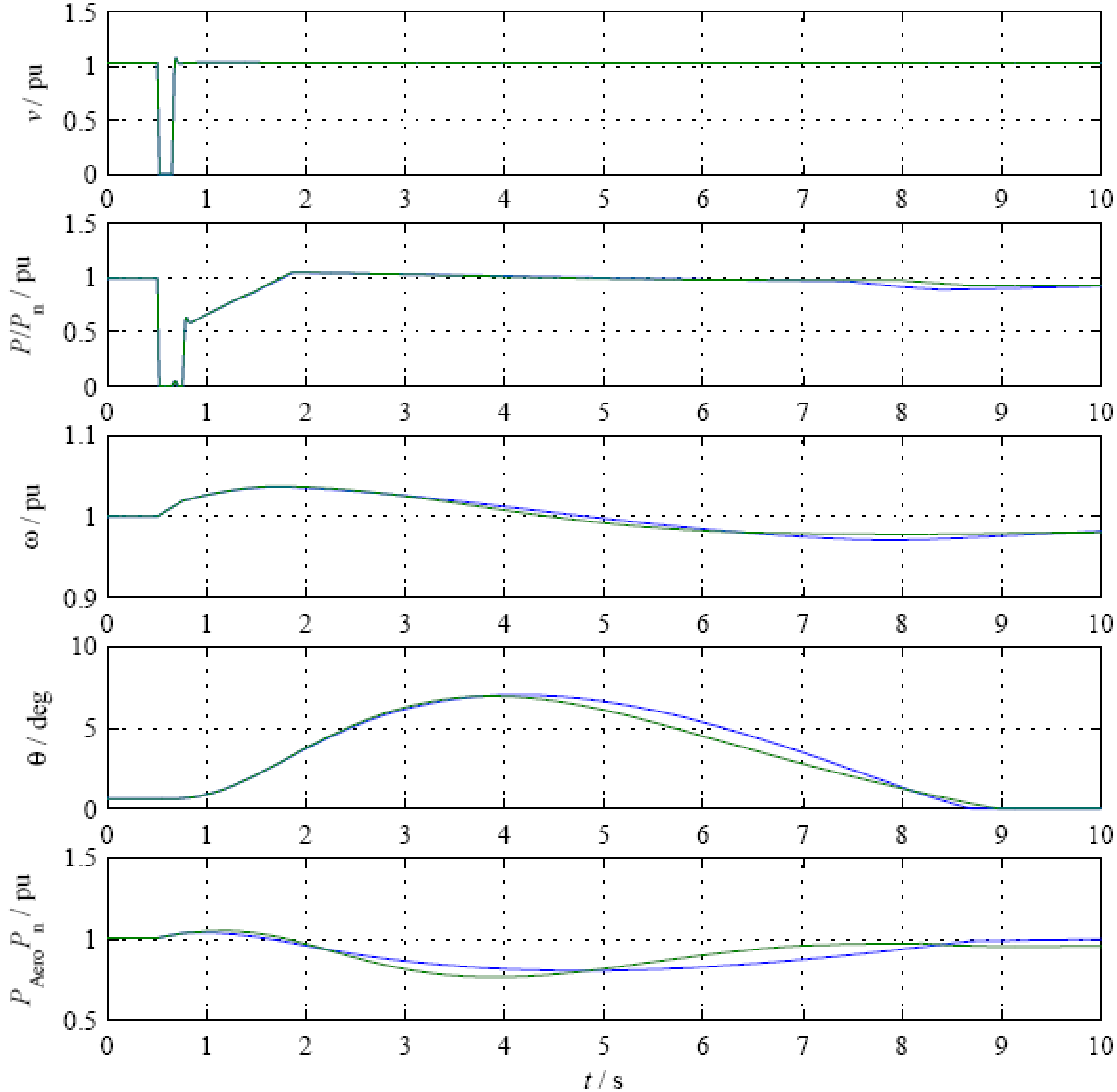
Aerodynamic Model: Comparison to cp-table at grid fault



Simulation of grid fault of a 2 MW wind turbine using the proposed aerodynamic model (blue) and comparison the simulation using a cp-table representation (green).

Summary

Generic Models

- Simplified model with limited number of parameters
- Flexible configuration
- Clear physical background
- Fully documented and logically designed model structure
- Thoroughly tested components
- Availability in different simulation environments expected in 2012

Questions?