

**CIGRÉ SC-A1
Electrical Rotating Machines Committee
Panel on Wind Generation**

**Wind Power Plant Electrical Performance
compliant with grids and connection codes**

Philip C. Kjaer. August 26, 2010. Paris.

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Products & offerings

Onshore

Turbine / IEC Wind Class	IEC I High Wind	IEC II Medium Wind	IEC III Low Wind
V52-850 kW	X	X	
V60-850 kW		X	X
V82- 1.65 MW		X	X
V80-2.0 MW	X		
V90-1.8 MW		X	
V90-2.0 MW			X
V100-1.8 MW			X
V90-3.0 MW	X	X	
V112-3.0 MW		X	X

Offshore

Turbine / IEC Wind Class	IEC I High Wind	IEC II Medium Wind	IEC III Low Wind
V90-3.0 MW Offshore	X	X	
V112-3.0 MW Offshore		X	X

Options

SCADA.

Condition Monitoring.

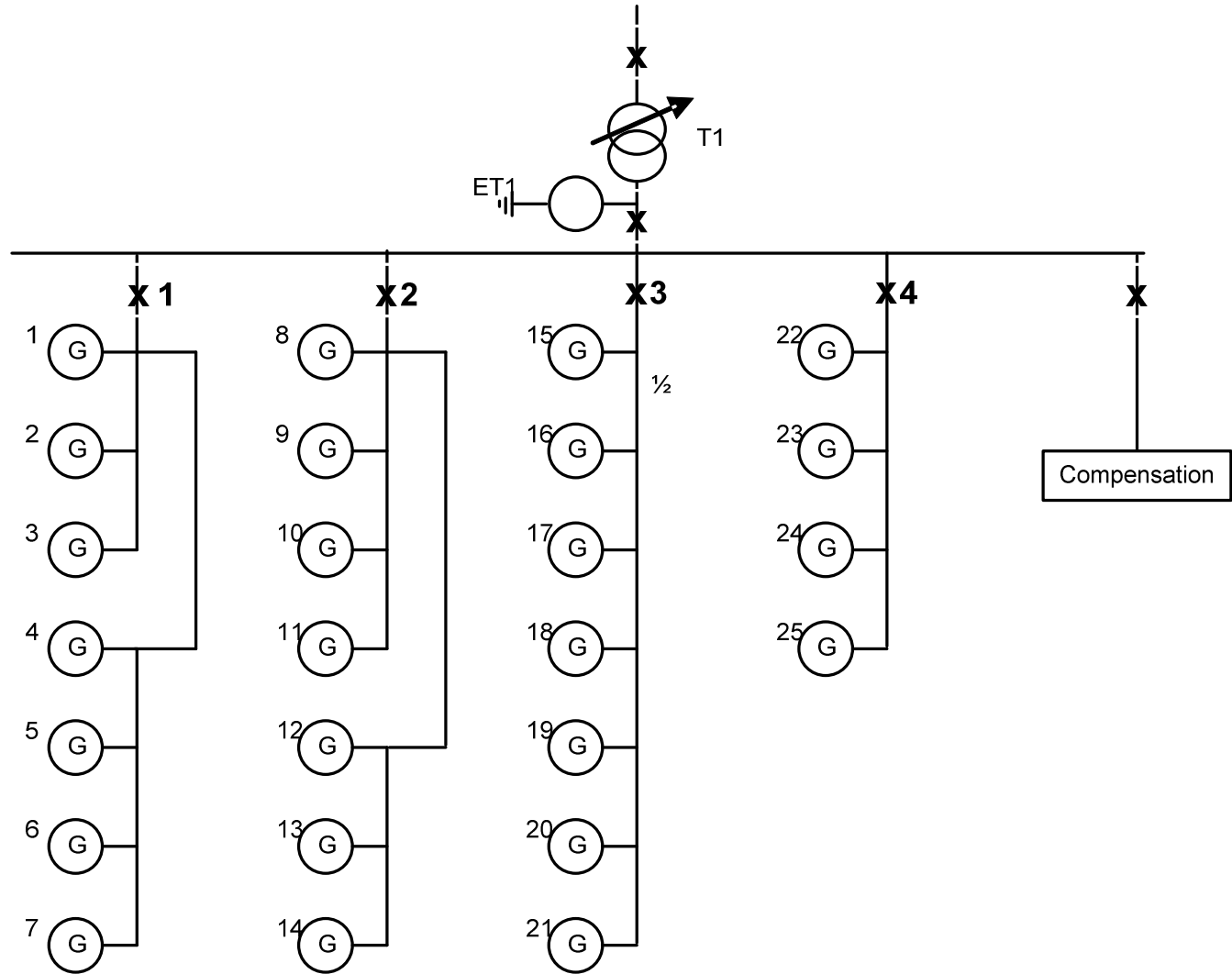


Power Plant Solutions:

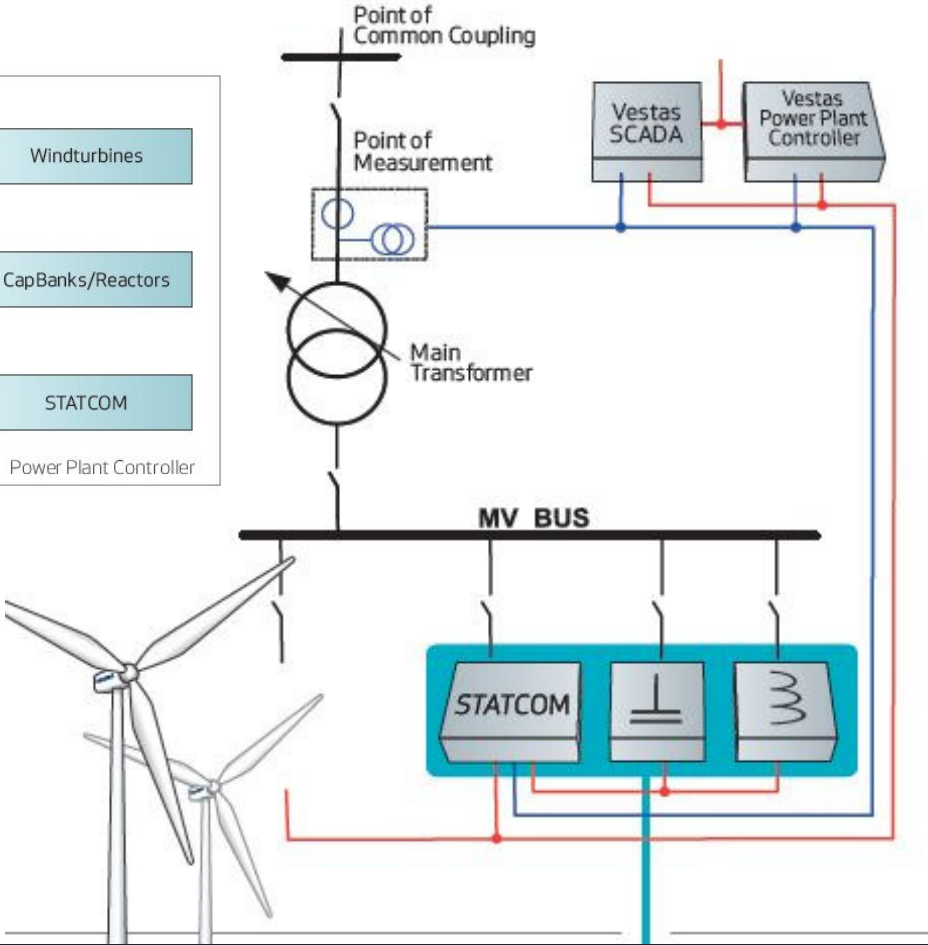
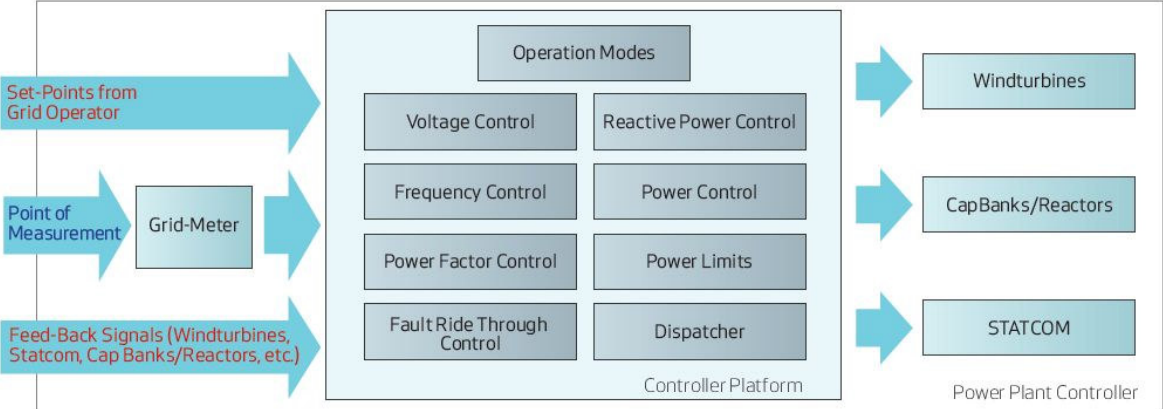
- planning (siting, elec. pre-design)
- procurement.
- construction.
- operation & service.
- optimisation.

Wind Power Plants

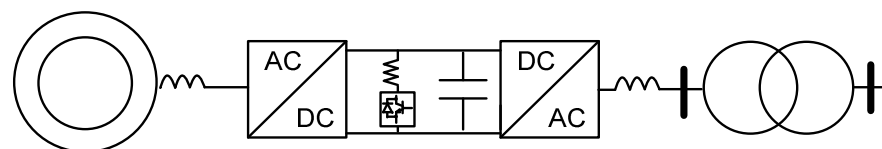
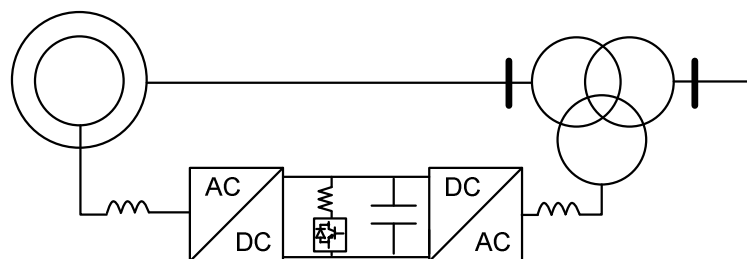
Flexible configuration, scaling and parallelling.



Power Plant architecture

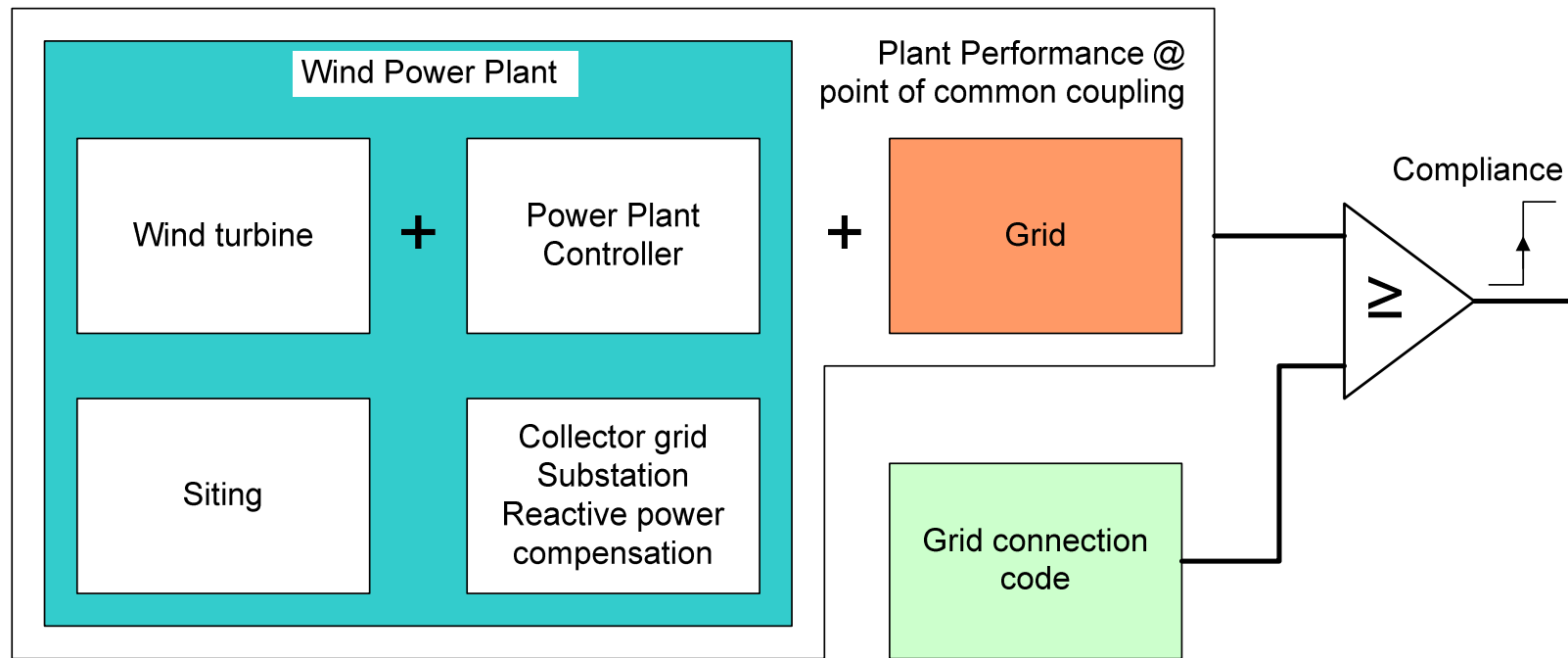


Variable-speed wind turbine topologies

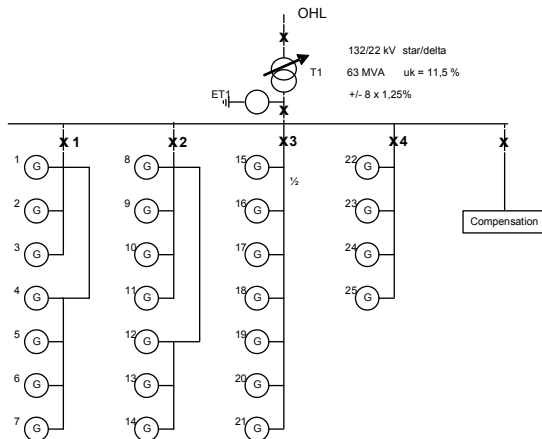
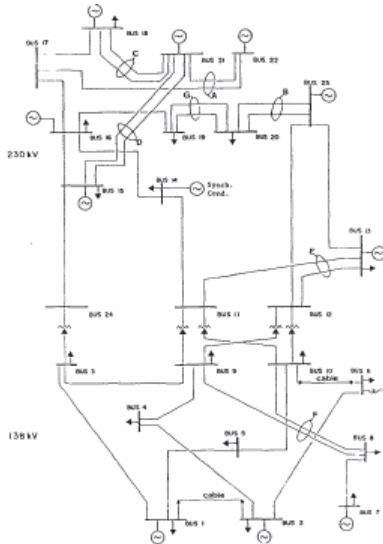


	Doubly-fed	Full-converter
Minimum speed	Limited by rotor design voltage.	From zero speed.
Stator current control	Controlled from rotor side → bandwidth limited by machine rotor time constant.	Controlled directly from generator converter.
Grid current control	Mainly as stator current; though grid converter controlled directly.	Controlled directly from grid converter.
Grid voltage minor disturbances	Impacts stator currents directly. Compensation from rotor side.	DC-link allows decoupling generator from grid with appropriate control.
Grid voltage major disturbances	Impacts stator and rotor currents directly. Power dissipation through converter.	Decoupled. Power dissipation in DC-link.
Grid frequency excursions	Impacts stator directly. Compensation from rotor side.	DC-link allows decoupling generator from grid.
Short-circuit current contribution	Transient peak ~4pu, then controlled to ~1pu.	Transient peak <2pu, then controlled to ~1pu.

Grid connection codes + route to compliance

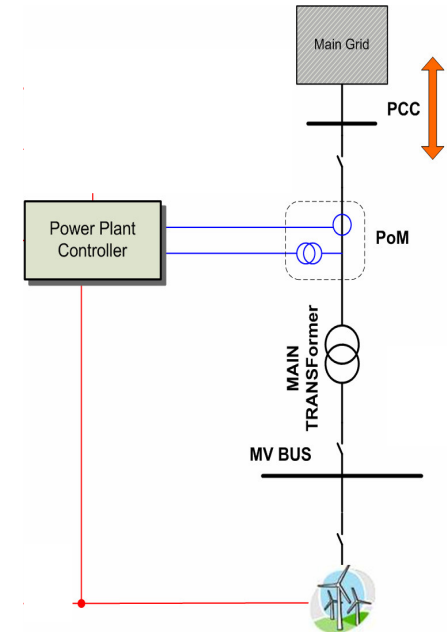
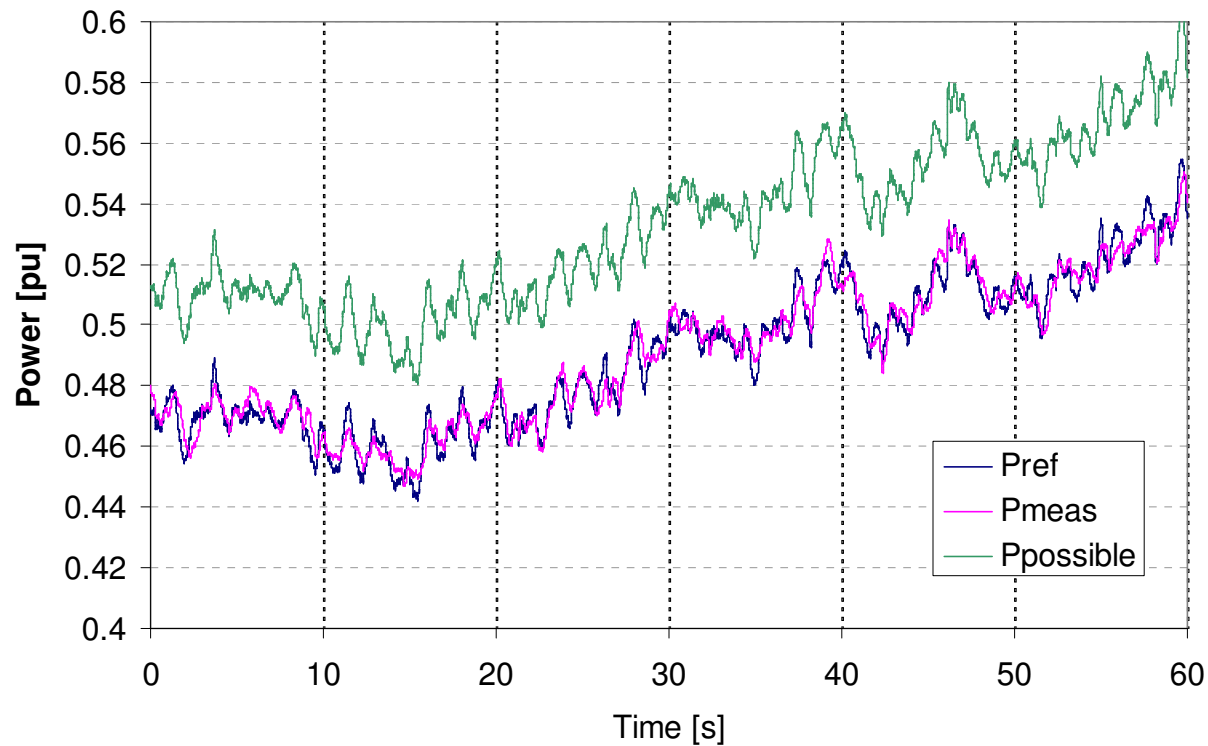


Electrical planning & design – studies



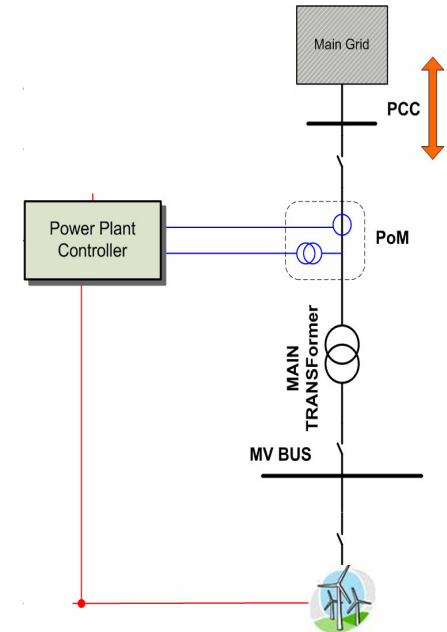
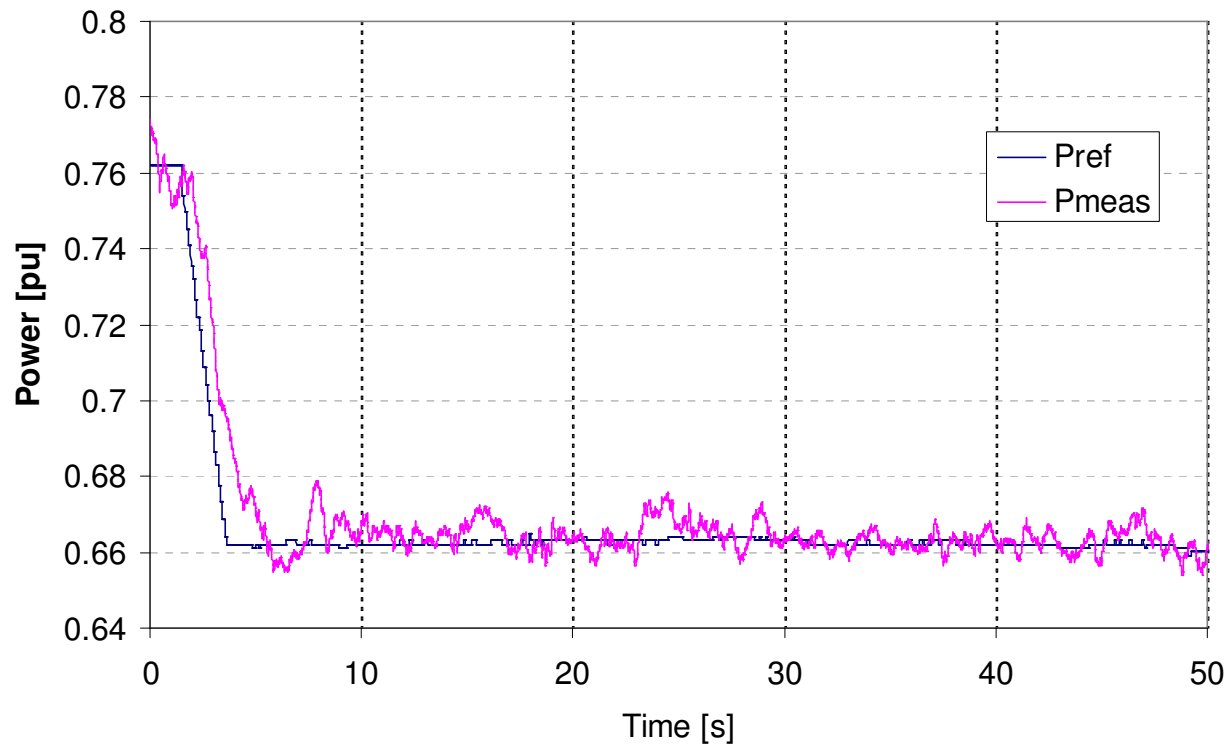
	Documentation & simulation models		
	Datasheet	Positive sequence model	Electrical machine transient model
Transmission load flow	✓	✓	
Transmission transient/voltage stability		✓	(✓)
Transmission protection	✓	✓	
Plant load flow		✓	
Plant short-circuit		✓	
Plant dynamic control		✓	✓
Plant transients			✓
Plant protection coordination	✓		✓
Plant temporary over-voltage			(✓)

Power Plant performance. Plant active power control.



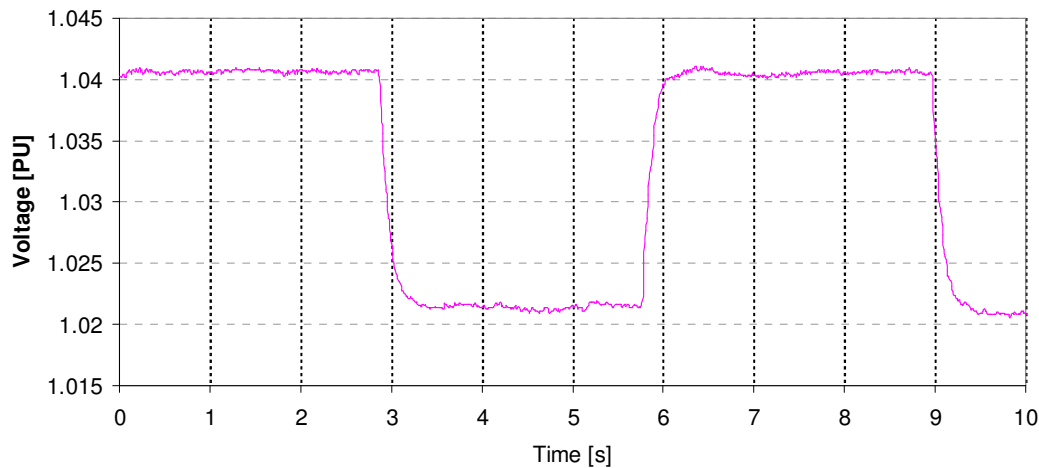
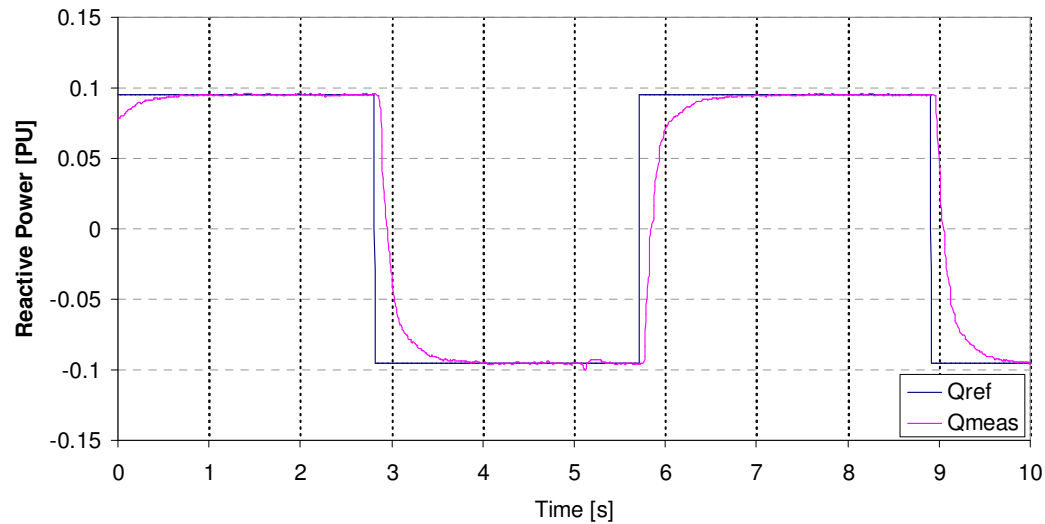
$$P_{\text{ref}} = P_{\text{avail}} \times 0.92$$

Power Plant performance. Plant active power control.

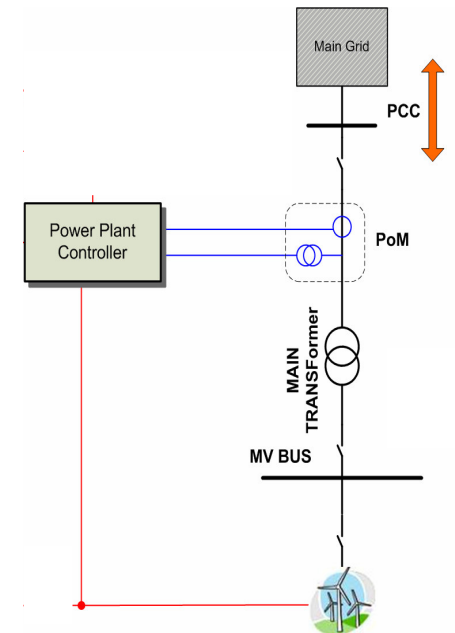


P_{ref} stepped
0.76pu \rightarrow 0.66pu

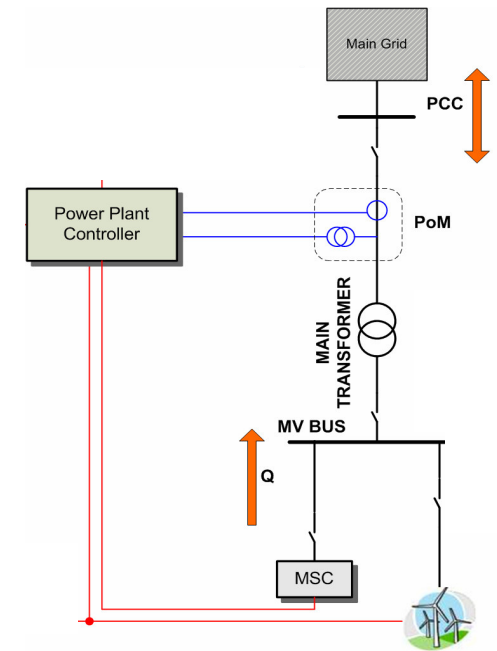
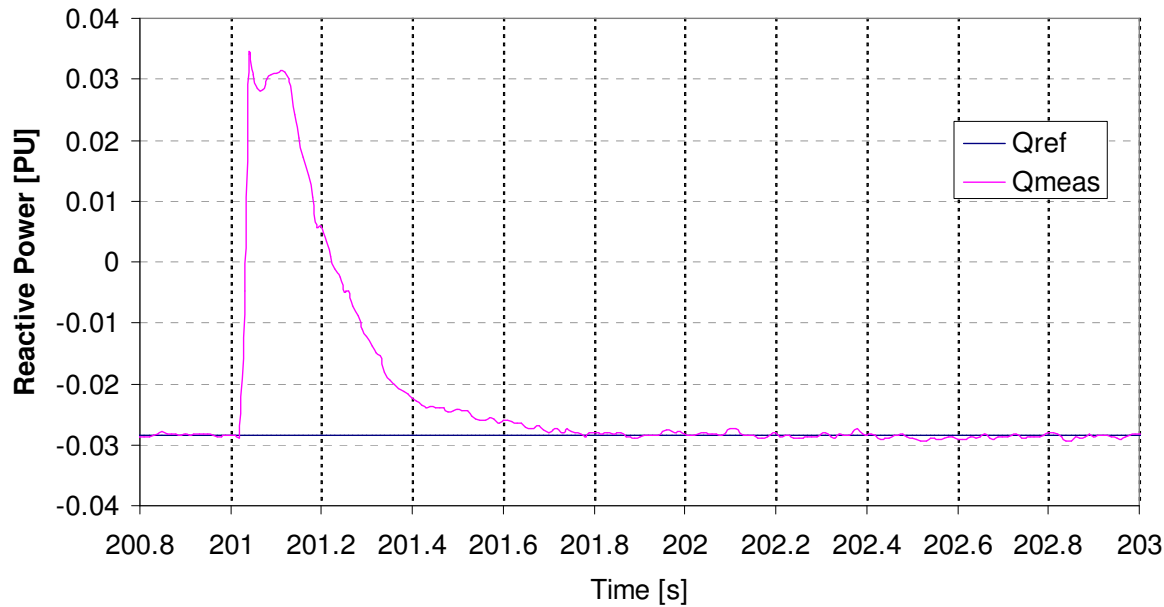
Power Plant performance. Plant reactive power control.



Q_{ref} stepped ± 0.10 pu

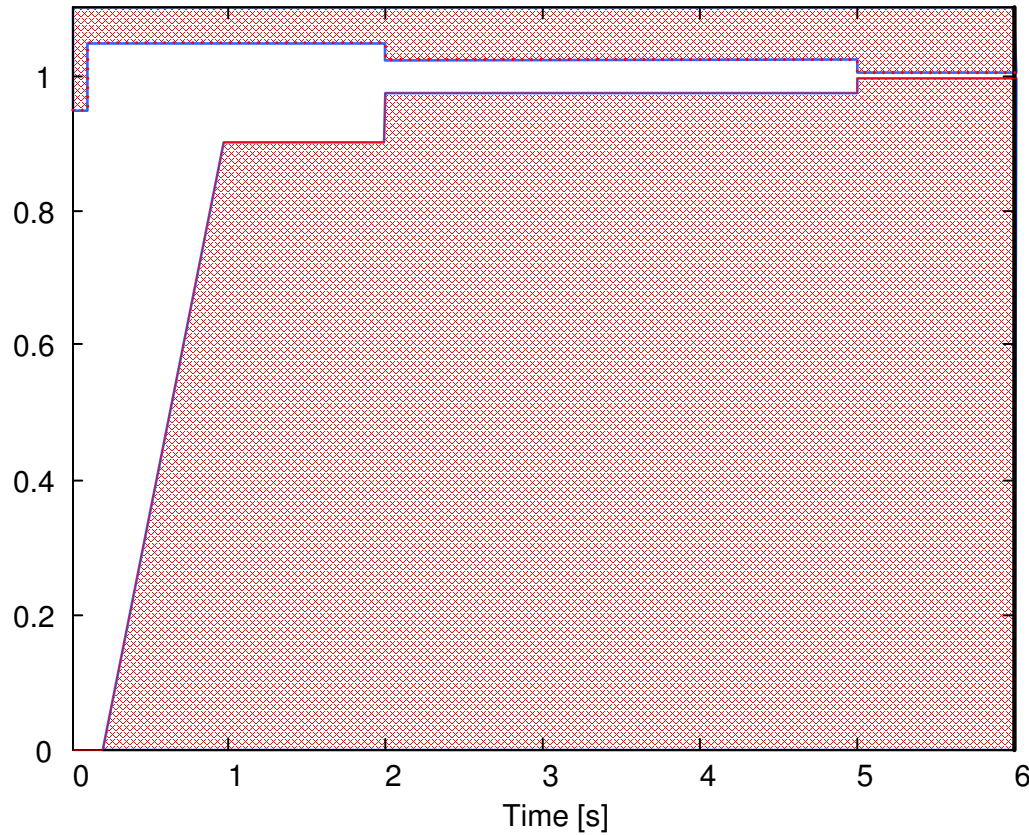


Power Plant performance. Plant reactive power control.



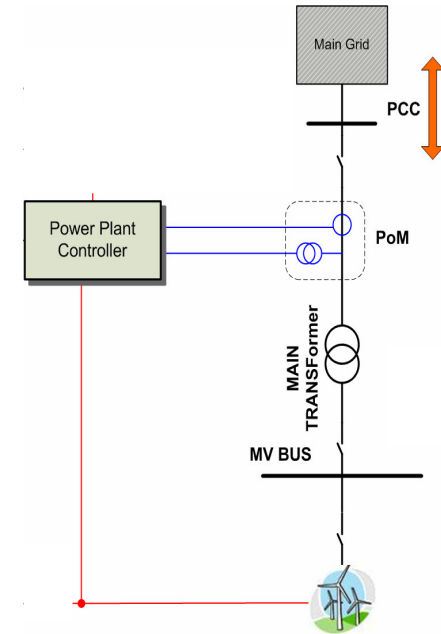
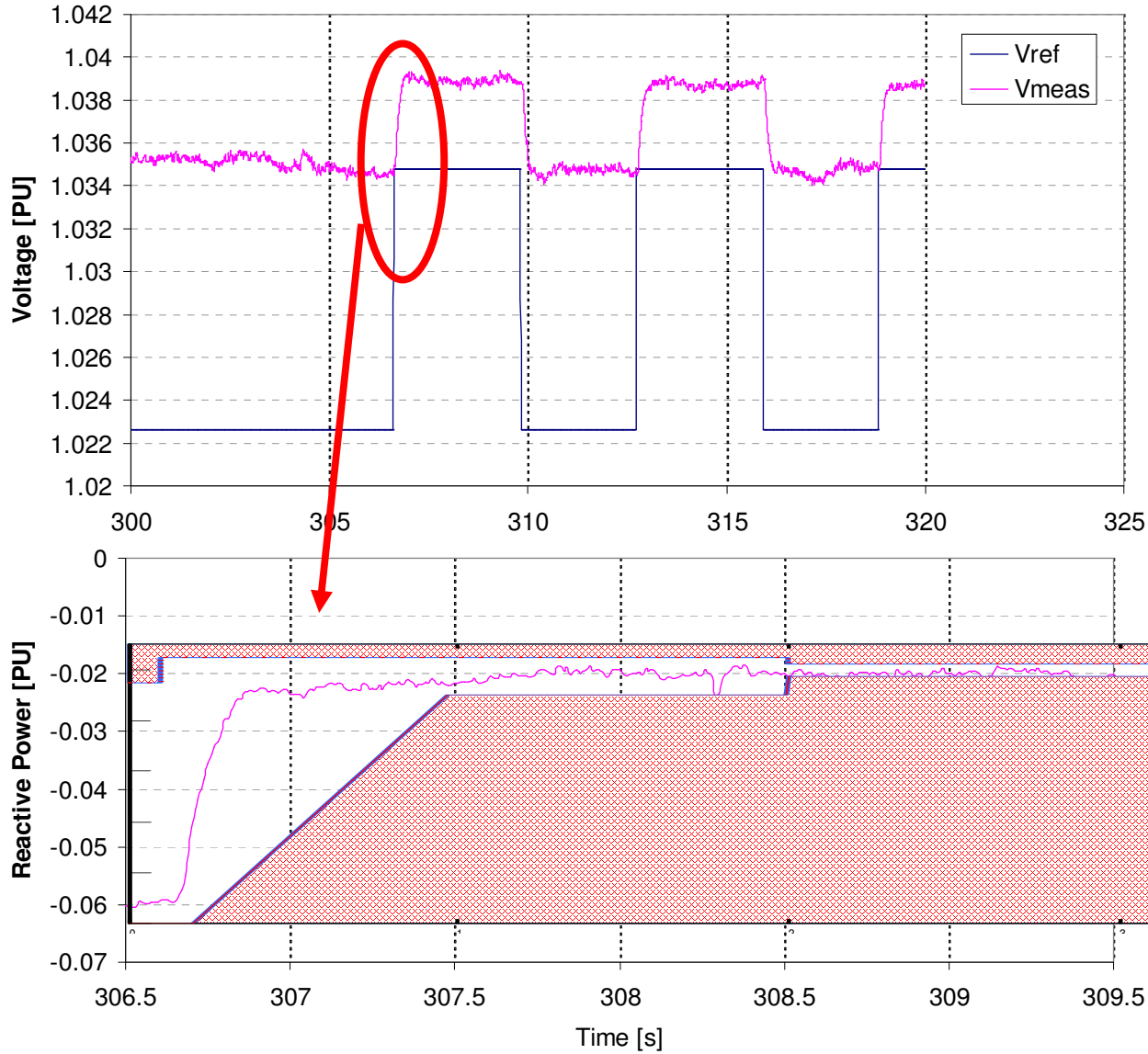
$Q_{ref} = -0.03pu$ as
capacitor of 0.06pu is
switched

Power Plant performance. Plant voltage control (slope) – requirements to performance.

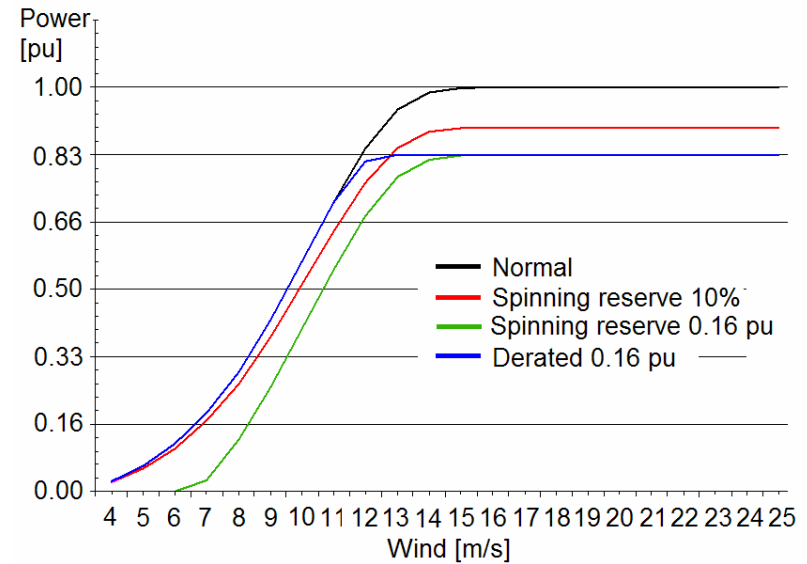
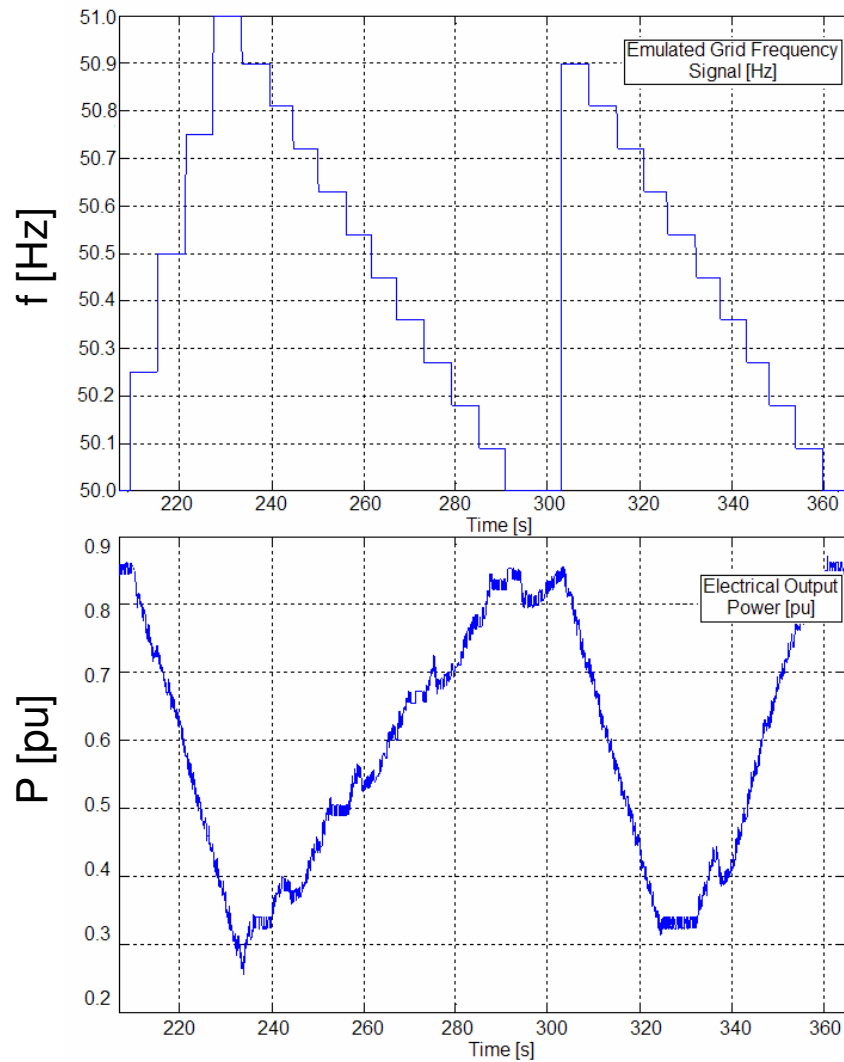


When voltage reference is stepped, the reactive power response must fall within envelope.

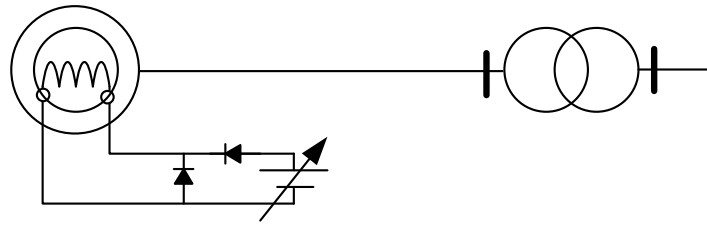
Power Plant performance. Plant voltage control (slope).



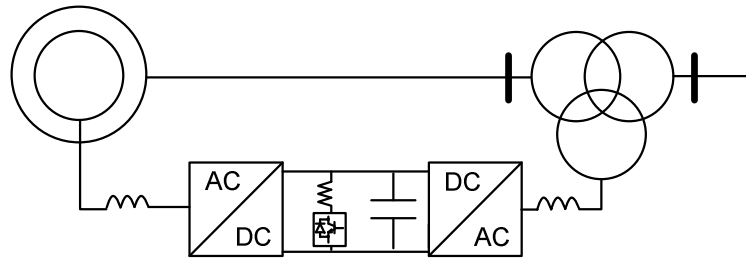
Power Plant performance. Plant frequency response (slope).



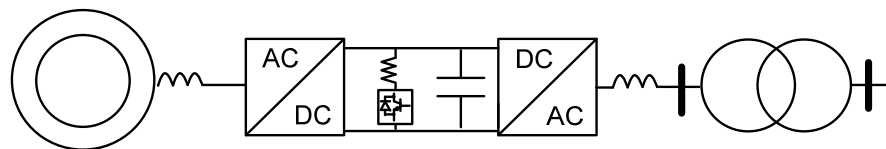
WTG short-circuit current signatures



Synchronous generator

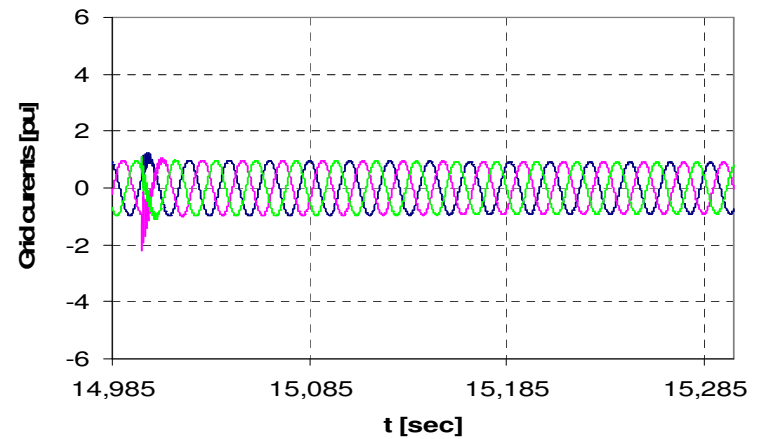
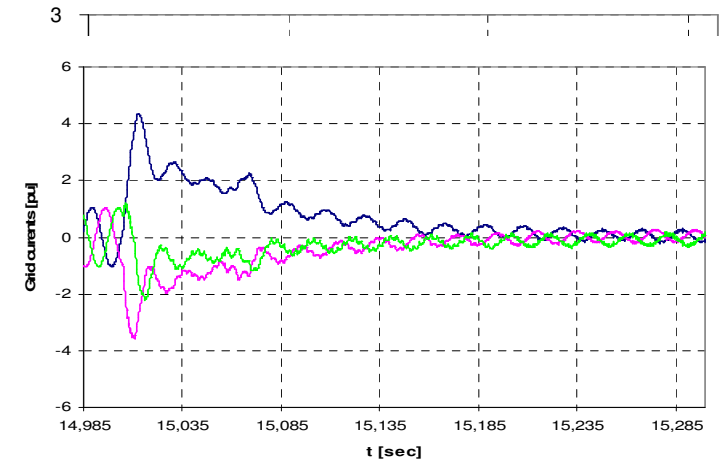
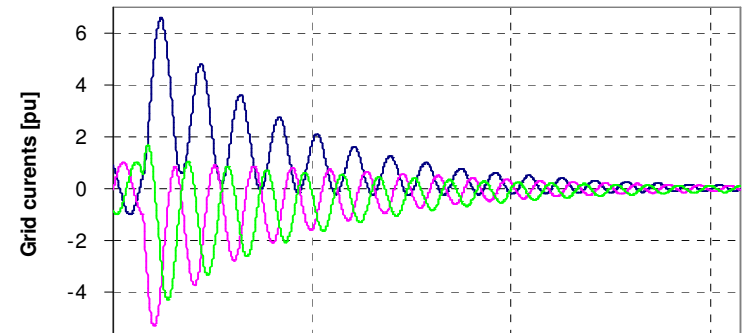


Doubly-fed asynchronous generator



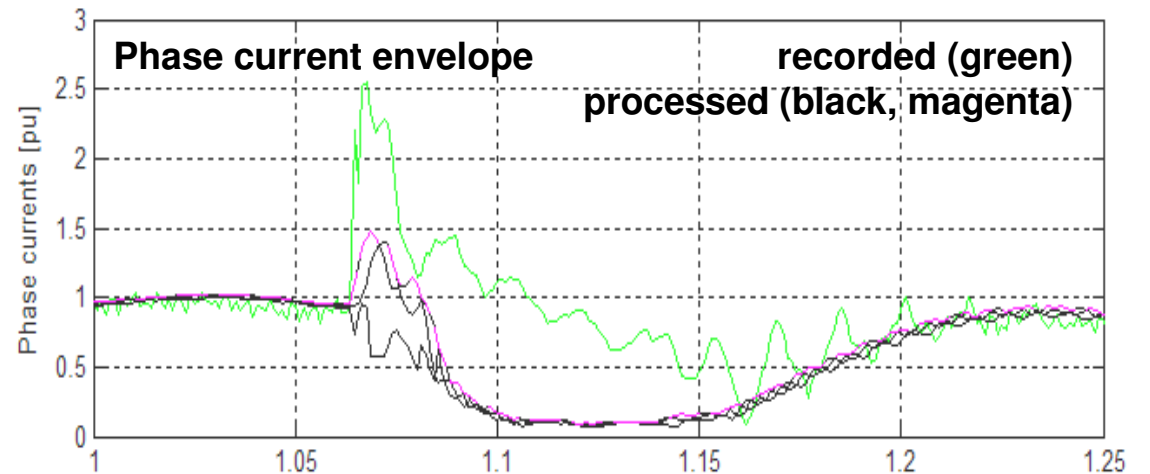
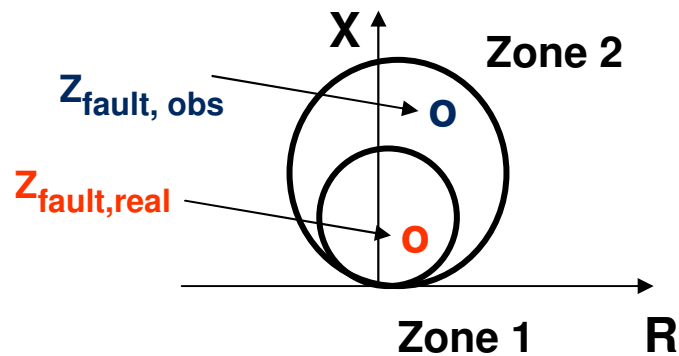
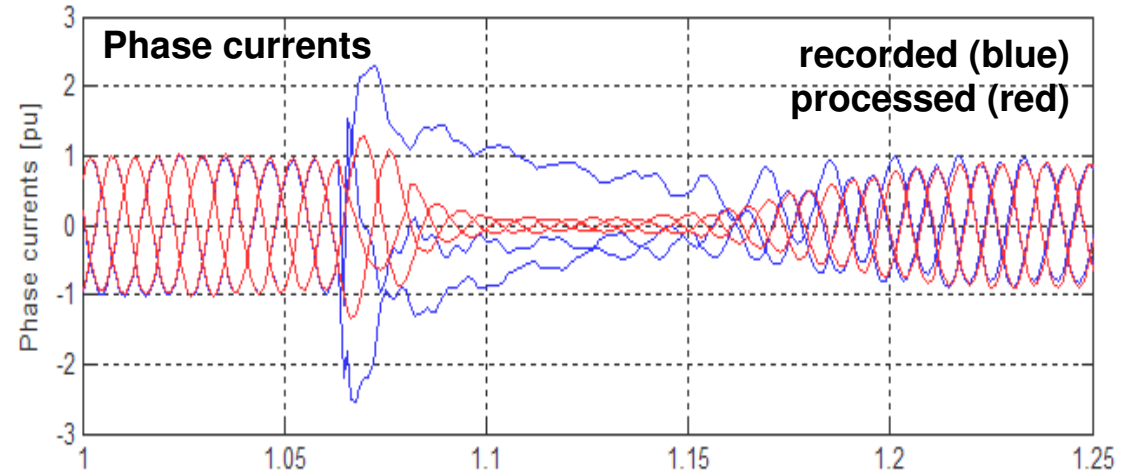
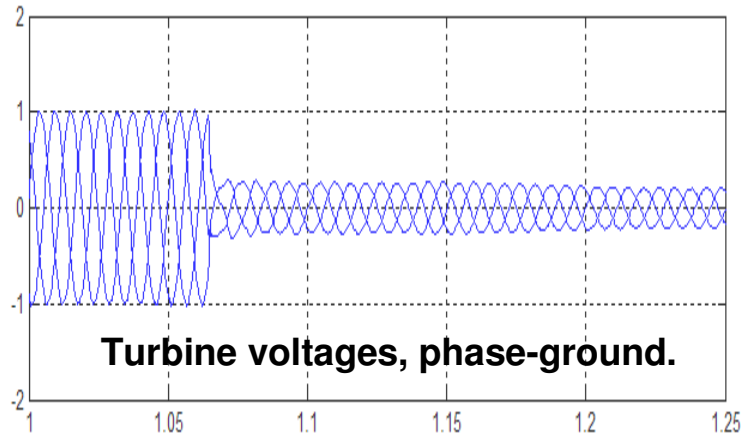
Full power electronic conversion

Sample waveforms



Example of doubly-fed system short-circuit waveforms

Sample waveforms



Simple extraction of fundamental components results in over-estimation of impedance.

Summary

- 1. Harmonisation in connection code formats & terminology allow wind power plant designers to develop global plant solutions and associated design tools.**
- 2. A generic plant architecture facilitates rapid designs and early assessment of their compliance with codes.**
- 3. Examples of solutions, design process and measured plant results document representative performance – in compliance with connection codes.**

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