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.

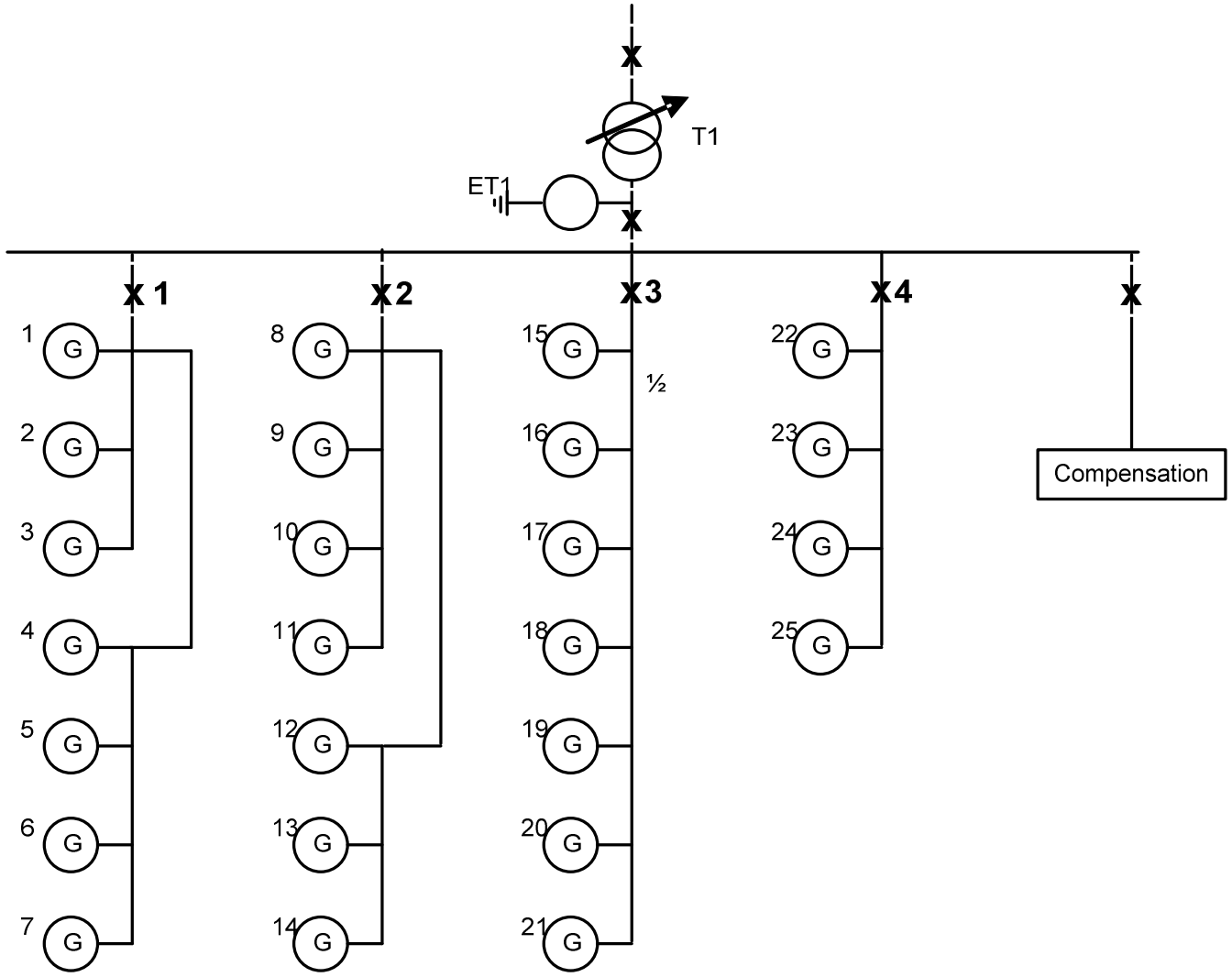
Condition Monitoring.

Power Plant Solutions:

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

Wind Power Plants

Flexible configuration, scaling and parallelling.



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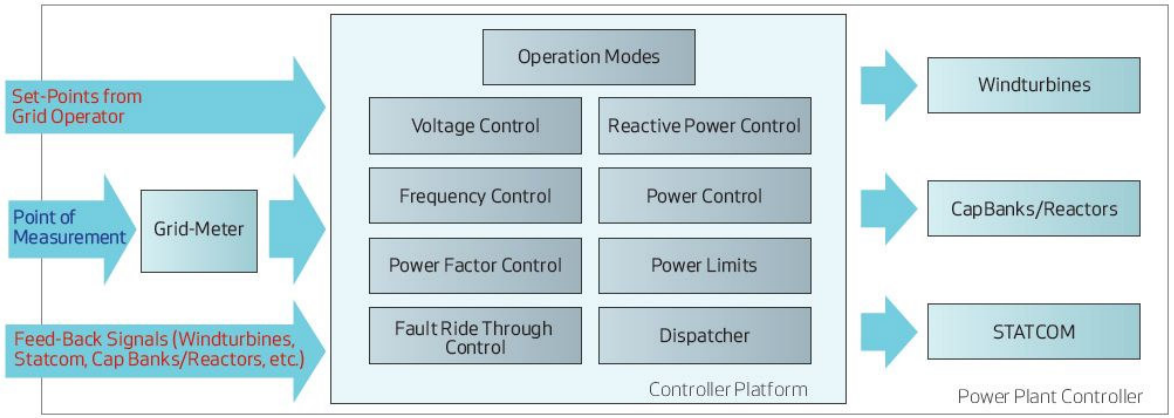
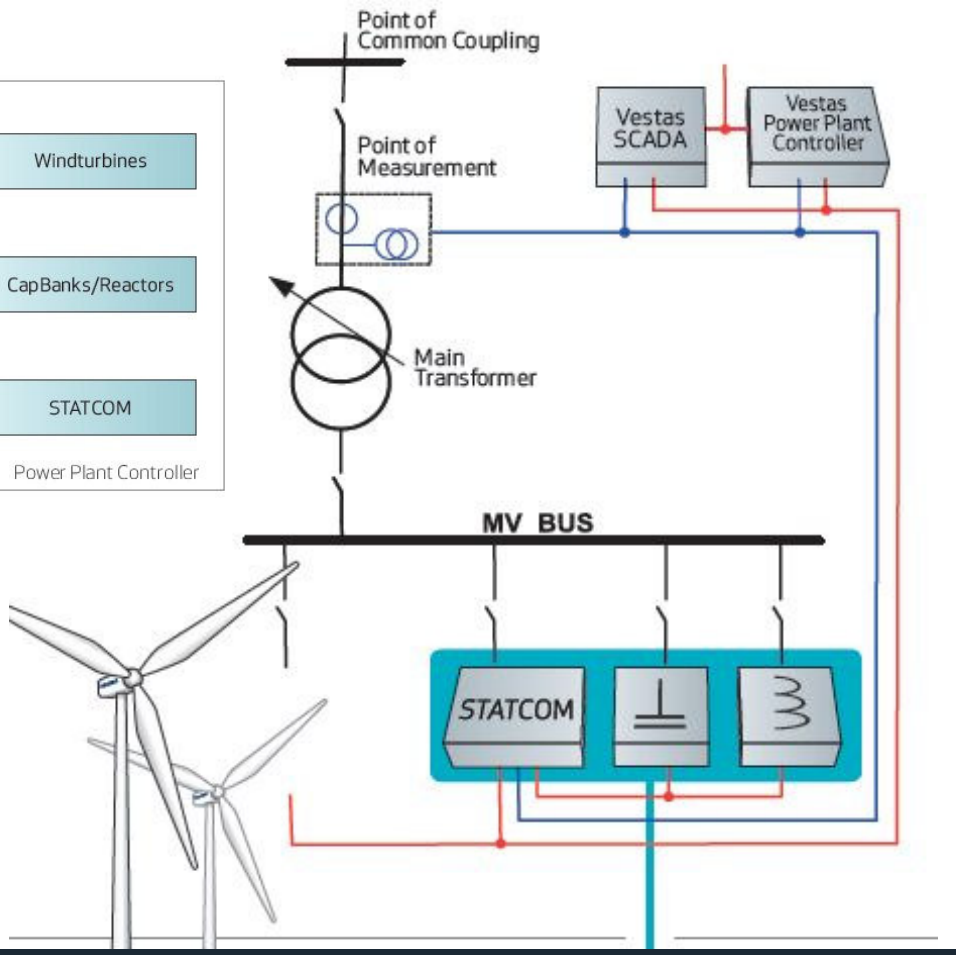
Power Plant architecture





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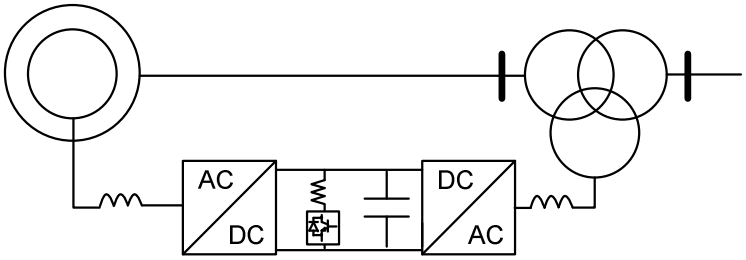
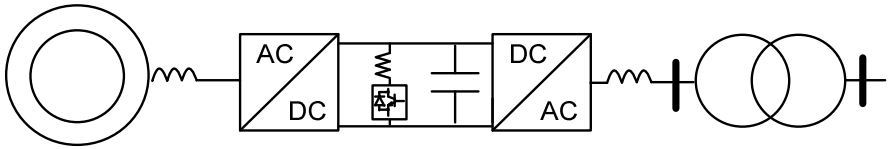
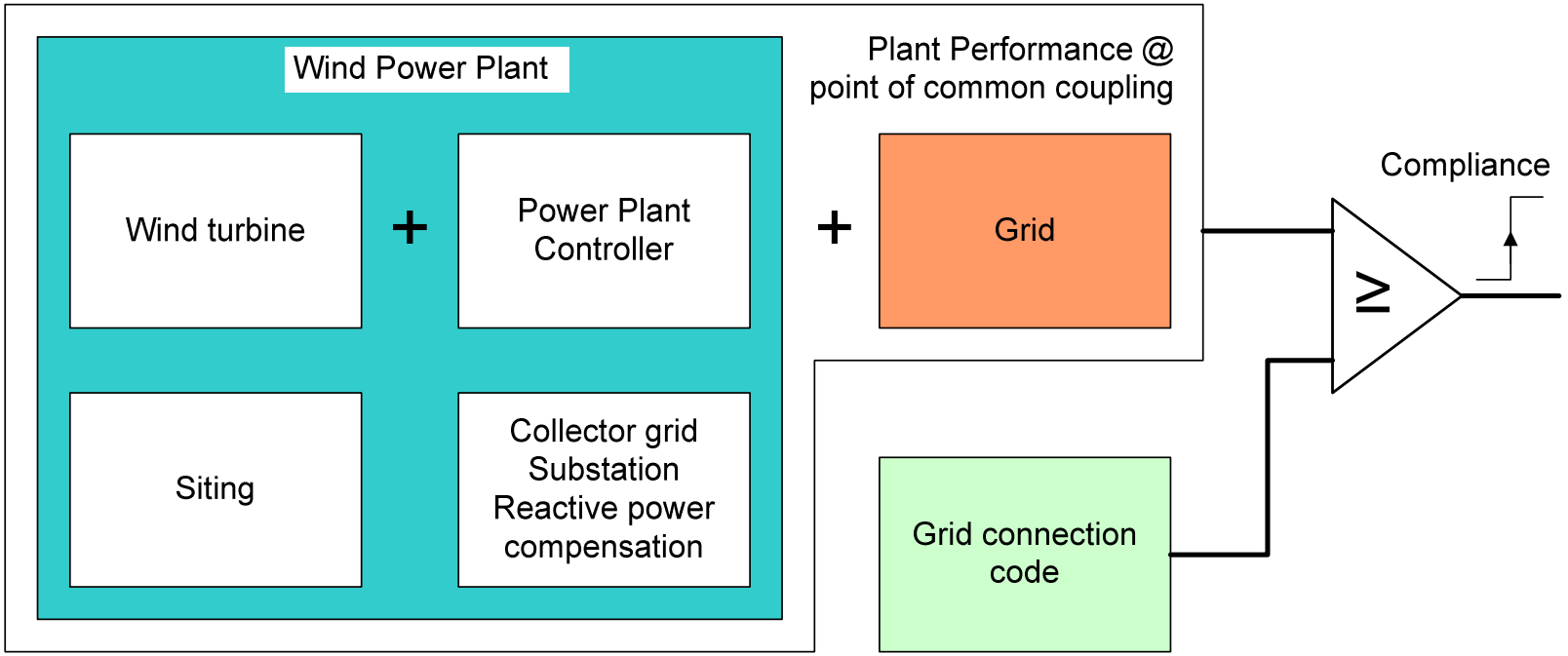
Variable-speed wind turbine topologies



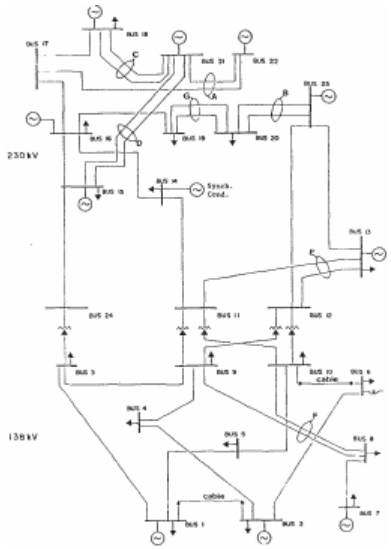


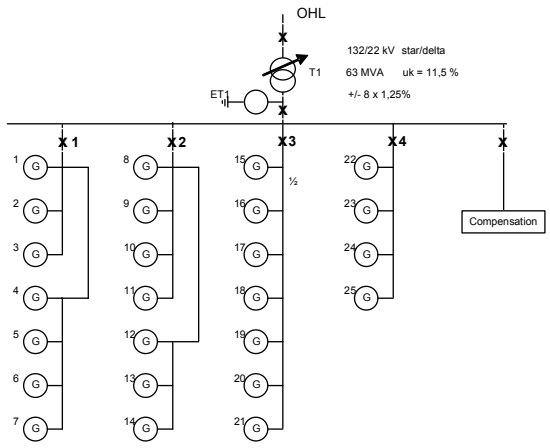
	Doubly-fed	**Full-converter**
Minimum speed	Limited by rotor design voltage.	From zero speed.
Stator current control	Controlled from rotor side → bandwidth limited by machine rotor time constant.	Controlled directly from generator converter.
Grid current control	Mainly as stator current; though grid 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



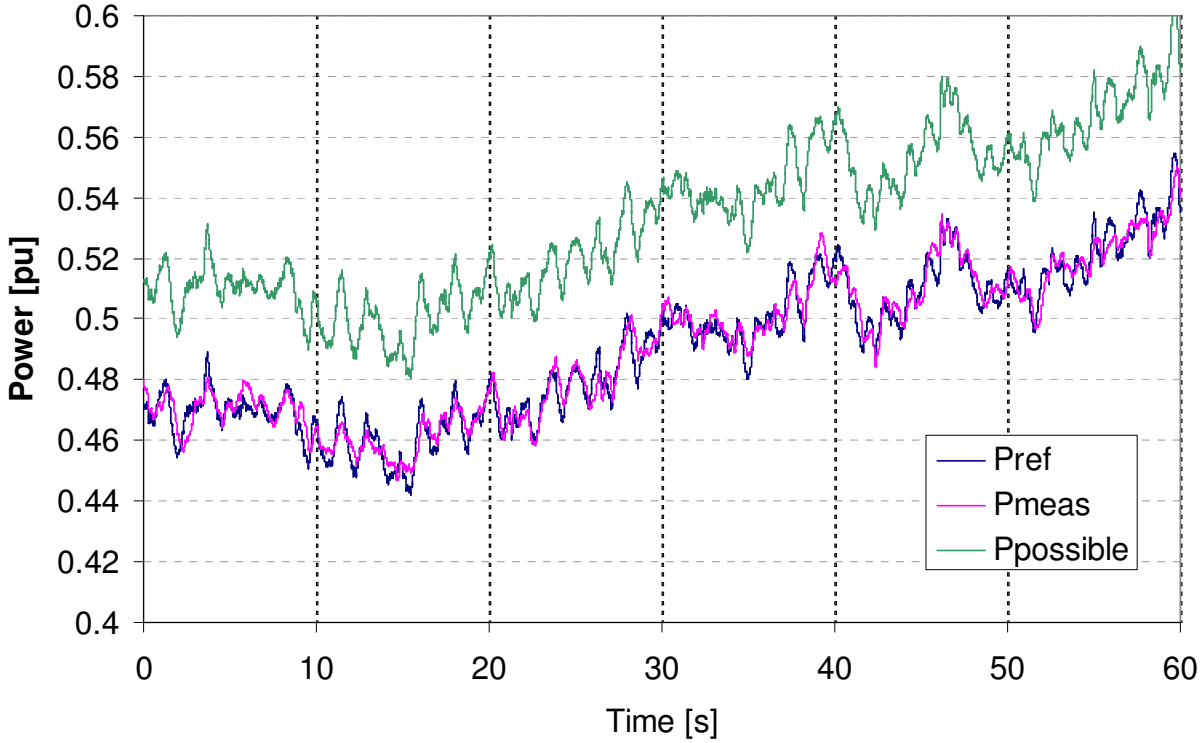
Electrical planning & design – studies

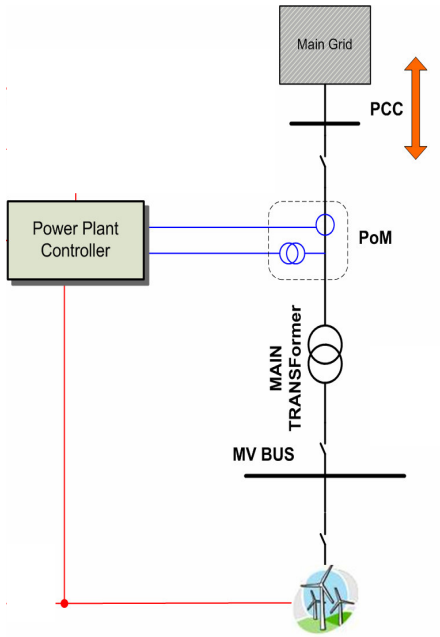




	Documentation & simulation models		
	Datasheet	Positive sequence model	Electrical machine transient model
Transmission load flow	✓	✓	
Transmission transient/voltage stability		✓	(✓)
Transmission protection	✓	✓	
Plant load flow		✓	
Plant short-circuit		✓	
Plant dynamic control		✓	✓
Plant transients		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

Power Plant performance.
Plant active power control.





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

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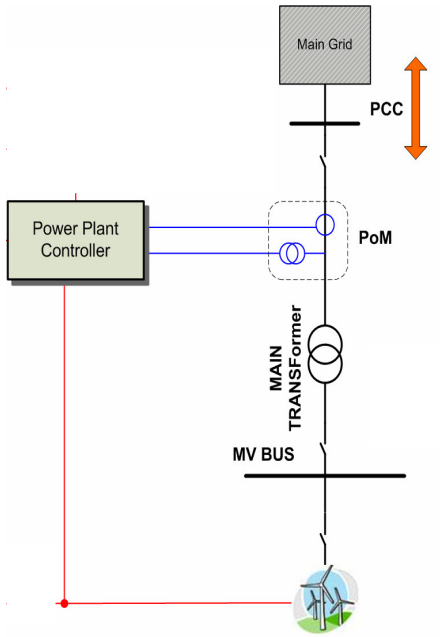
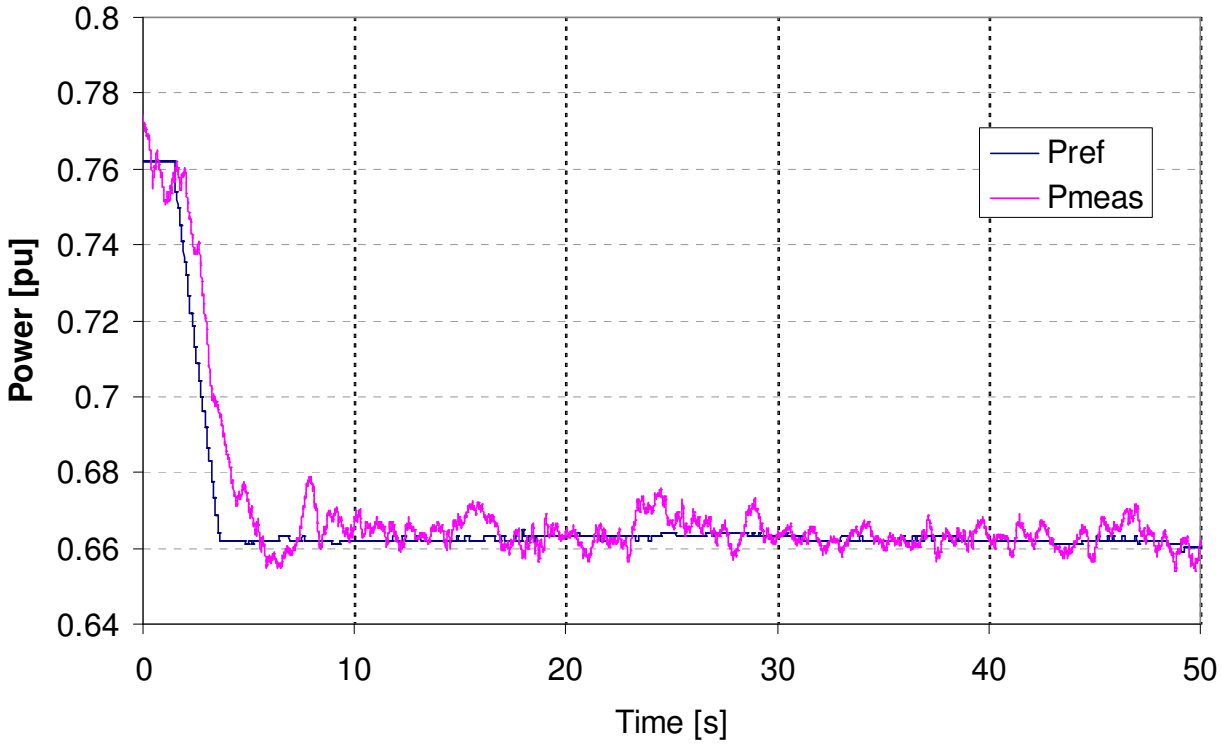
Power Plant performance.
Plant active power control.





P_{ref} stepped

0.76pu → 0.66pu

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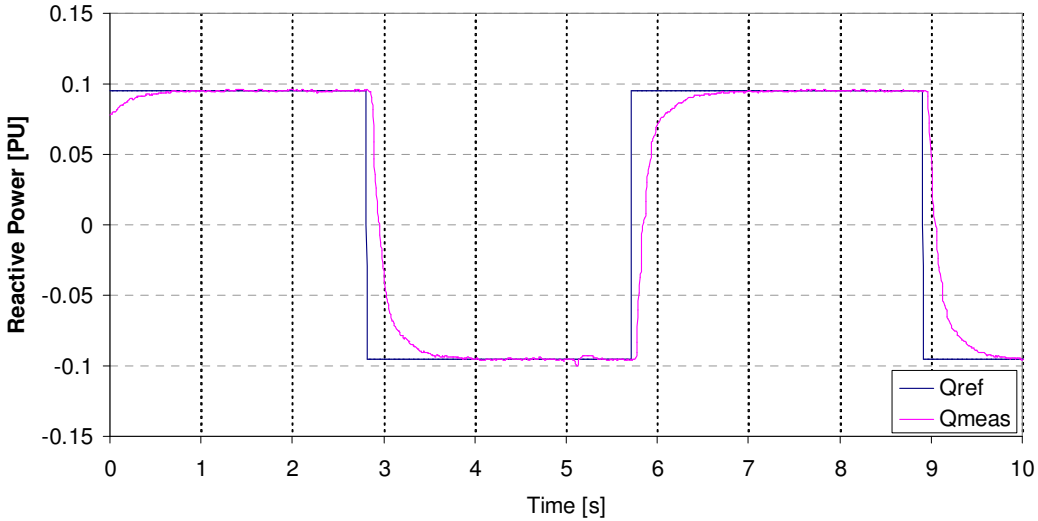
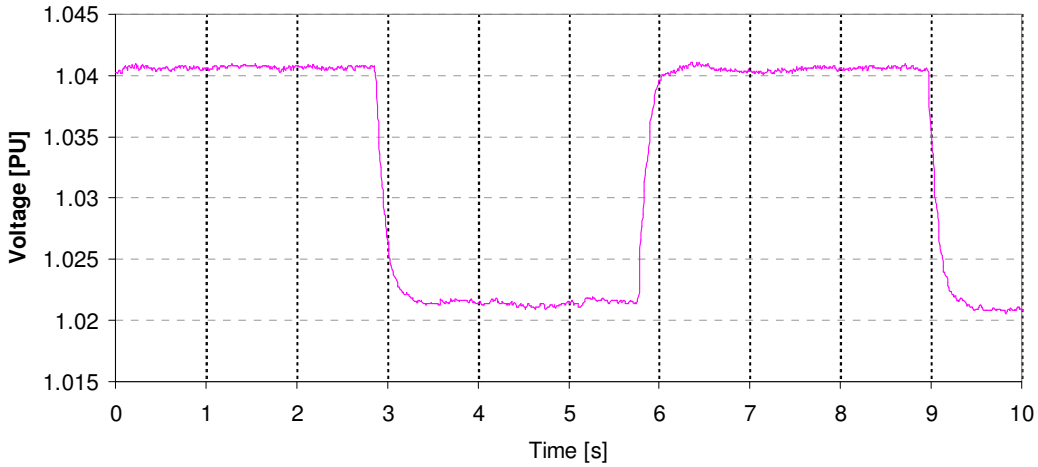
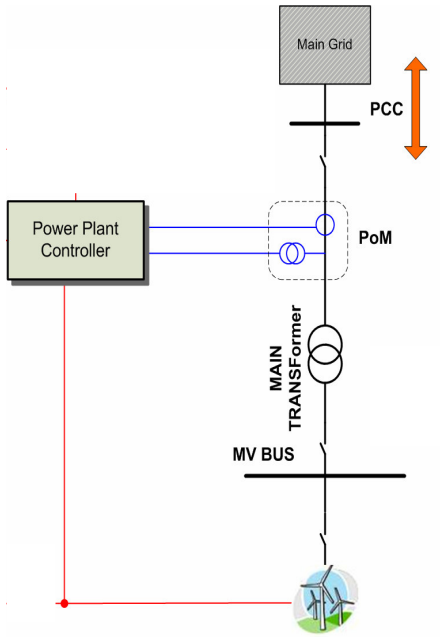
Power Plant performance.
Plant reactive power control.







Q_{ref} stepped ±0.10pu

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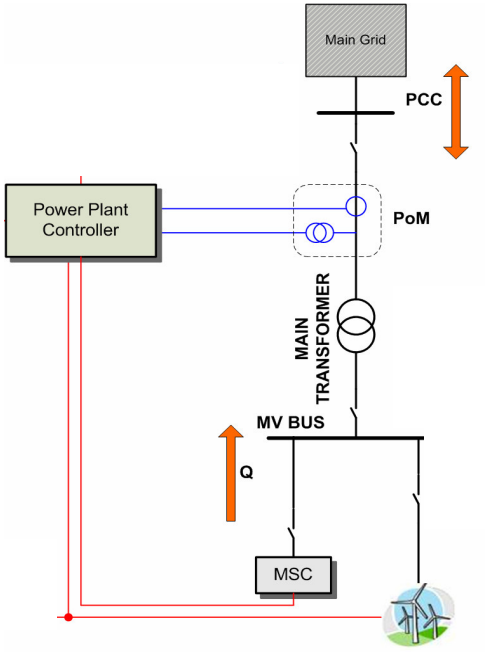
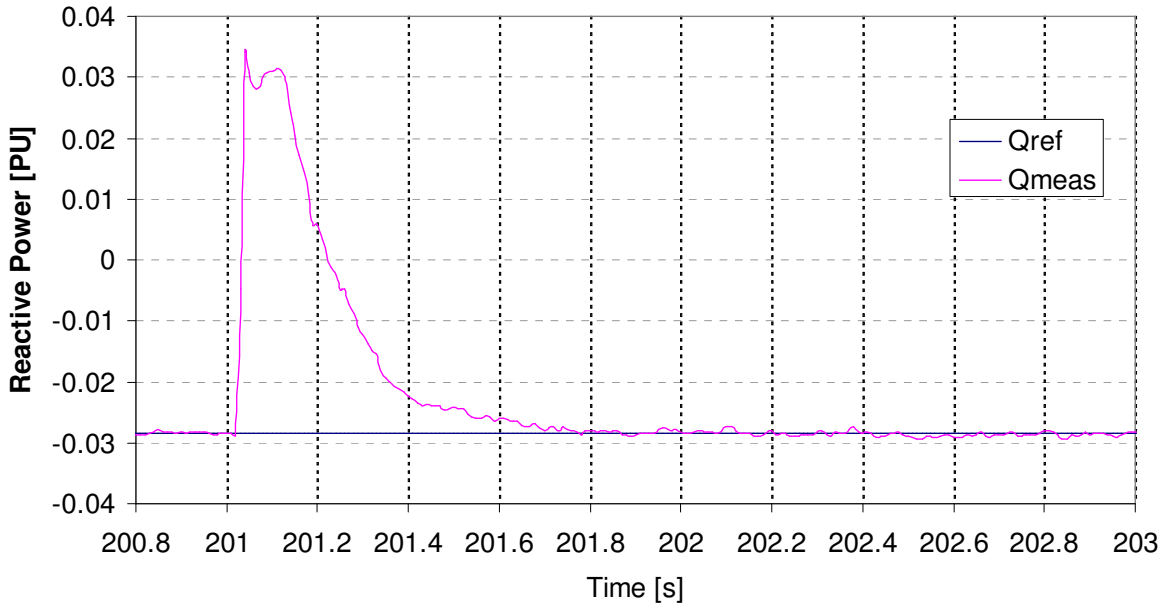
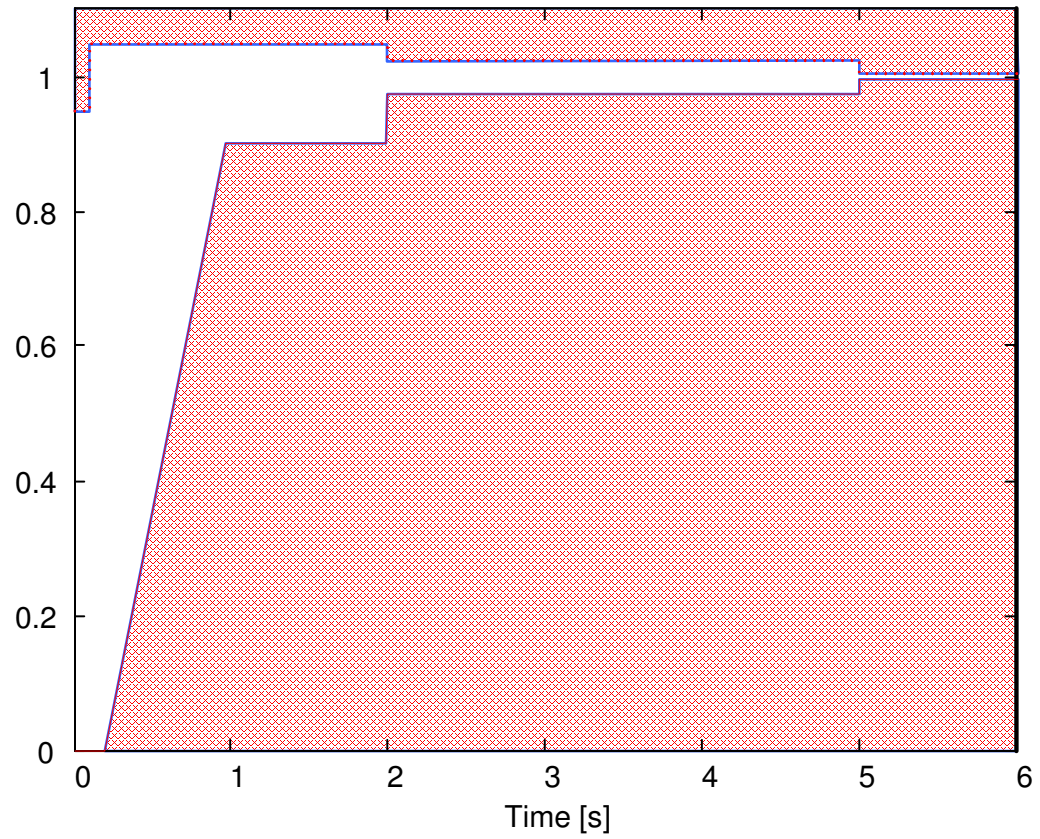
Power Plant performance.
Plant reactive power control.





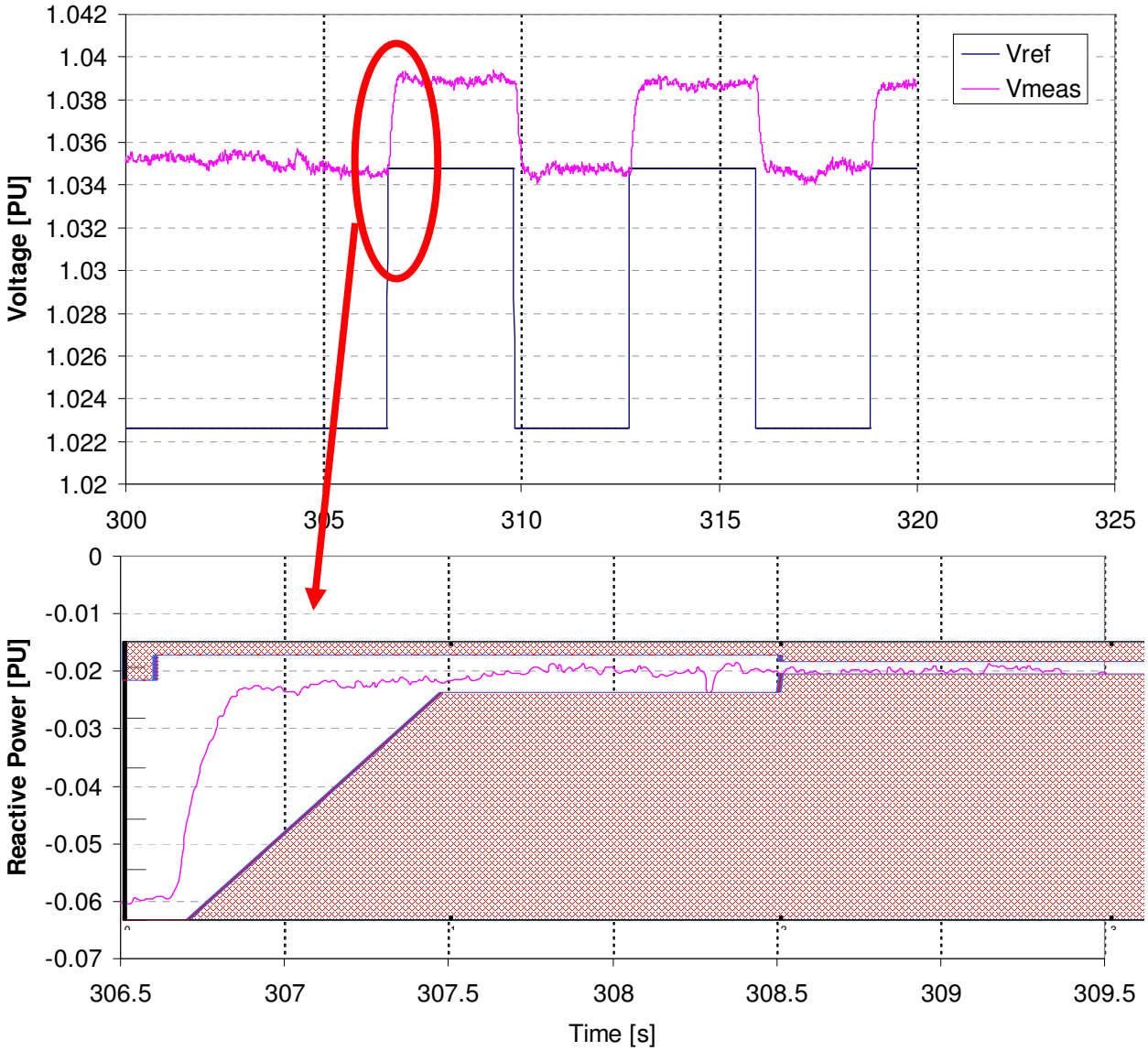
Q_{ref} = -0.03pu as capacitor of 0.06pu is switched

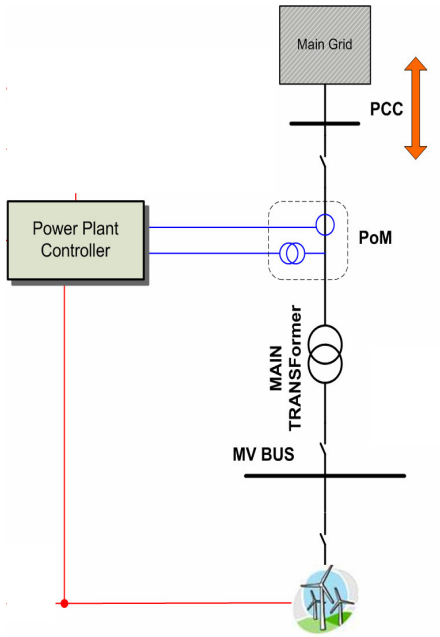
Power Plant performance.
Plant voltage control (slope) – requirements to performance.



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

Power Plant performance.
Plant voltage control (slope).





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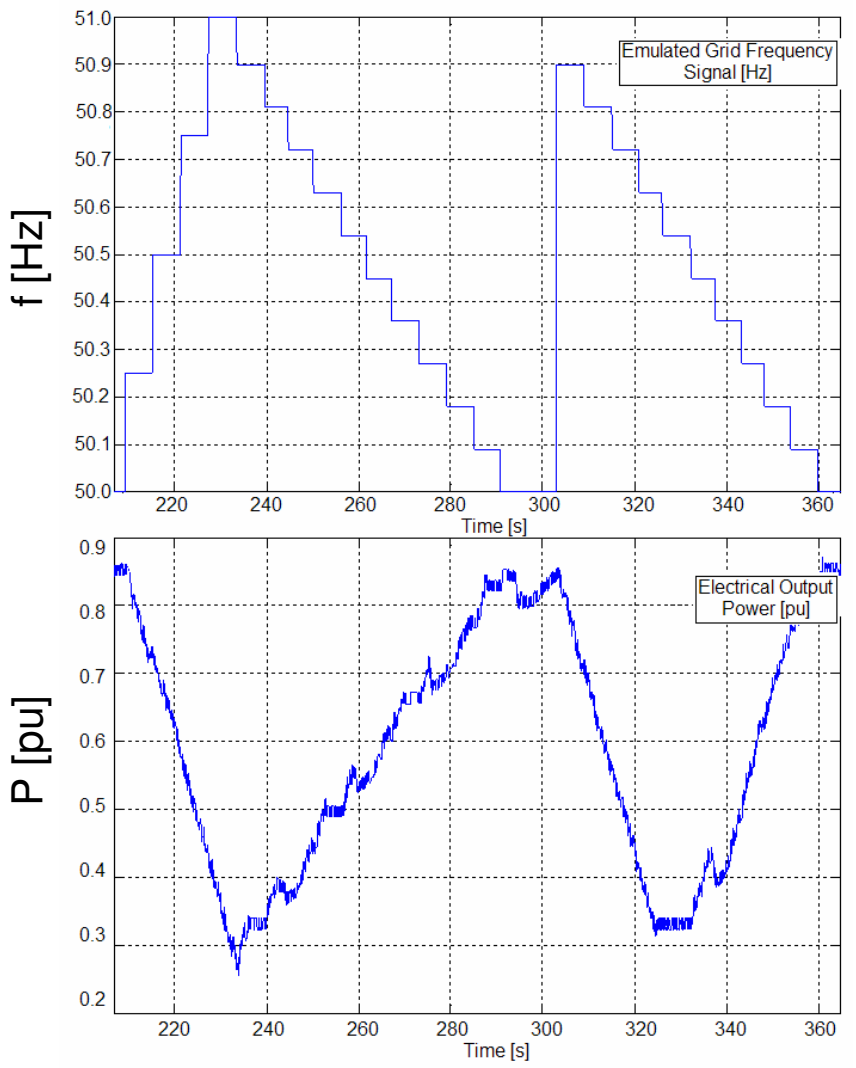
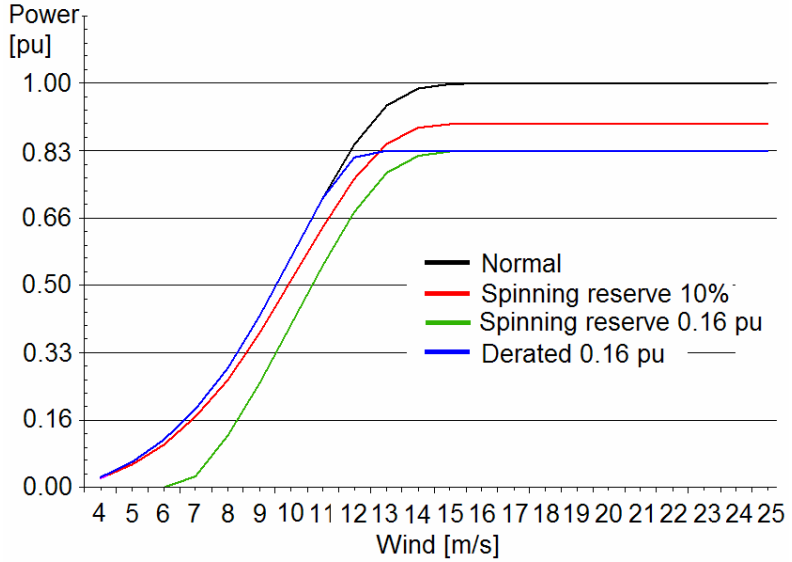
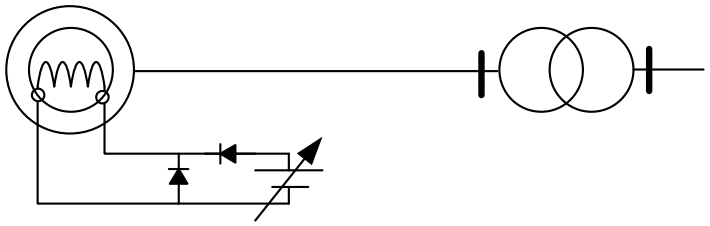
Power Plant performance.
Plant frequency response (slope).

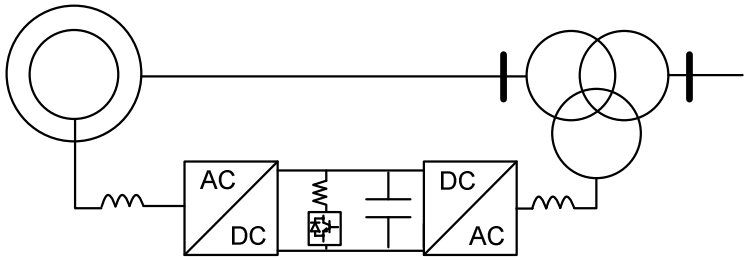




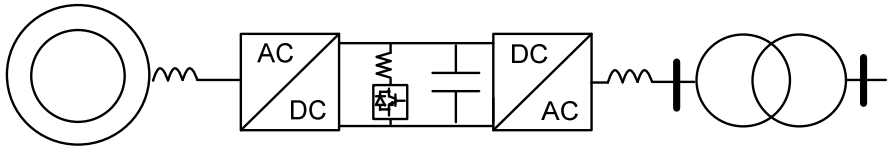
WTG short-circuit current signatures



Synchronous generator

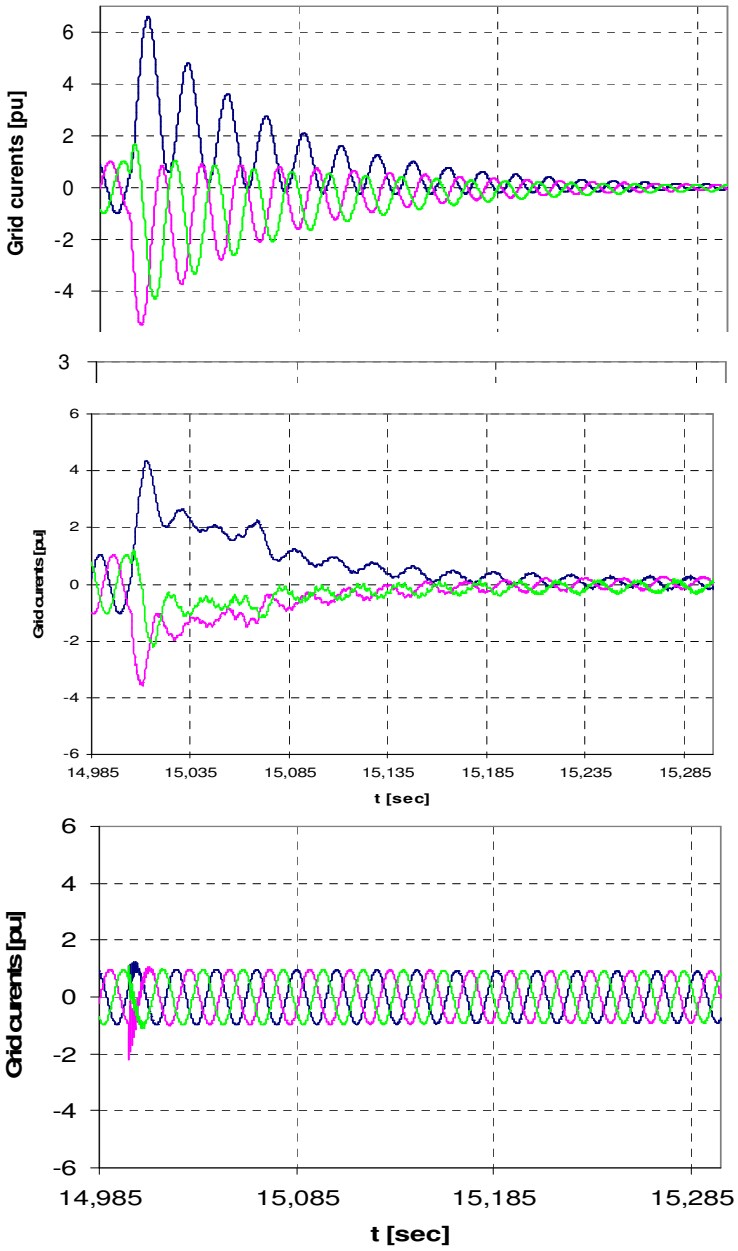


Doubly-fed asynchronous generator



Full power electronic conversion

Sample waveforms



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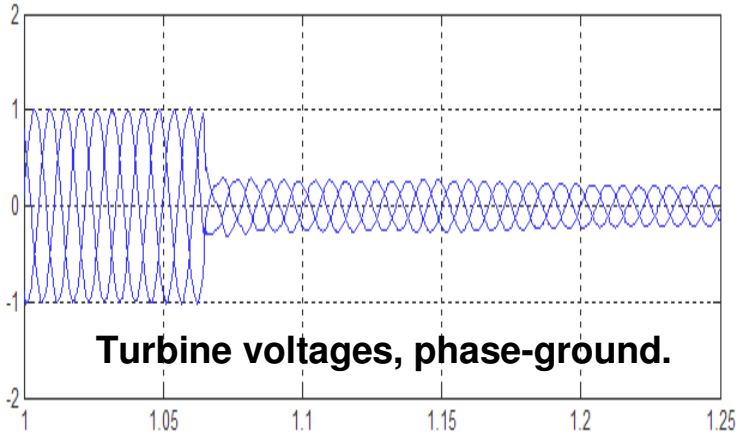
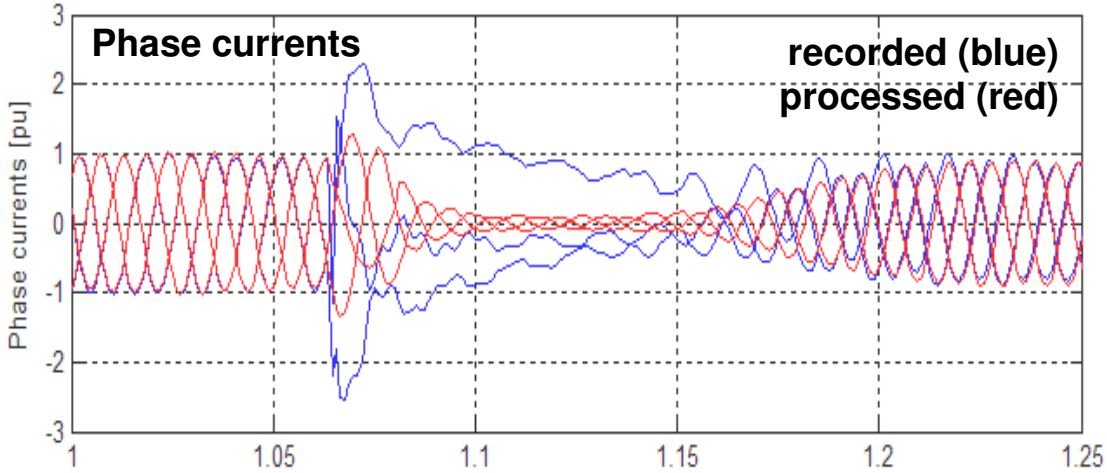
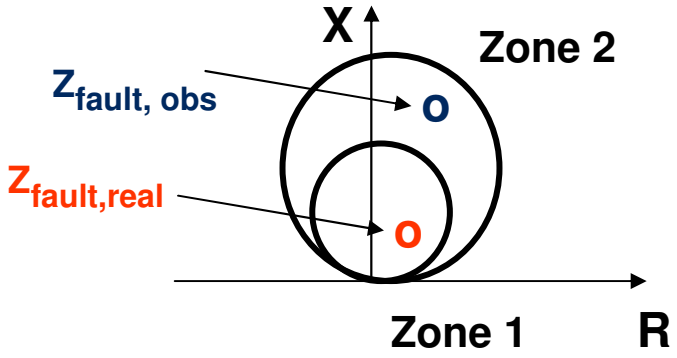
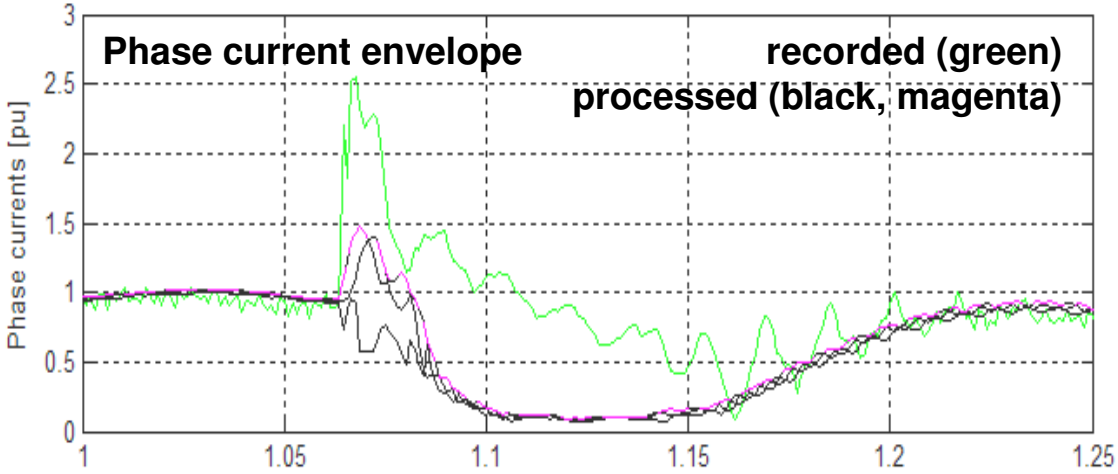
Example of doubly-fed system short-circuit waveforms

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.**

THANK YOU FOR YOUR ATTENTION

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