

**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.

***Vestas***<sup>®</sup>

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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.

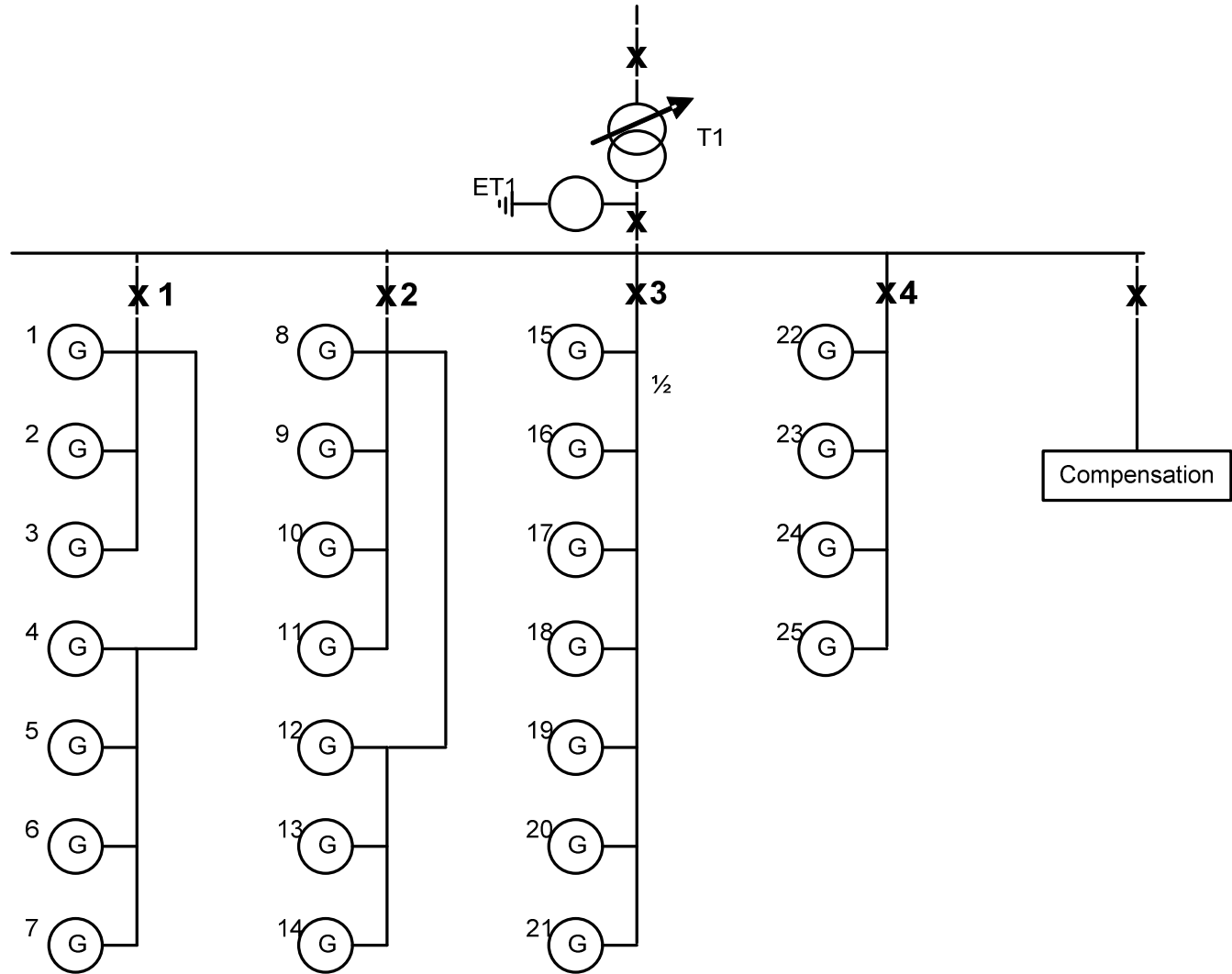


### Power Plant Solutions:

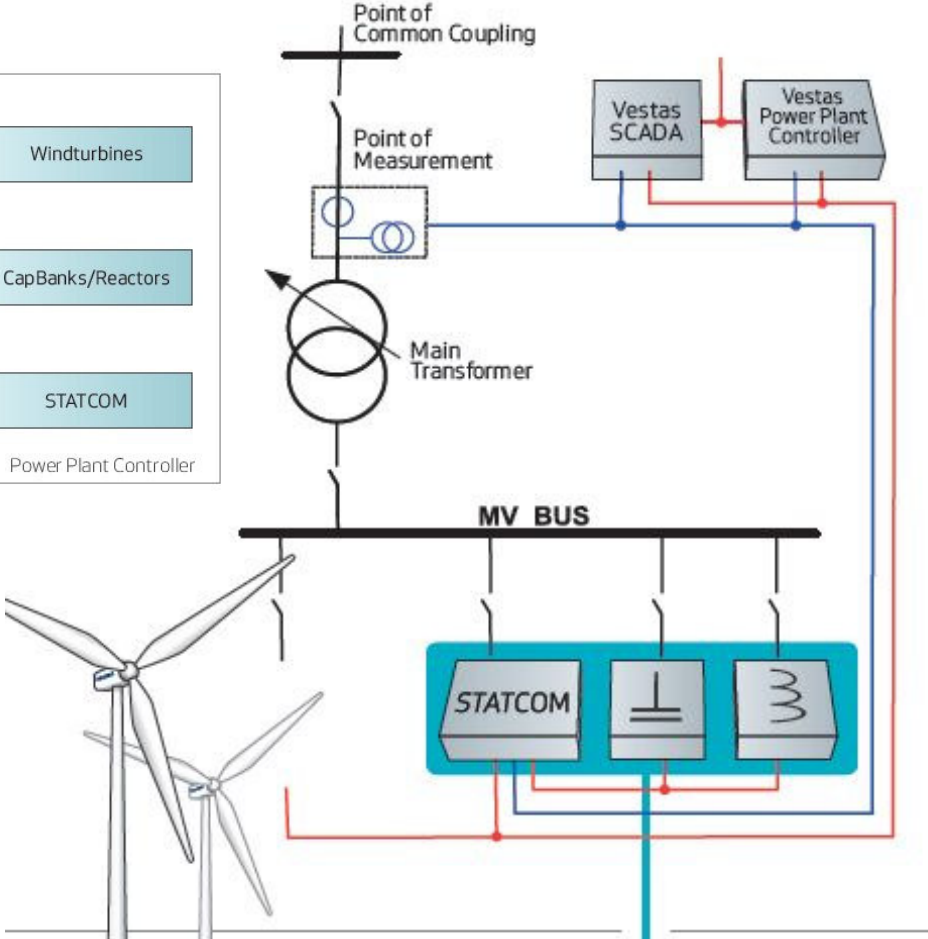
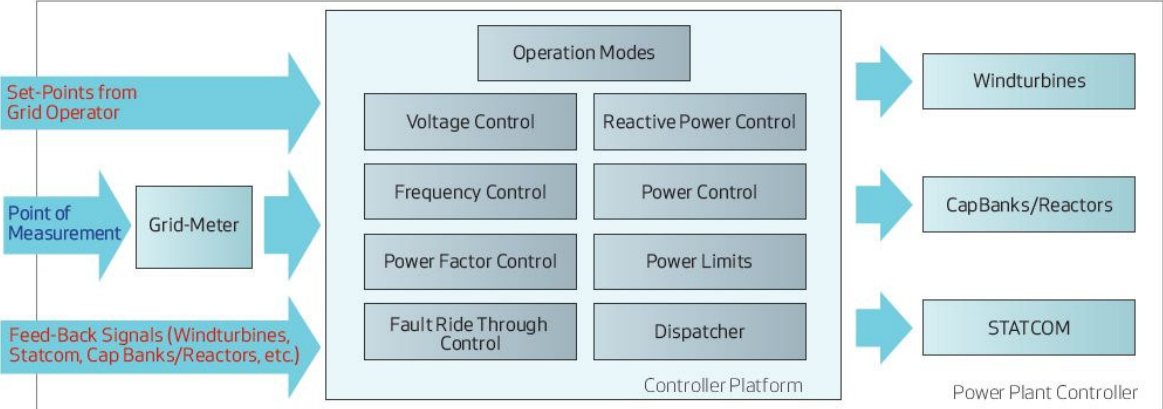
- planning (siting, elec. pre-design)
- procurement.
- construction.
- operation & service.
- optimisation.

# Wind Power Plants

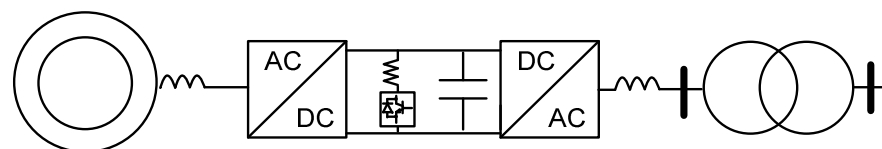
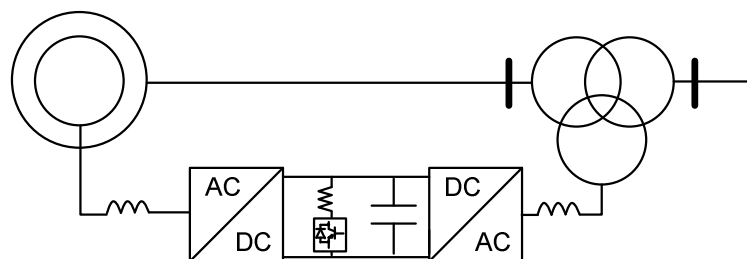
Flexible configuration, scaling and parallelling.



# Power Plant architecture

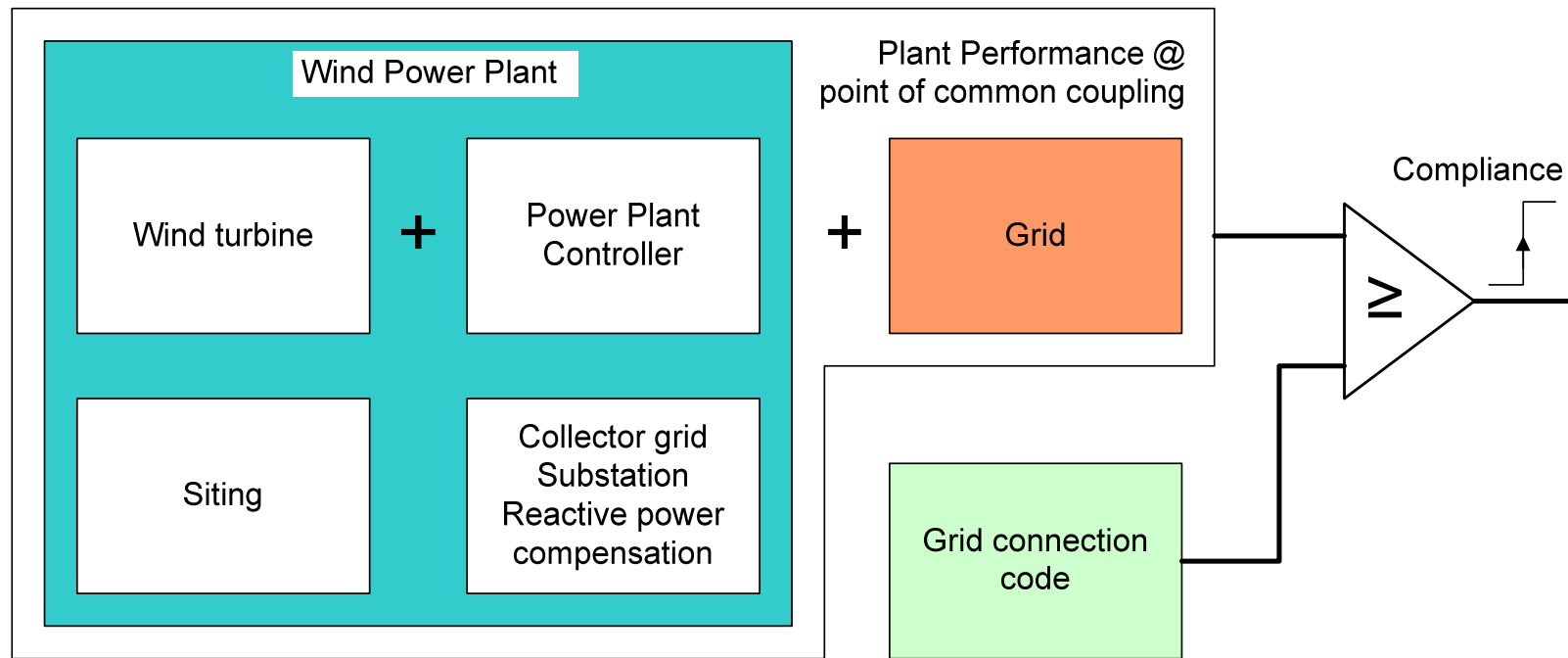


# Variable-speed wind turbine topologies

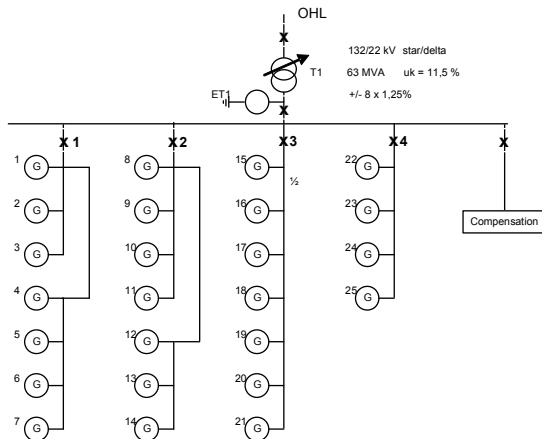
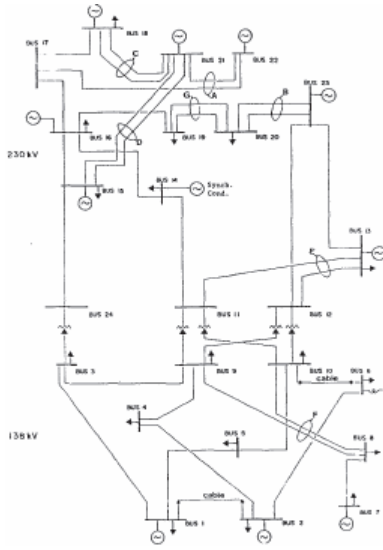


	<b>Doubly-fed</b>	<b>Full-converter</b>
Minimum speed	Limited by rotor design voltage.	From zero speed.
Stator current control	Controlled from rotor side → bandwidth limited by machine rotor time constant.	Controlled directly from generator converter.
Grid current control	Mainly as stator current; though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

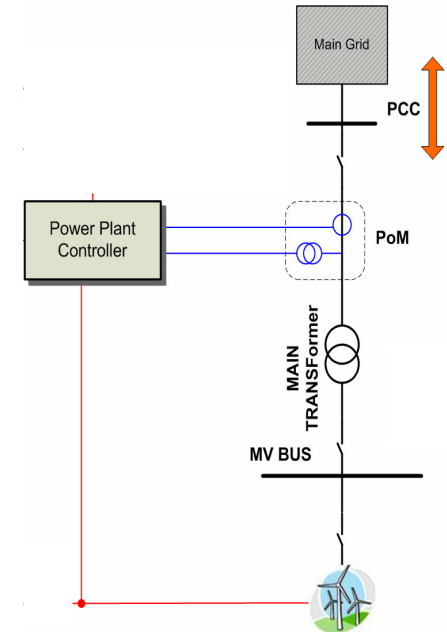
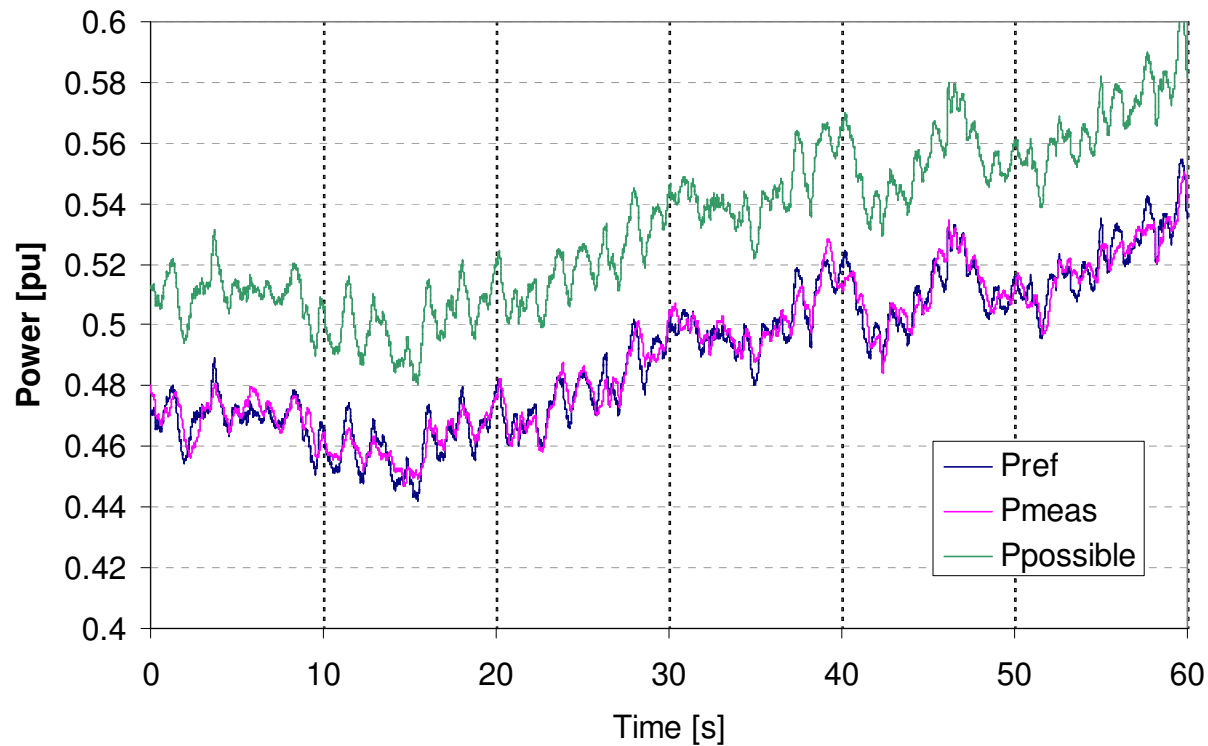


# Electrical planning & design – studies



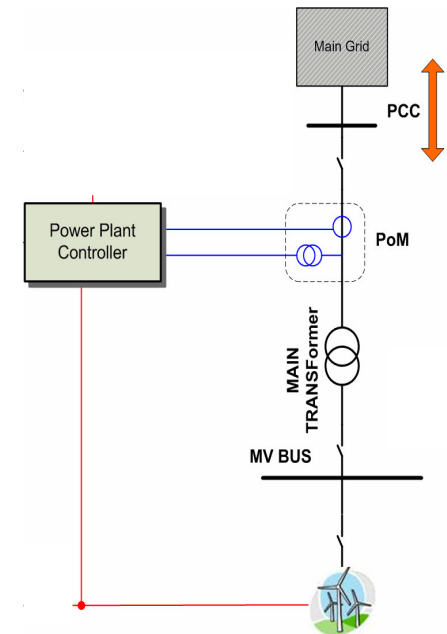
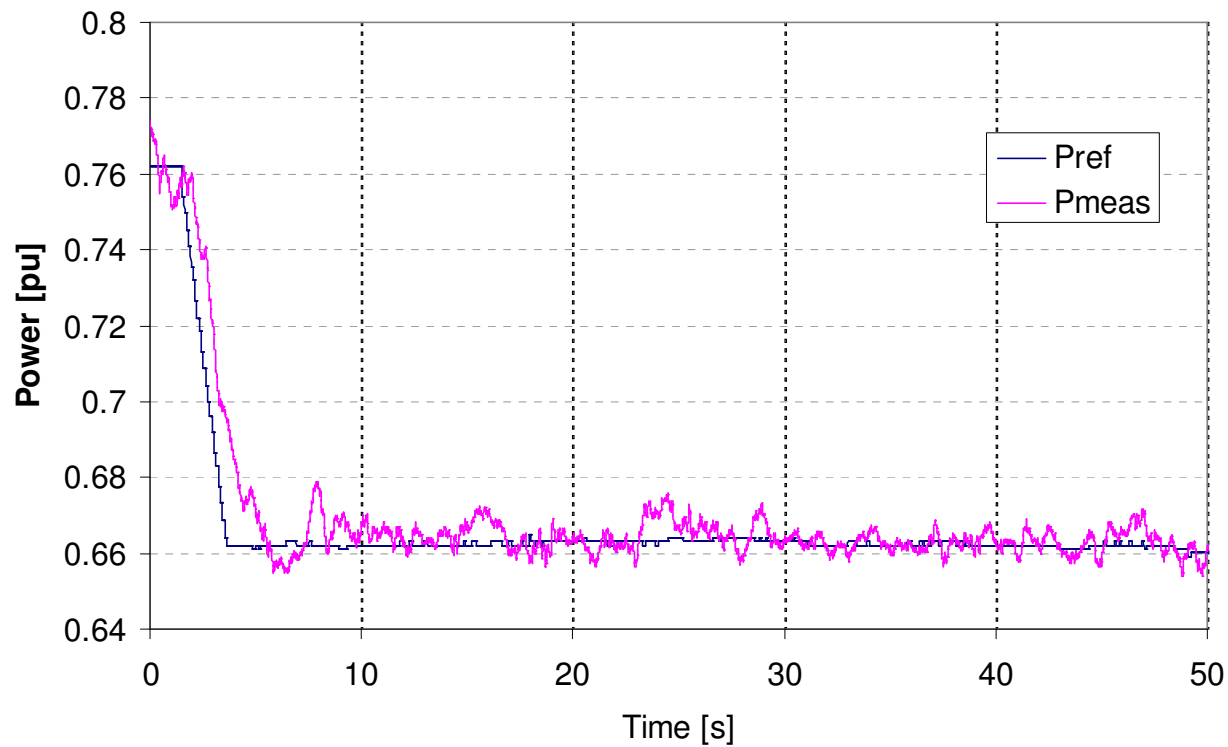
	Documentation & simulation models		
	Datasheet	Positive sequence model	Electrical machine transient model
Transmission load flow	✓	✓	
Transmission transient/voltage stability		✓	(✓)
Transmission protection	✓	✓	
Plant load flow		✓	
Plant short-circuit		✓	
Plant dynamic control		✓	✓
Plant transients		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

# Power Plant performance. Plant active power control.



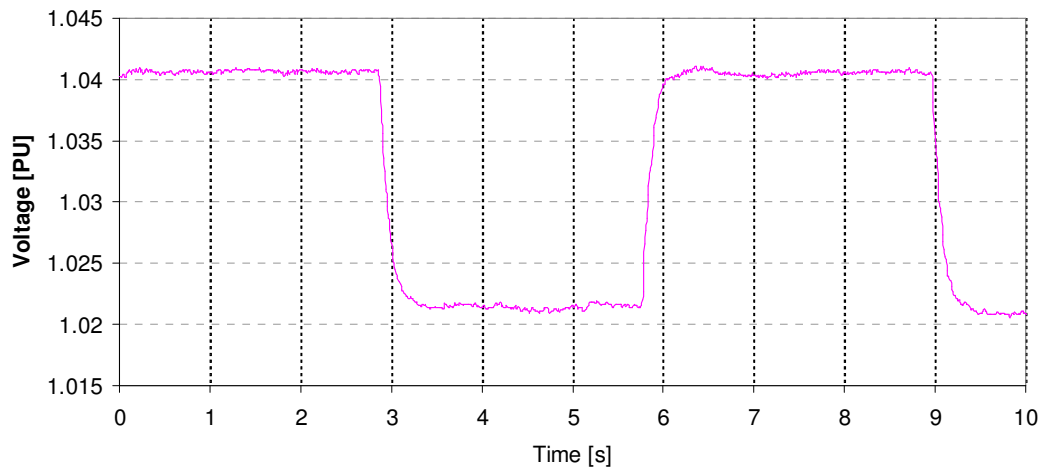
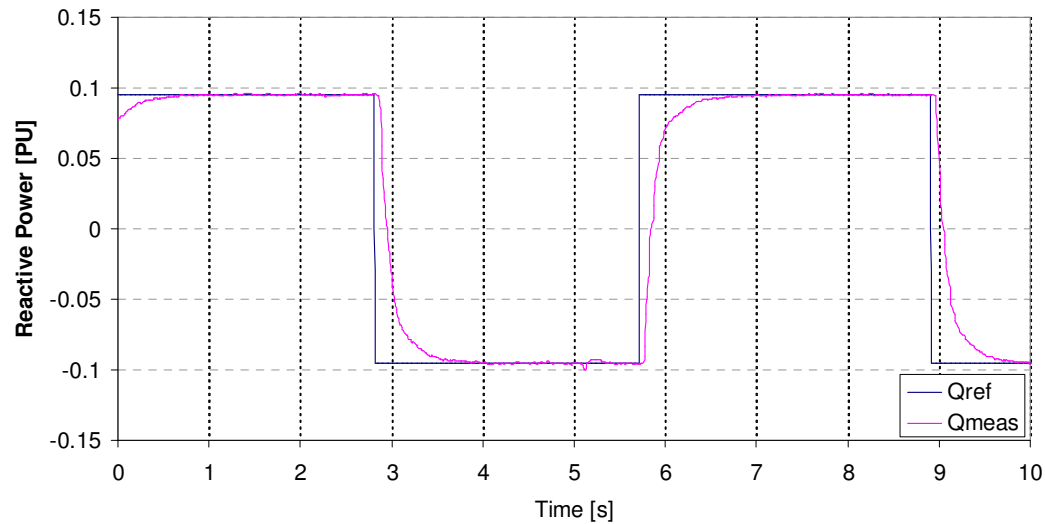
$$P_{\text{ref}} = P_{\text{avail}} \times 0.92$$

# Power Plant performance. Plant active power control.

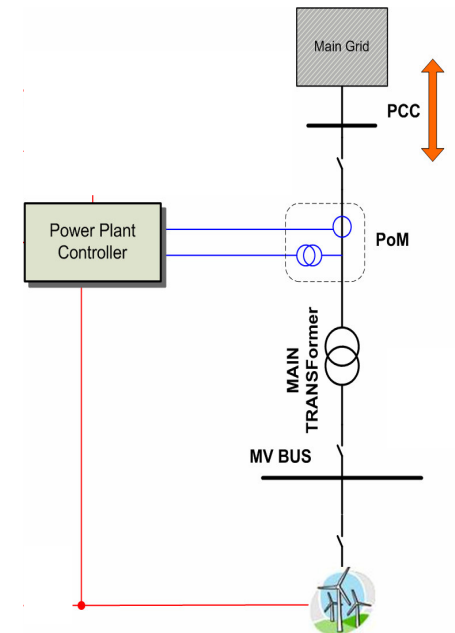


$P_{ref}$  stepped  
0.76pu  $\rightarrow$  0.66pu

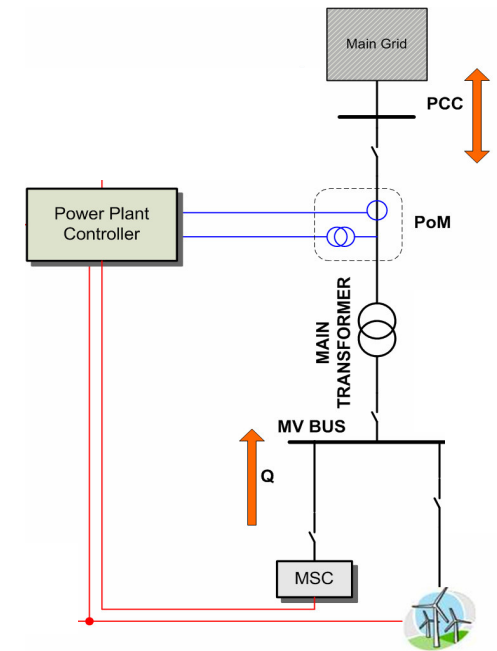
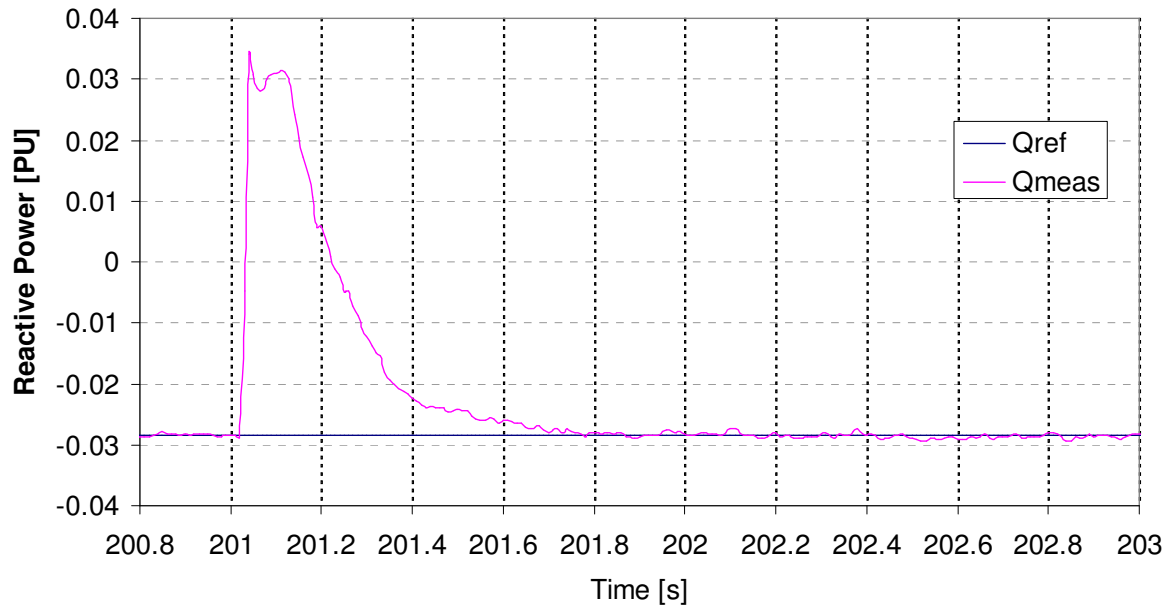
# Power Plant performance. Plant reactive power control.



$Q_{ref}$  stepped  $\pm 0.10$  pu

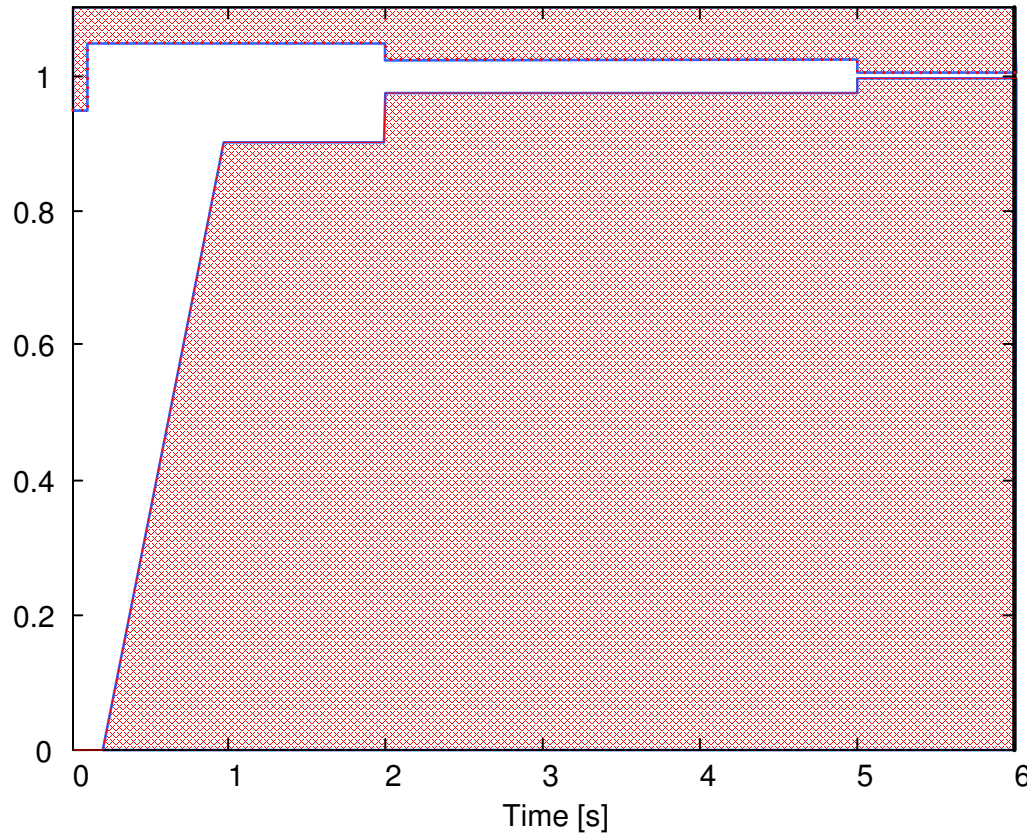


# Power Plant performance. Plant reactive power control.



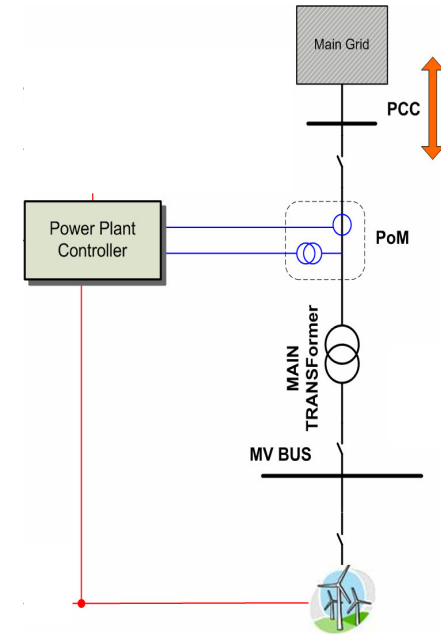
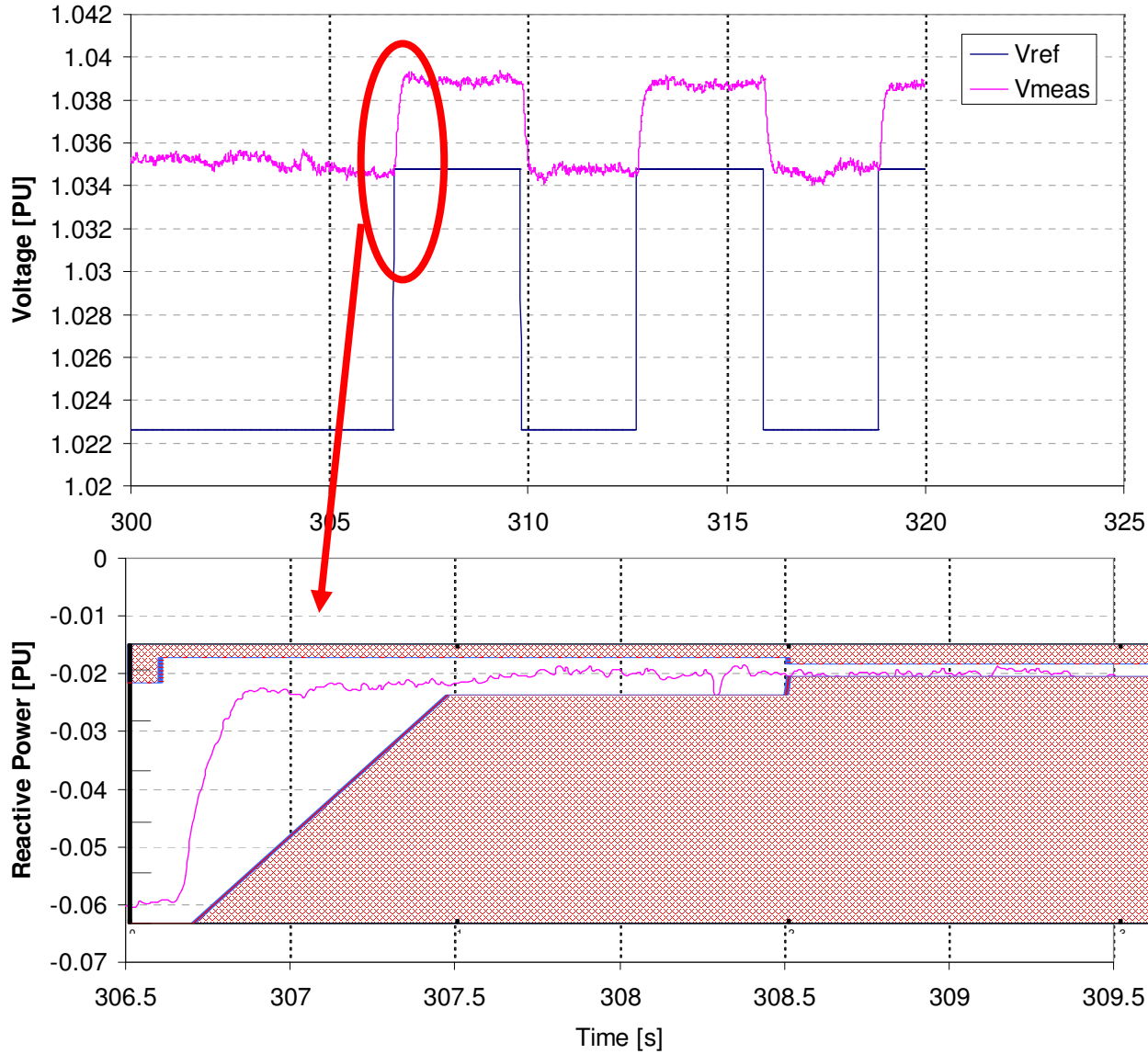
$Q_{ref} = -0.03$ pu as  
capacitor of 0.06pu is  
switched

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

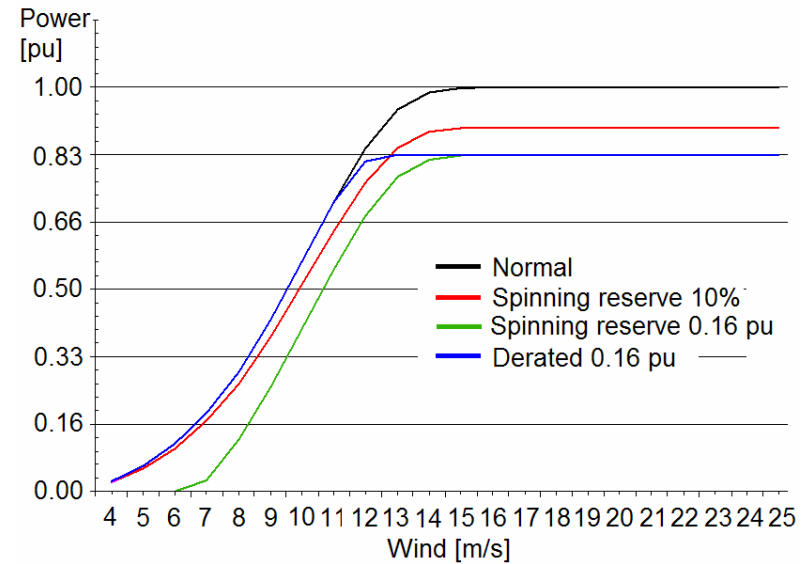
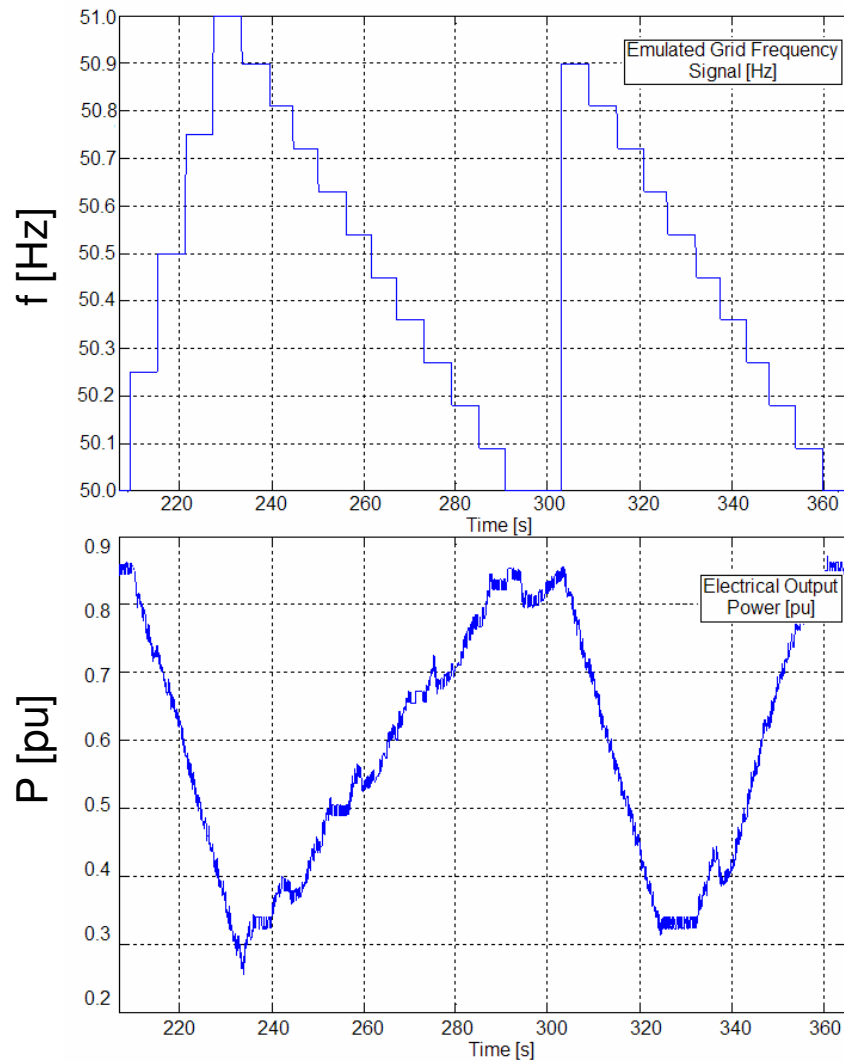


When voltage reference is stepped, the reactive power response must fall within envelope.

# Power Plant performance. Plant voltage control (slope).

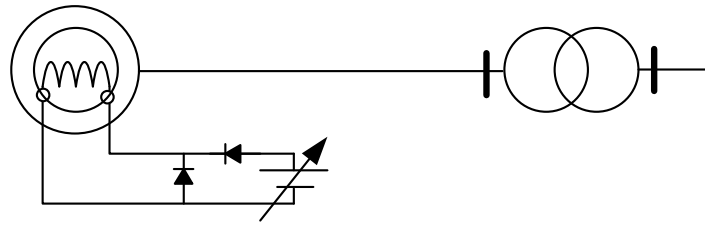


# Power Plant performance. Plant frequency response (slope).

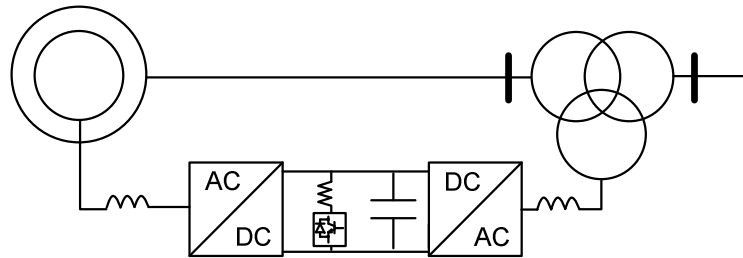


# WTG short-circuit current signatures

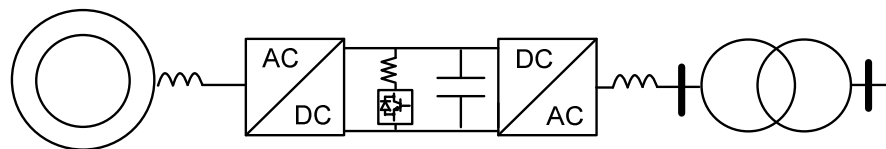
## Sample waveforms



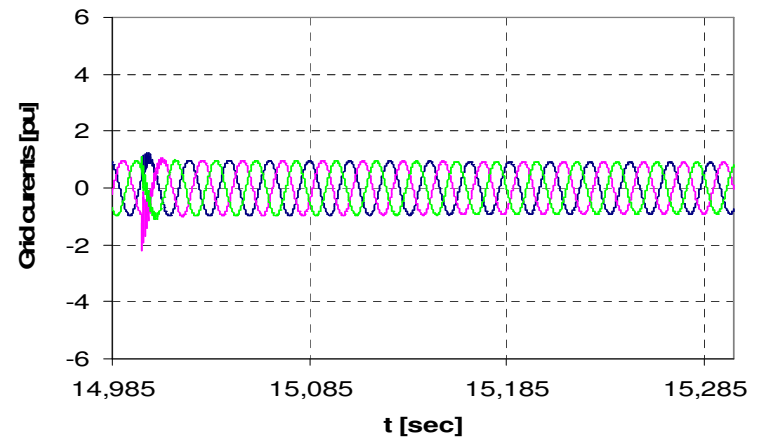
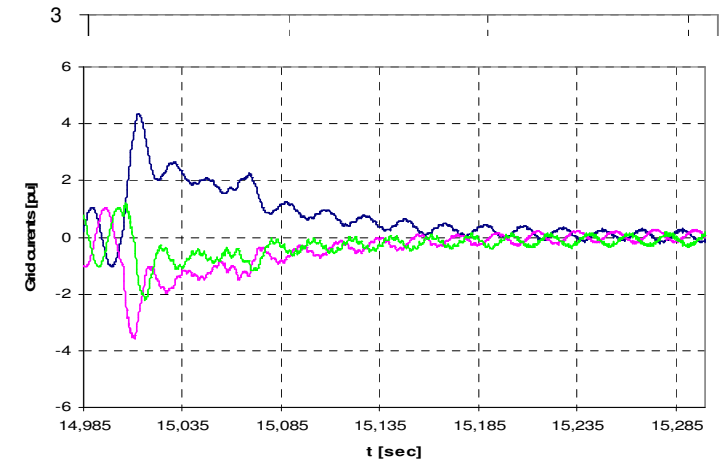
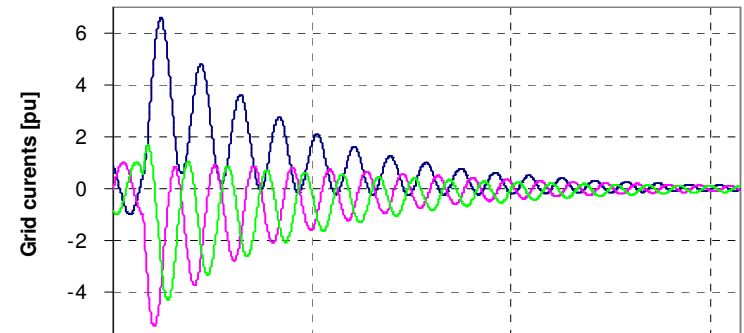
**Synchronous generator**



**Doubly-fed asynchronous generator**

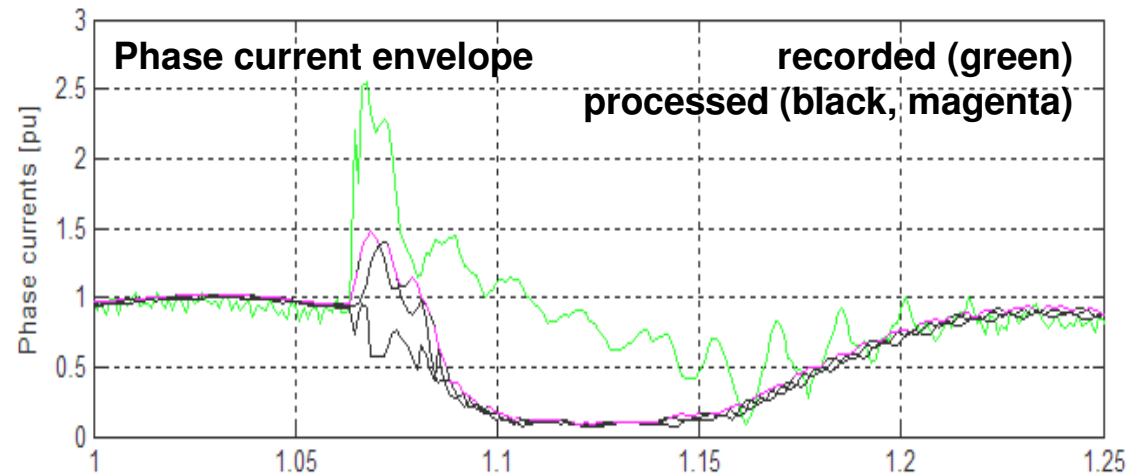
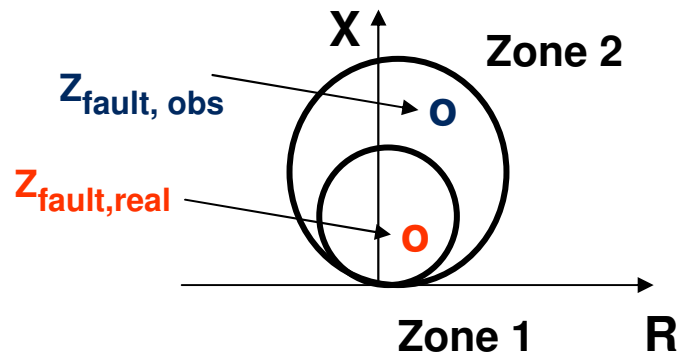
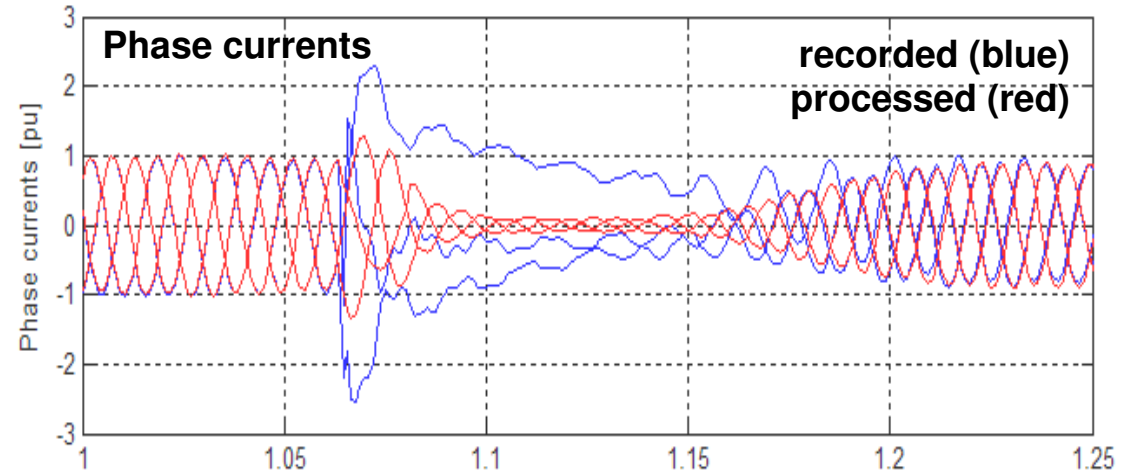
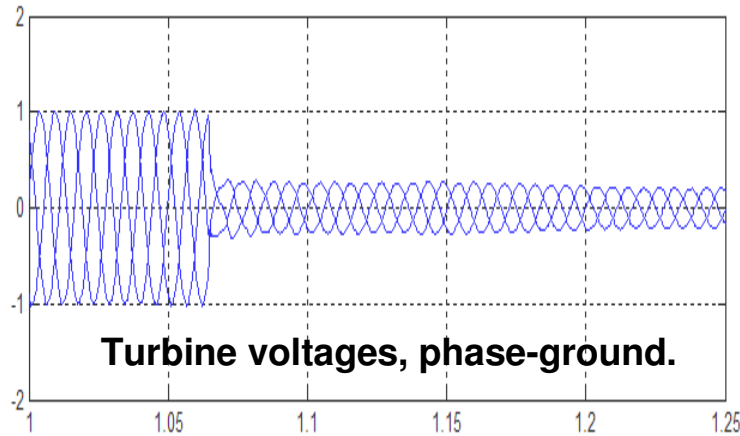


**Full power electronic conversion**



# 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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