Grid Code Testing of Wind Turbine by VSC-based Test Equipment

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CHALMERS

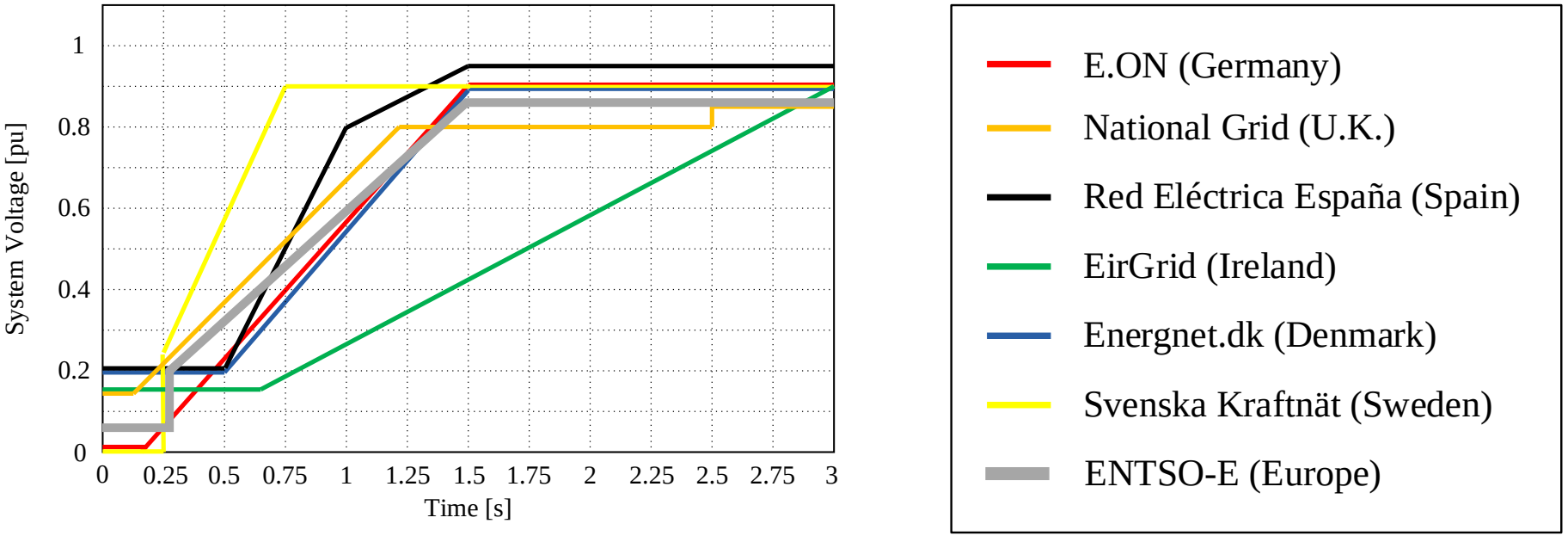
Grid code development for wind farms

- **Regulates** the interconnection of the generating plant
- Requirements for **steady-state** and **dynamic** condition of the grid
- **Steady state:** voltage, active and reactive power and frequency ranges for normal operation
- **Dynamic:** LVRT and control of the reactive current during fault
- Grid code **harmonization**: ENTSO-E (Nordic, Baltic, Continental EU.)



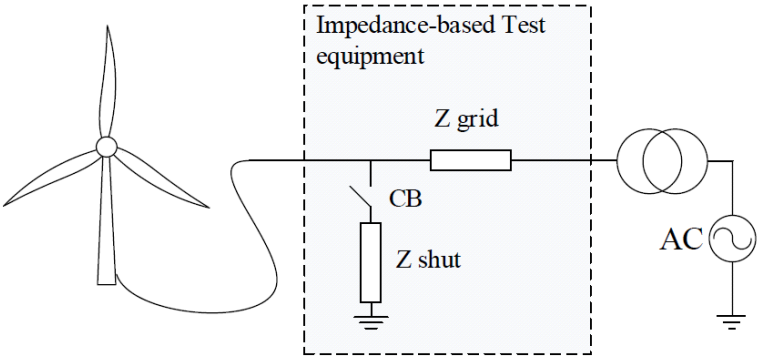
Low voltage ride through (LVRT)

- Voltage dip representation at the connection point (PCC).
- Reactive current injection during voltage dip (example: Danish grid code)



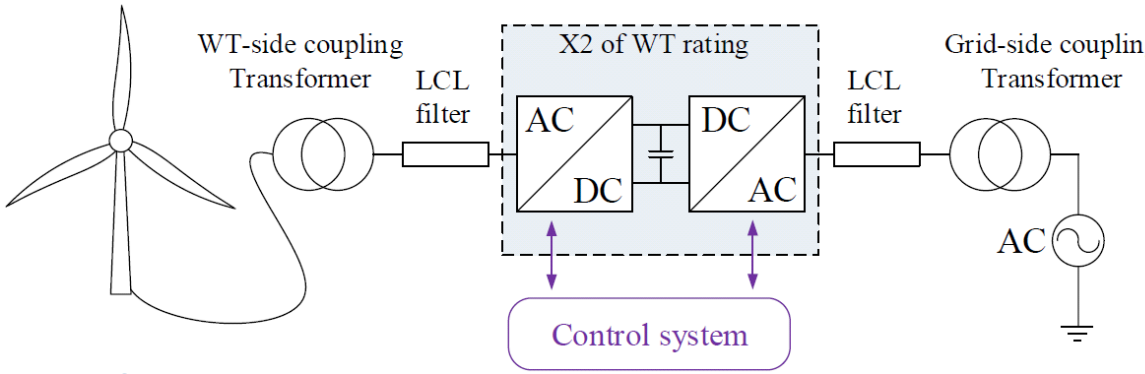
Grid Code testing equipment

Impedance-based



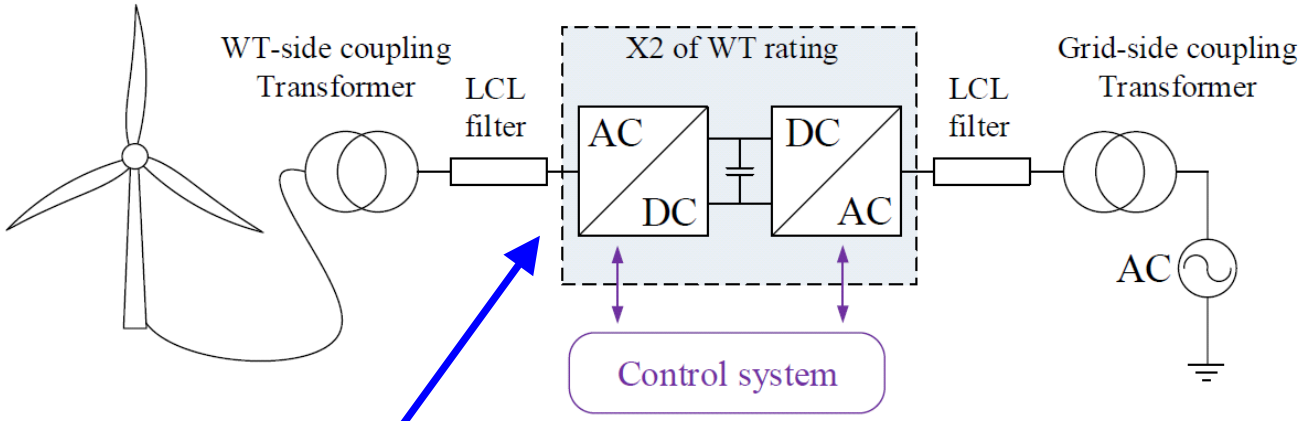
- **Pros**
  - Easy transportation
  - Simple and robust design
  - IEC standard
  - On site test of WT
- **Cons**
  - Limited to LVRT test only
  - Voltage is varied with steps
  - Dependent of the grid strength
  - No frequency variation

Voltage Source Converter - VSC-based

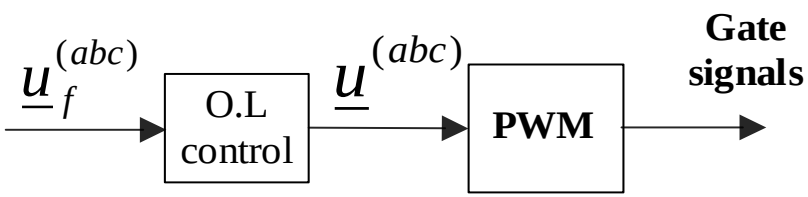


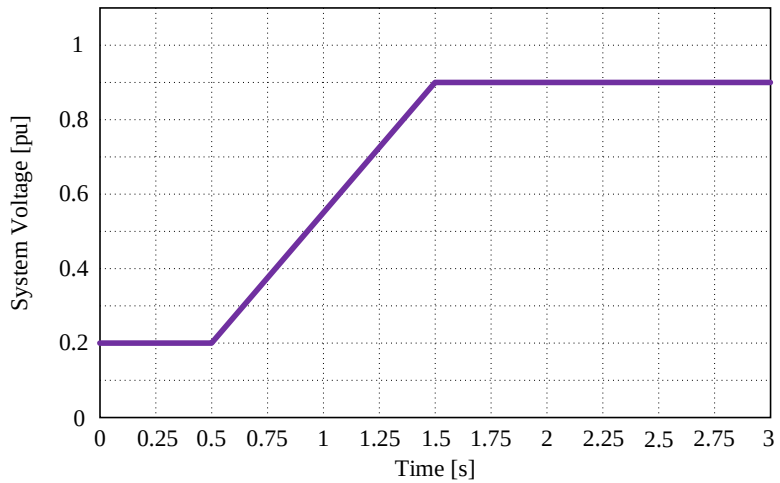
- **Pros**
  - Full control of applied voltage (freq. / φ / mag.)
  - AC grid is less affected
  - Testing beyond today's grid code
    - Inertia support
    - Frequency characterization
    - Power system regulation
- **Cons**
  - More expensive
  - Control system is more complex

Grid emulator for wind turbine



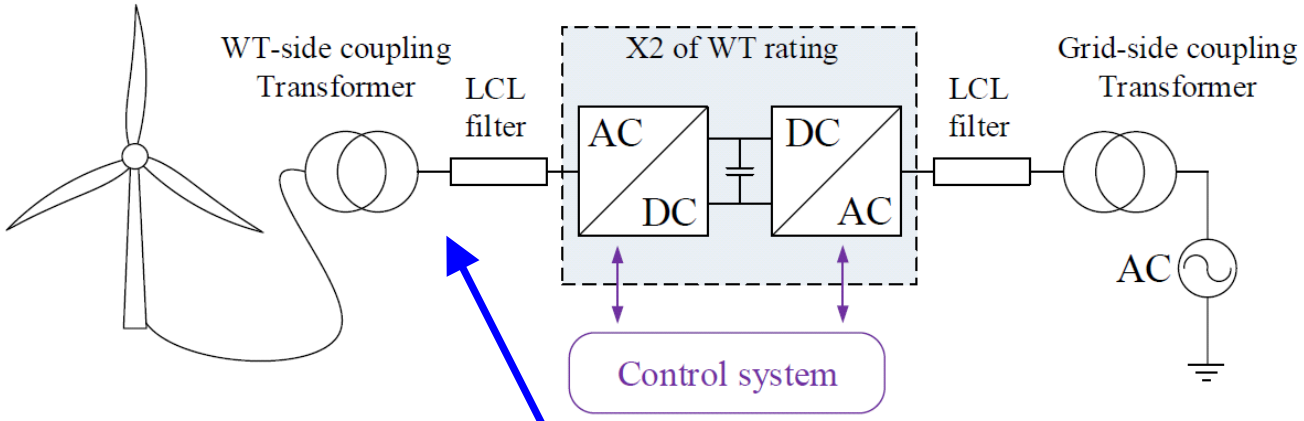
- **Open-loop control**



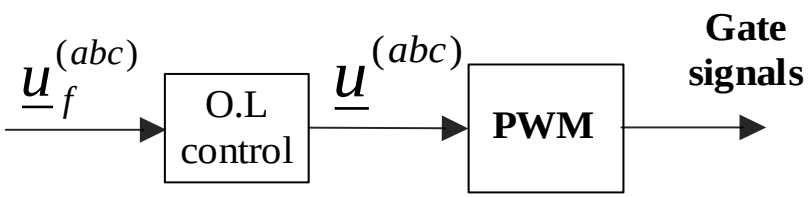


- Voltage variations
- Frequency variations

Frequency scan using VSC-based T.E.



- **Open-loop control**

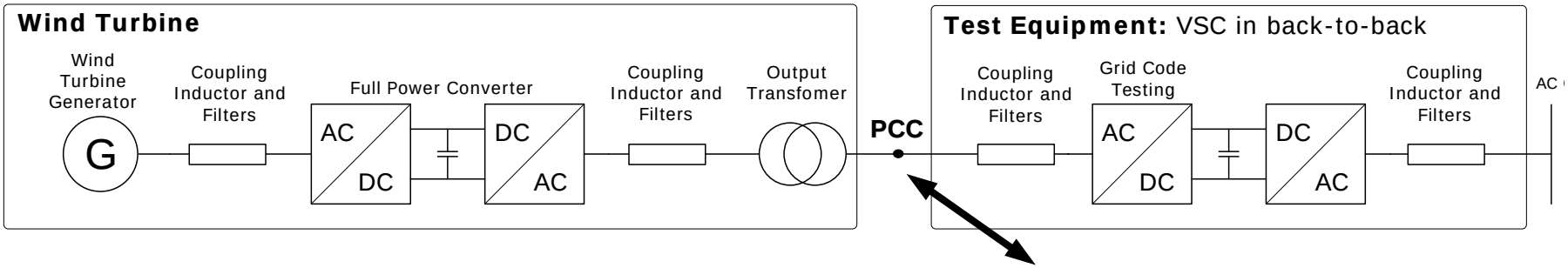


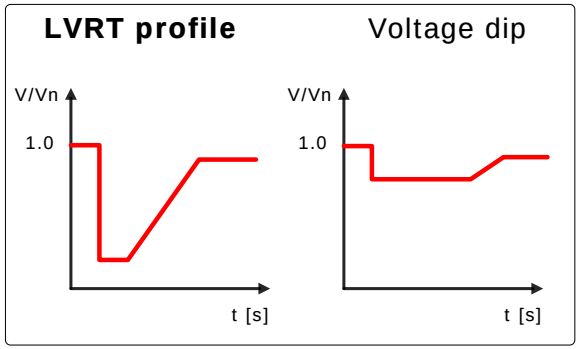
$$Z_{\mathrm{w,h}}(j\omega) = \frac{1}{3}\left(\frac{\hat{\underline{u}}_{\mathrm{h_a}}}{\hat{\underline{i}}_{\mathrm{h_a}}} + \frac{\hat{\underline{u}}_{\mathrm{h_b}}}{\hat{\underline{i}}_{\mathrm{h_b}}} + \frac{\hat{\underline{u}}_{\mathrm{h_c}}}{\hat{\underline{i}}_{\mathrm{h_c}}}\right)$$

$$\underline{u}^{(abc)} = \underline{u}_{\mathrm{f}}^{(abc)} + \hat{\underline{u}}_{\mathrm{h}}^{(abc)}$$

$$Y_{\mathrm{w,h}}(j\omega) = \frac{1}{Z_{\mathrm{w,h}}(j\omega)}$$

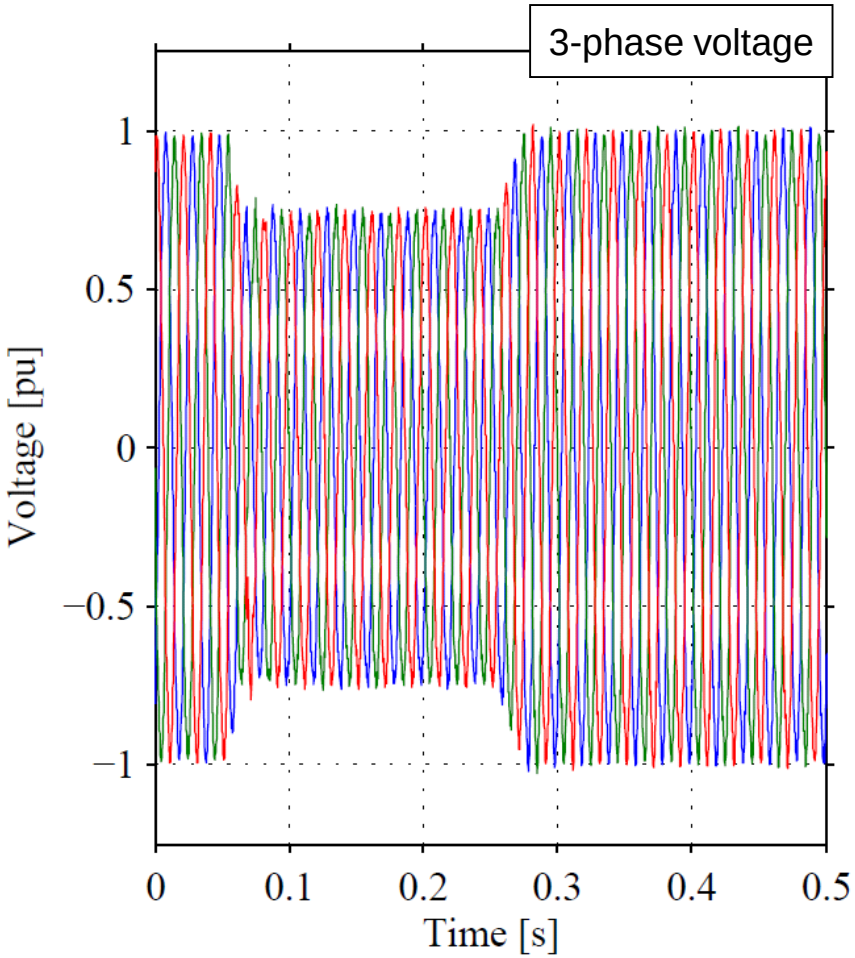
VSC-Based Method-Field Test in Göteborg

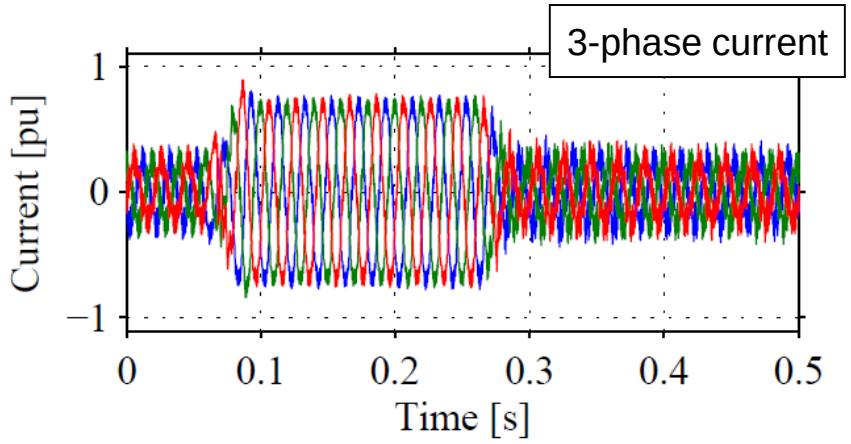


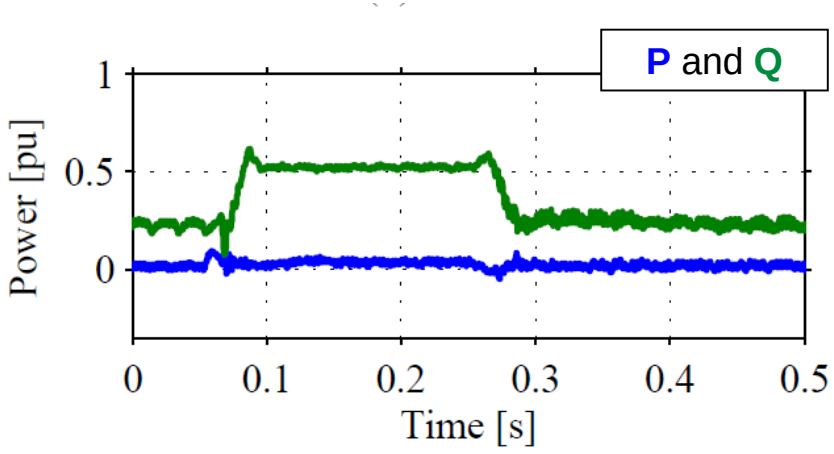


4 MW Full Power Converter WT
8 MW Converter as Test Eq.

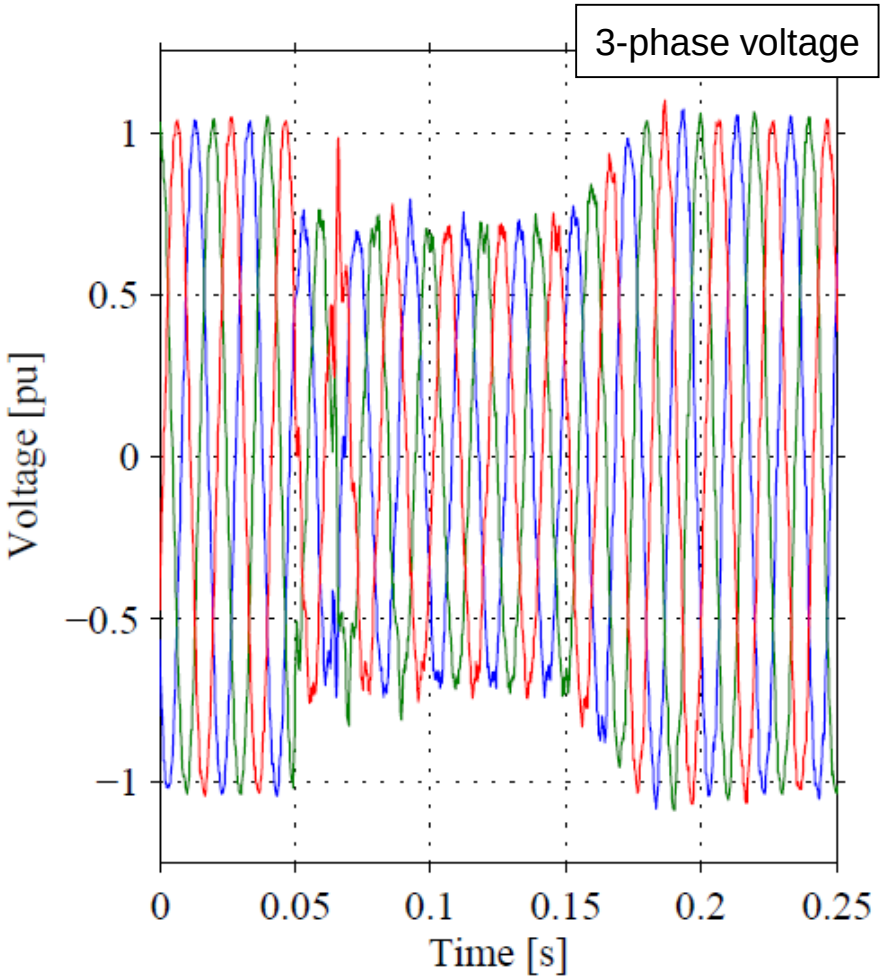
Voltage dip test at low power

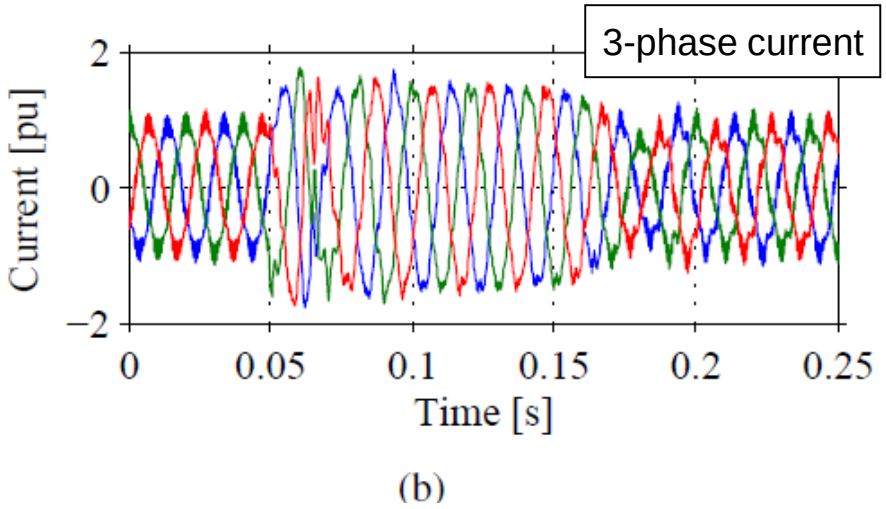


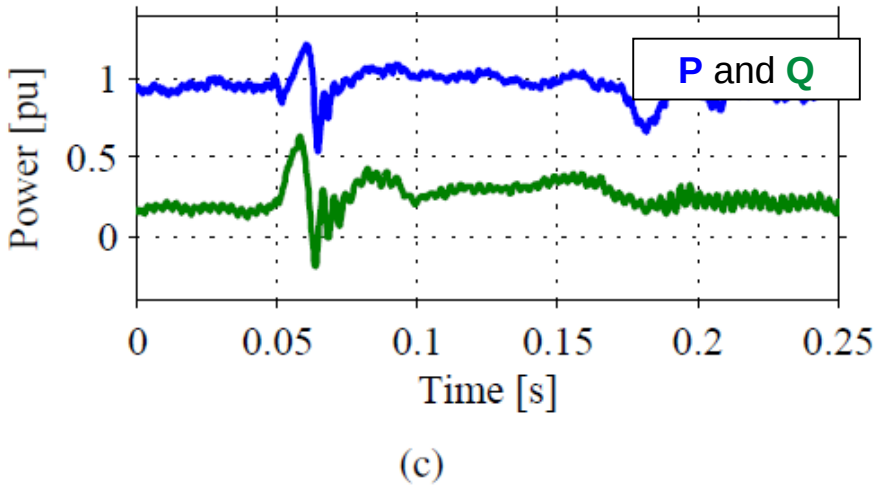




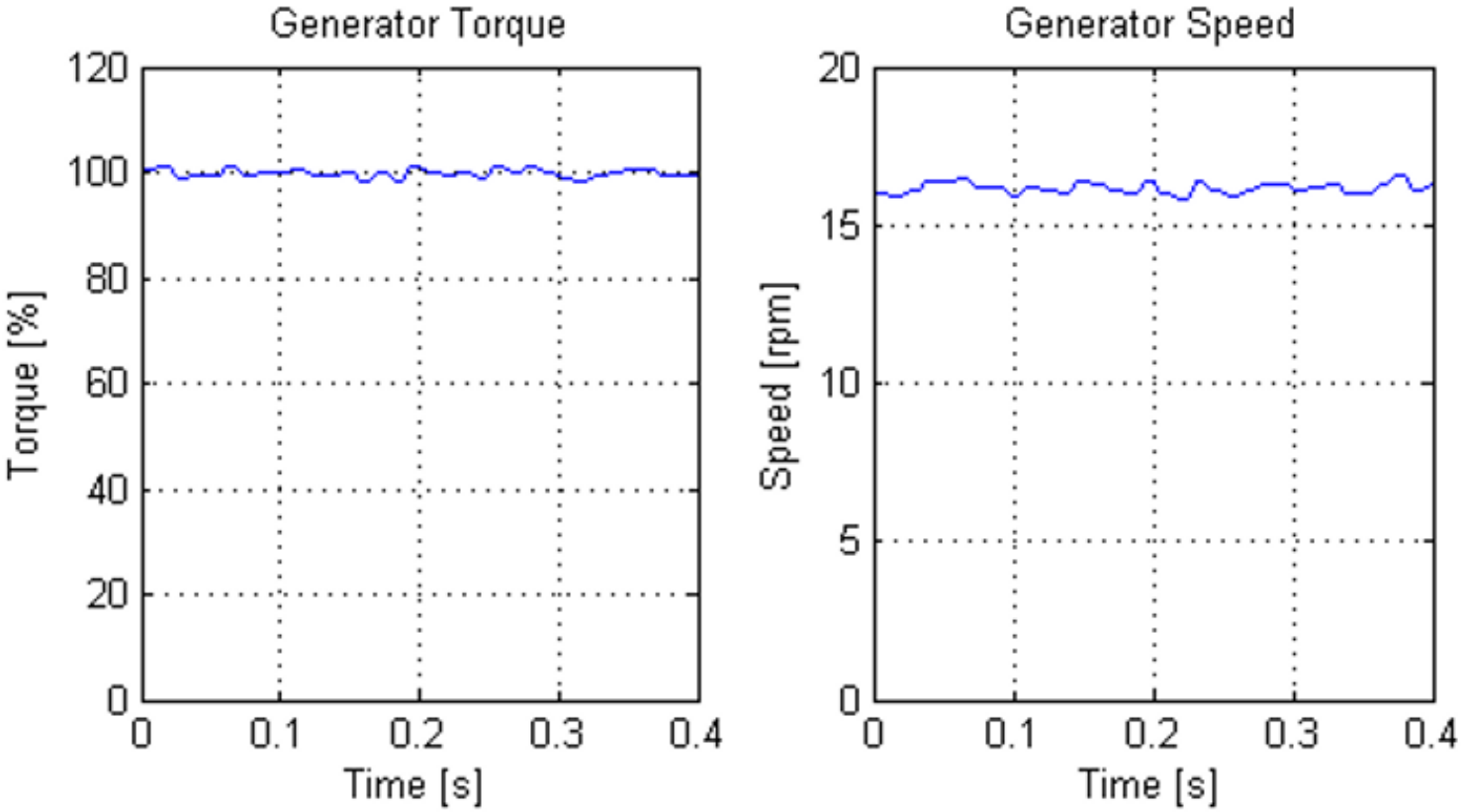
Voltage dip test at full power



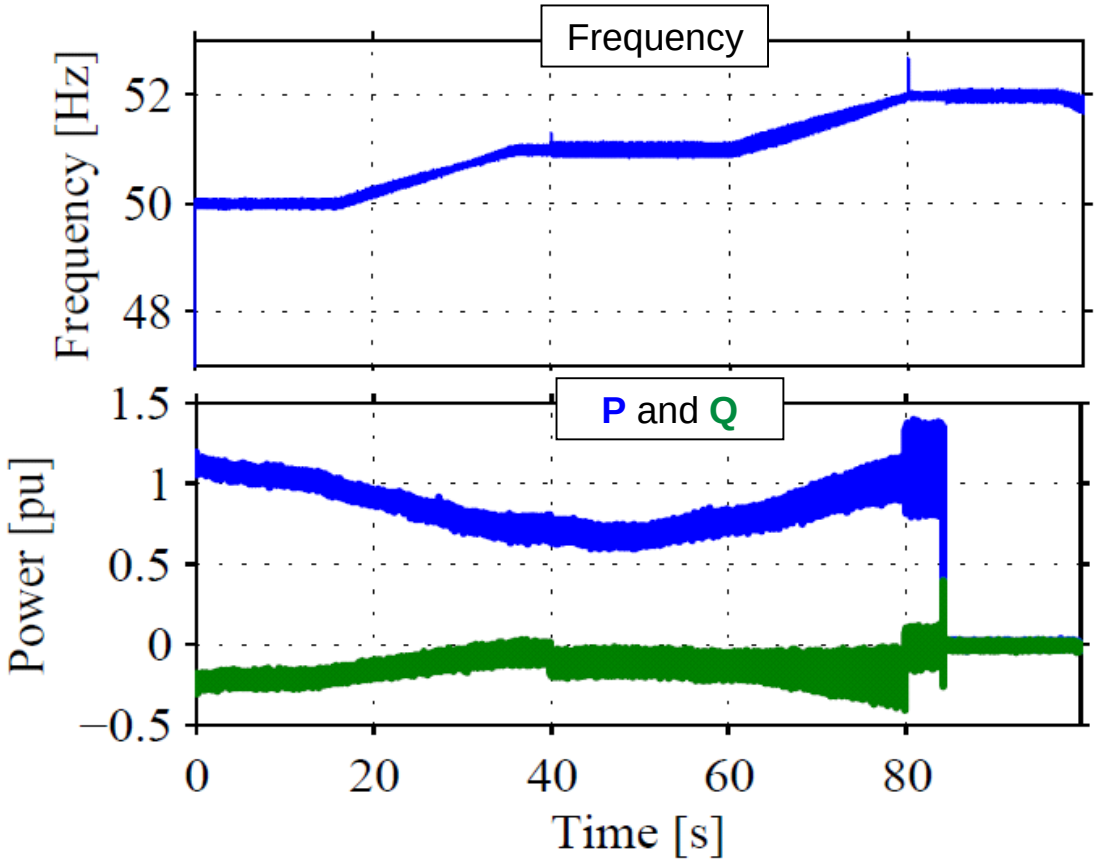




Generator response at the voltage dip test at high power



Frequency variation



Conclusions and Future Work

Conclusions.

- VSC-based Test Eqipment is flexible and allows for full characterization of the Wind Turbine electrical behavior
- Open-loop control is preferred
- Not only Grid Code test but also future requirements
- Theoretical Methodology validated by laboratory experiment and field test

Future Work

- With focus on the wind turbine controller
  - Close-loop voltage control in Wind Turbine
  - Frequency control in Wind Turbine to test for virtual inertia
  - To develop control strategies in test equipment to test of Power oscillation damping capabilities of the Wind Turbine

Thanks for your attention

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More information in the PhD. thesis of Nicolas Espinoza:

Wind Turbine Characterization by Voltage Source Converter Based Test Equipment

http://publications.lib.chalmers.se/publication/245596-wind-turbine-characterization-by-voltage-source-converter-based-test-equipment