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**Wind Energy Science Conference 2017, DTU Lyngby, June 2017**

Citation for the published paper:

Carlson, O. ; Espinoza, N. (2017) "Grid Code Testing of Wind Turbine by VSC-based Test Equipment". Wind Energy Science Conference 2017, DTU Lyngby, June 2017

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

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**Division of Electric Power Engineering**



**SWPTC**  
SWEDISH WIND POWER TECHNOLOGY CENTRE

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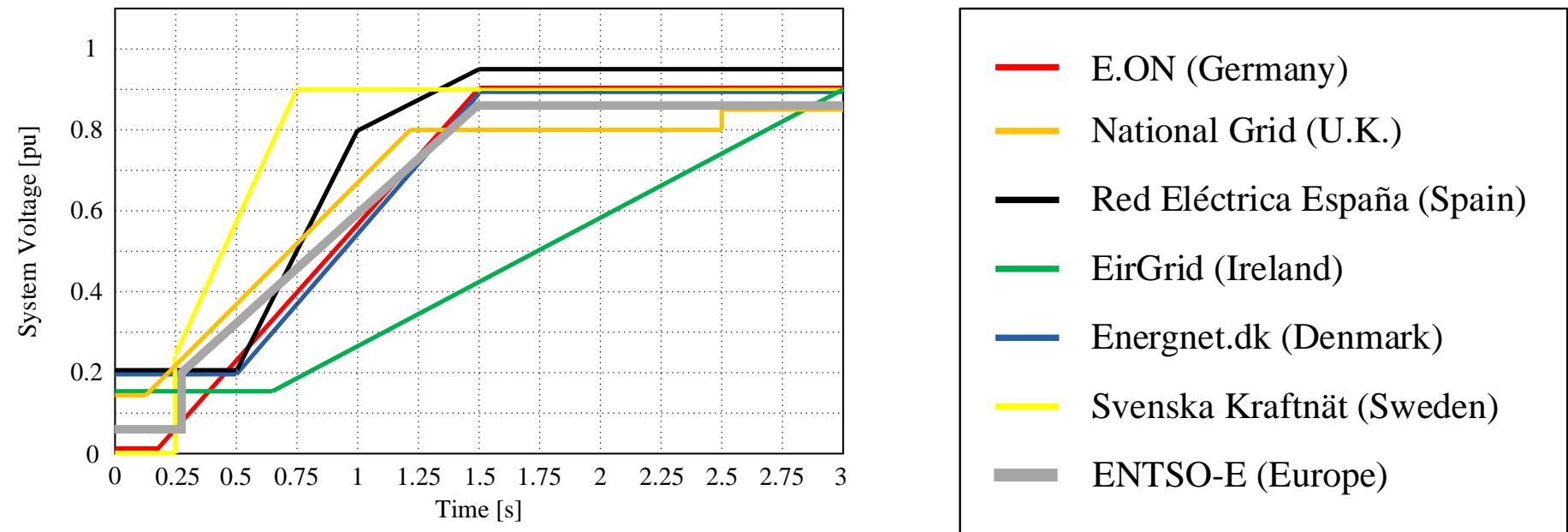
# Grid code development for wind farms

- **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.)



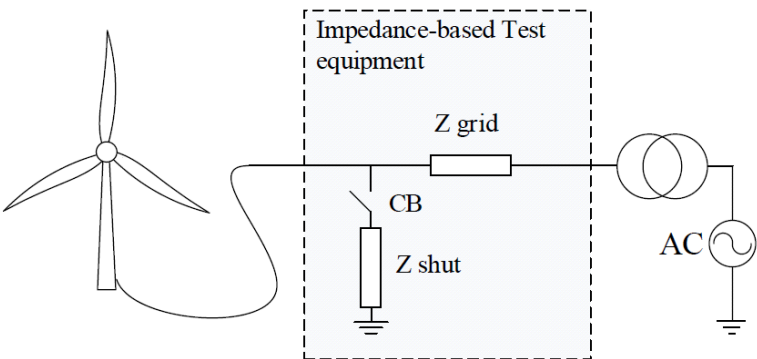
# Low voltage ride through (LVRT)

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



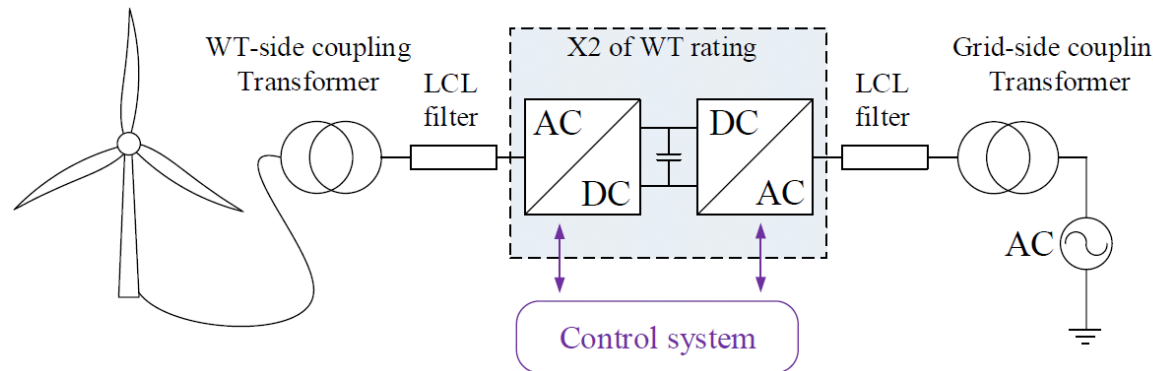
# Grid Code testing equipment

## Impedance-based



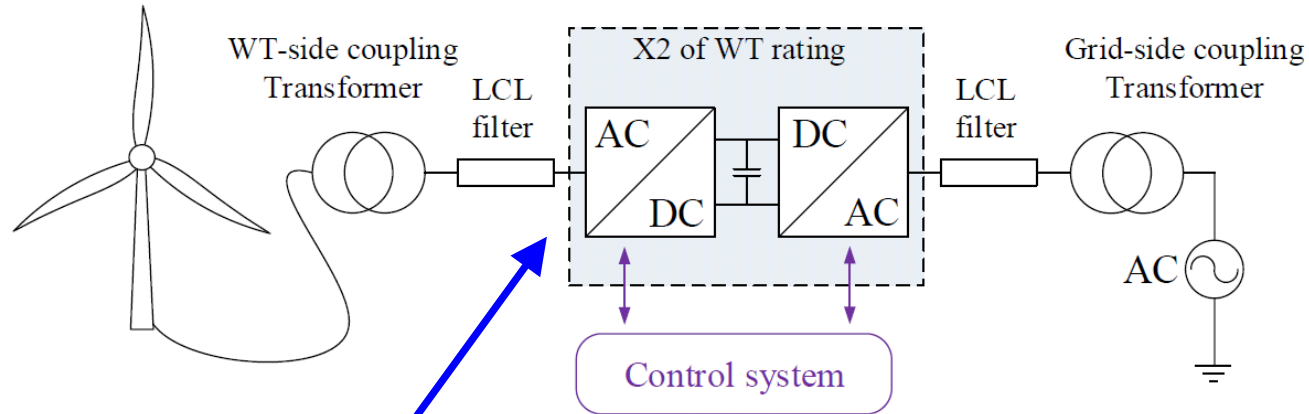
- **Pros**
  - Easy transportation
  - Simple and robust design
  - IEC standard
  - On site test of WT
- **Cons**
  - Limited to LVRT test only
  - Voltage is varied with steps
  - Dependent of the grid strength
  - No frequency variation

## Voltage Source Converter - VSC-based

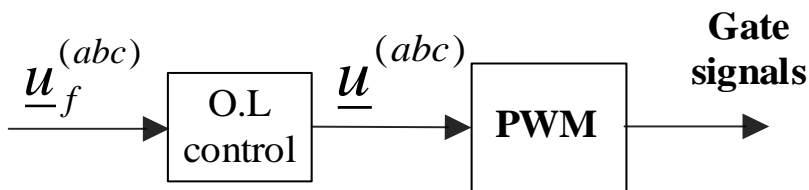


- **Pros**
  - Full control of applied voltage (freq. /  $\phi$  / mag.)
  - AC grid is less affected
  - Testing beyond today's grid code
    - Inertia support
    - Frequency characterization
    - Power system regulation
- **Cons**
  - More expensive
  - Control system is more complex

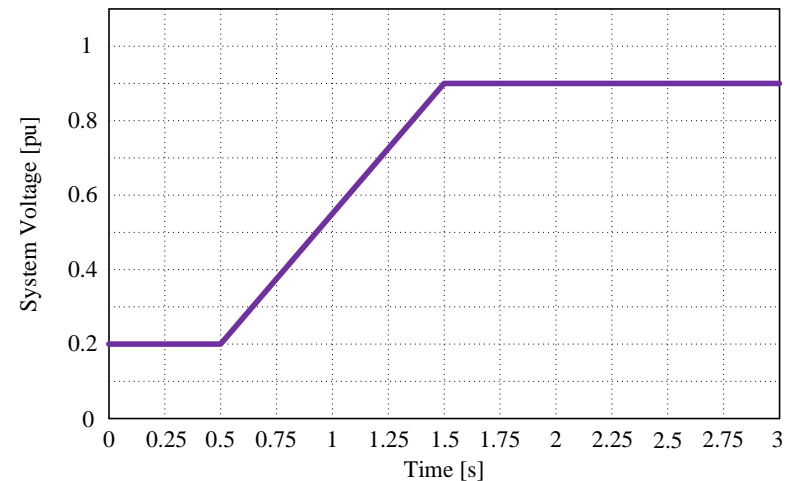
# Grid emulator for wind turbine



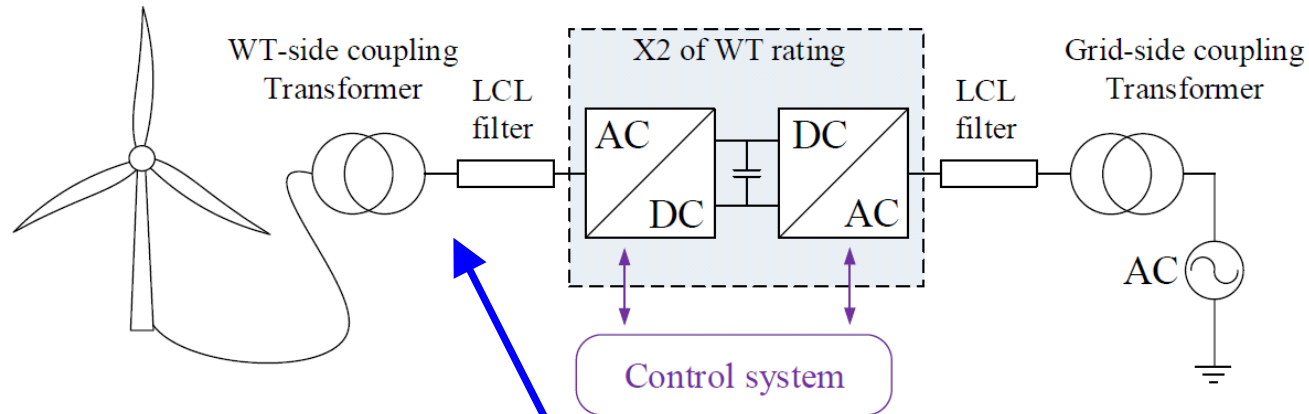
- **Open-loop control**



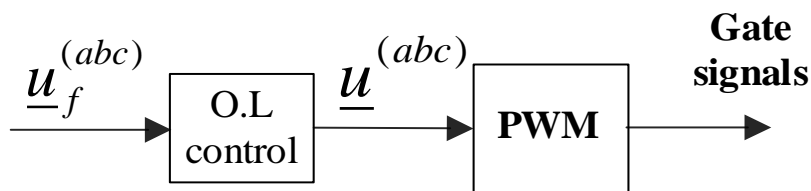
- Voltage variations
- Frequency variations



# Frequency scan using VSC-based T.E.



- **Open-loop control**

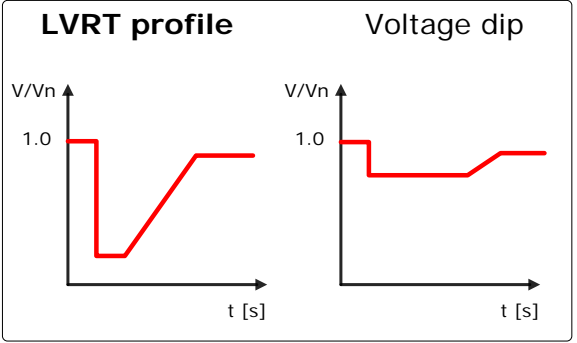
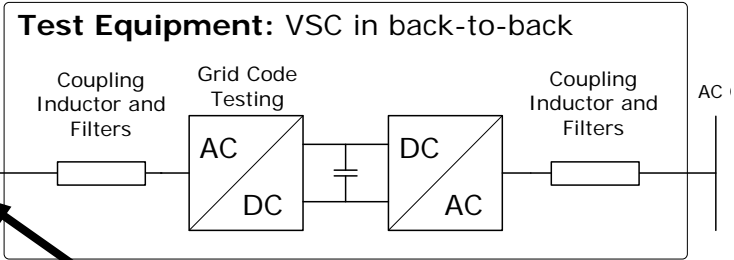
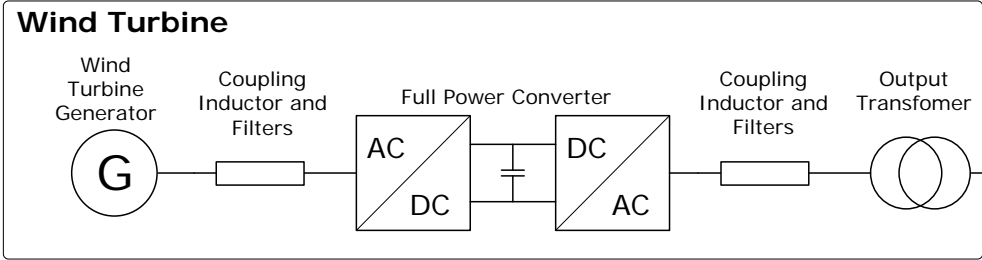


$$\underline{u}^{(abc)} = \underline{u}_f^{(abc)} + \hat{\underline{u}}_h^{(abc)}$$

$$Z_{w,h}(j\omega) = \frac{1}{3} \left( \frac{\hat{u}_{ha}}{\hat{i}_{ha}} + \frac{\hat{u}_{hb}}{\hat{i}_{hb}} + \frac{\hat{u}_{hc}}{\hat{i}_{hc}} \right)$$

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

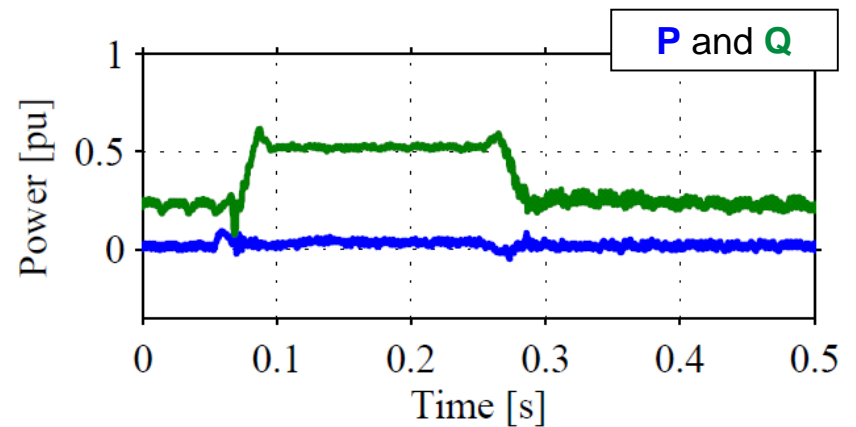
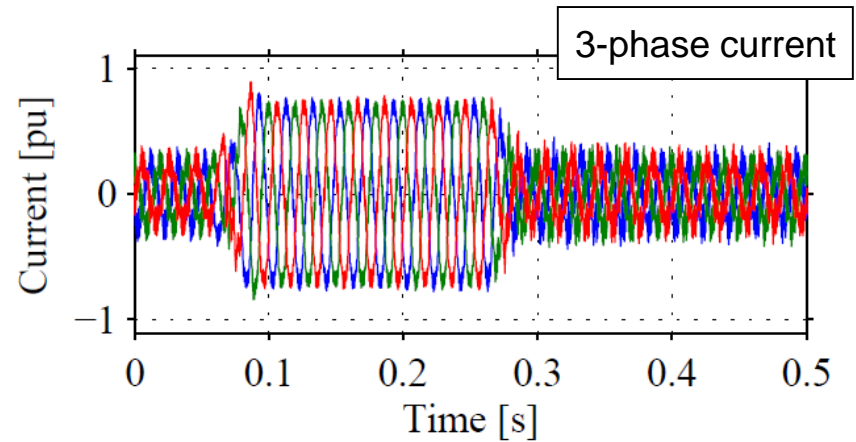
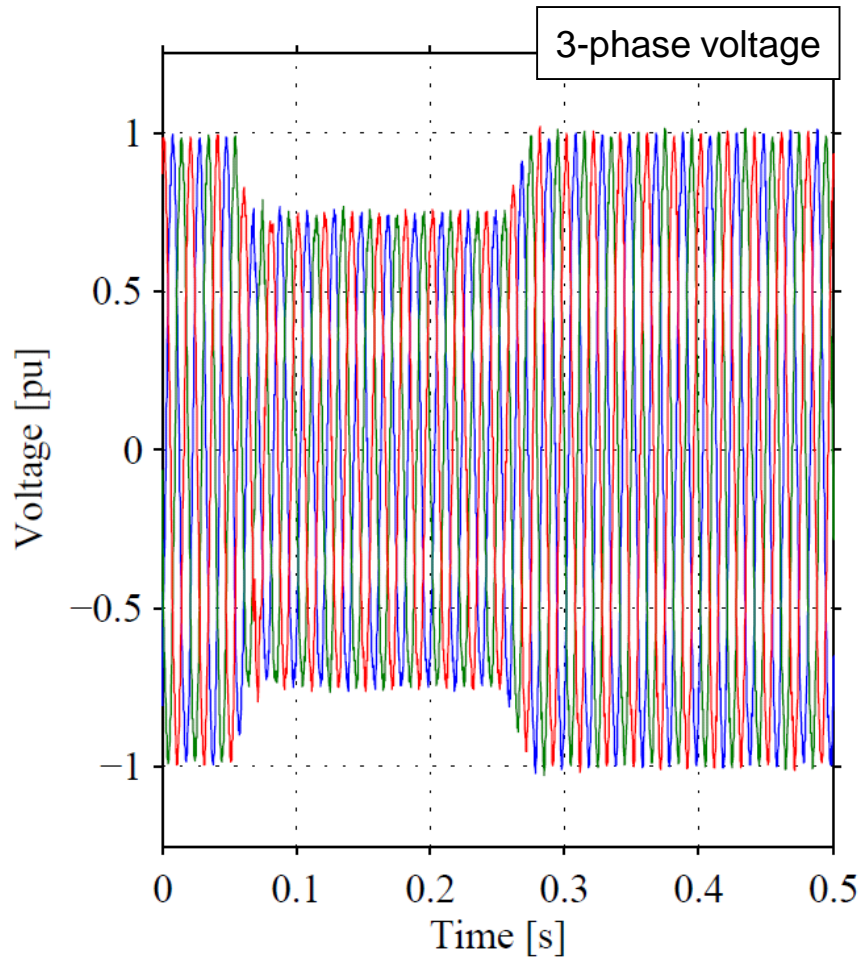
# VSC-Based Method-Field Test in Göteborg



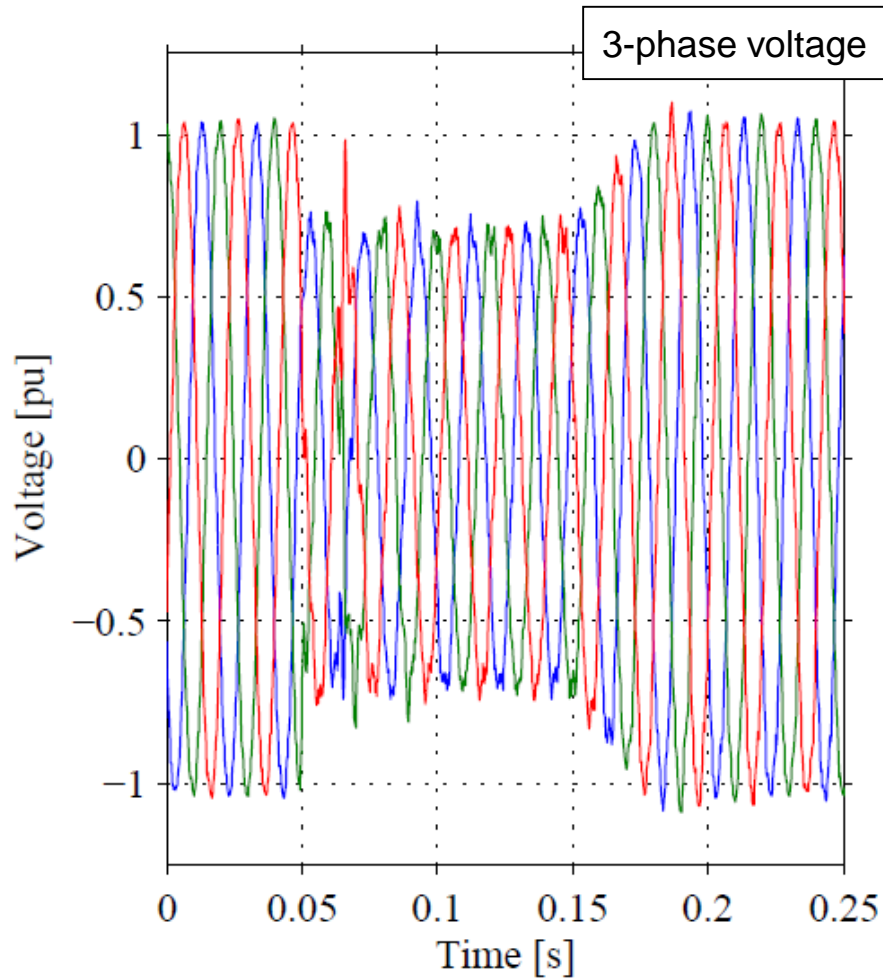
**4 MW Full Power Converter WT  
8 MW Converter as Test Eq.**



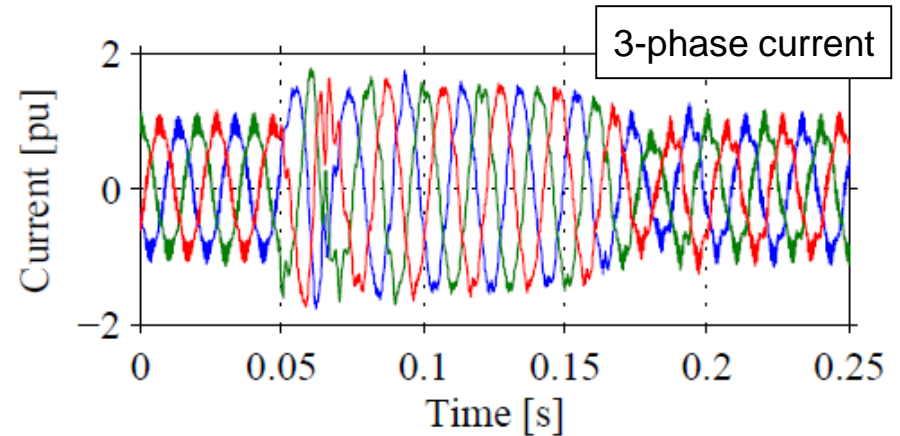
# Voltage dip test at low power



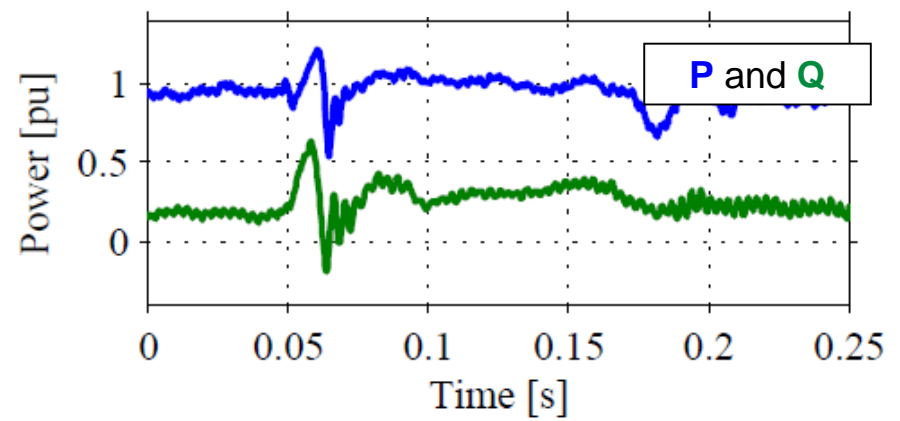
# Voltage dip test at full power



(a)

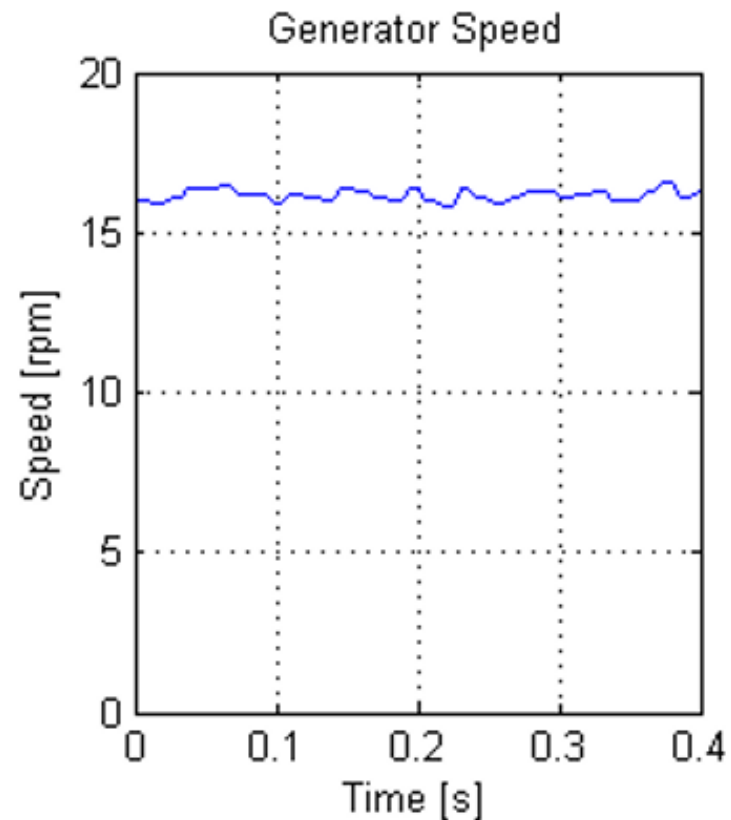
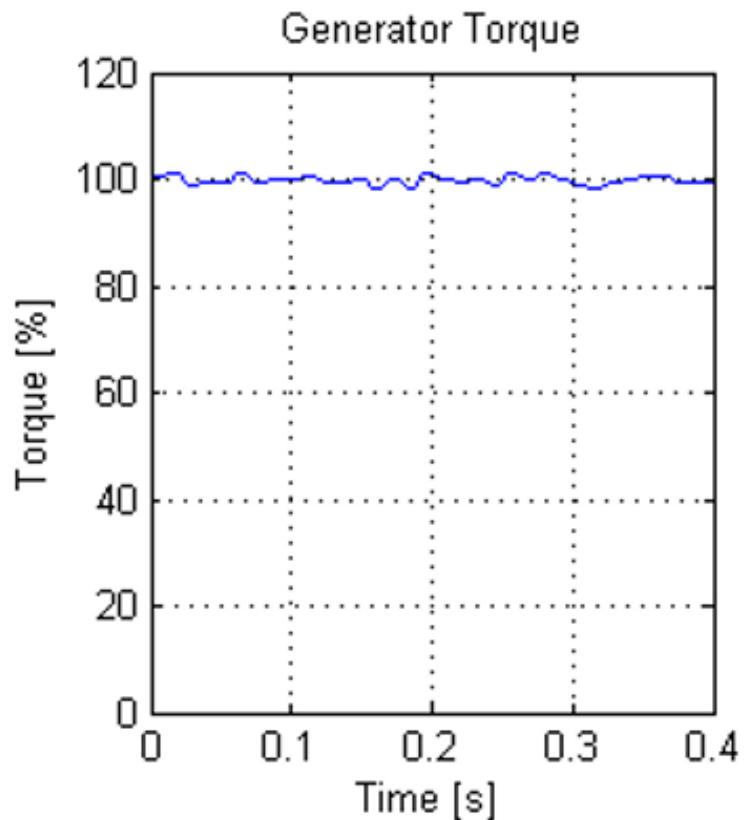


(b)

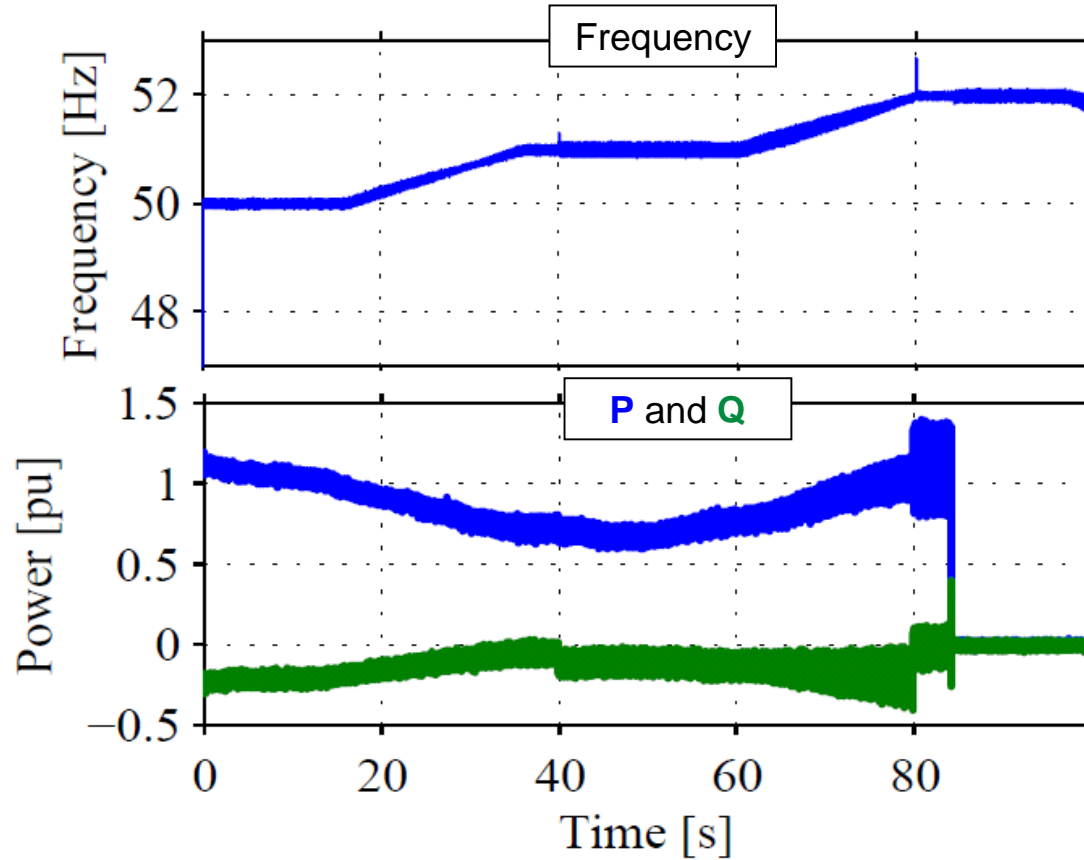


(c)

# Generator response at the voltage dip test at high power



# Frequency variation



# Conclusions and Future Work

## Conclusions.

- VSC-based Test Equipment 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>