Modeling, Simulating and Validating Wind Turbine Behavior During Grid Disturbances

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Power Quality Phenomena

- Grid frequency
- Voltage magnitude
- Supply voltage variations
- Flicker
- Harmonics and inter-harmonics
- Unbalance
Power Quality and the Effect of Small Scale Wind Power

• Voltage Dips

• Voltage Fluctuations and Flicker
  – Flicker emission during start-up
  – Flicker emission during continuous operation

• Harmonics
In the Dutch system (15 000 MW load):

1500 MW wind power connected to the grid (mainly MV).

Average size 750 kW.

This can grow to 3000 MW or 4000 MW.
Voltage Dips and protection – Requirements of National Dutch Grid Code:

• Production means connected to low voltage should be disconnected within 0.1 or 0.2 second when the voltage goes under 80% of the nominal voltage (units smaller then 5 kVA) or under 70% (units bigger then 5 kVA)

• Production means connected to the medium voltage have no specific rules

• Production means connected to high voltage should stay at the grid as long as the critical clearing time permits
Voltage level during a three-phase fault in Diemen (Amsterdam)
E. On Requirements for Generating Units in Case of Faults:

• **Near-to-generator** three-phase short-circuits must not generally result in generating unit instability or in disconnection from the network. Active power output must resume immediately following fault clearing and be increased with a gradient of at least 20% of rated power per second.

• With **far-from-generator** three-phase short-circuits, disconnection of the generating unit from the network is not permitted even with fault clearing in back-up time of the network protection.
E.On Curve

Line-to-line voltage $U/U_N$

Time in ms

Lower value of the voltage band

Time fault occurred

0 150 700 1500 3000

100%
70%
45%
15%
Voltage Fluctuations and Flicker –
Requirements of National Dutch Grid Code:

• Voltage variations $\leq 10\% \ U_{nom}$

• Voltage variations $\leq 3\% \ U_{nom}$ in situations without loss of production, disconnection of heavy loads or faulted connections

• Long term flicker $P_{lt} \leq 1$ during 99.5% of the time

• Long term flicker $P_{lt} \leq 5$ during 100% of the time
Harmonic Current Emission Limits (IEC 61000-3-12):

<table>
<thead>
<tr>
<th>Minimum $R_{sce}$</th>
<th>Admissible individual harmonic current $I_h/I_1$ (%)</th>
<th>Admissible harmonic current distortion factors (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$I_5$</td>
<td>$I_7$</td>
</tr>
<tr>
<td>33</td>
<td>10.7</td>
<td>7.2</td>
</tr>
<tr>
<td>66</td>
<td>14</td>
<td>9</td>
</tr>
<tr>
<td>120</td>
<td>19</td>
<td>12</td>
</tr>
<tr>
<td>250</td>
<td>31</td>
<td>20</td>
</tr>
<tr>
<td>≥350</td>
<td>40</td>
<td>25</td>
</tr>
</tbody>
</table>

The relative values of even harmonics up to order 12 shall not exceed $16/h \%$. Even harmonics above order 12 are taken into account in $THD_i$ and $PWHD_i$ in the same way as odd order harmonics.
Generic Model of Wind Turbines

- **Generator (electrical part)**
  - $V_{sd}$, $V_{sq}$
  - $I_{sd}$, $I_{sq}$
  - $I_{rd}$, $I_{rq}$
  - $P_{gen}$
  - $w_r$

- **Pitch control**
  - $T_m$
  - $w_r$
  - $P_{eref}$
  - $P_{ref}$
  - $V_w$

- **Turbine**
  - $w_r$
  - $V_w$

- **Rectifier + DC-link + Inverter**
  - $V_{gsc}$
  - $I_{gsc}$
  - $V_{dc~ref}$
  - $Q_{ref}$
  - $I_{sd}$, $I_{sq}$
  - $I_{rd}$, $I_{rq}$

- **Rectifier + DC-link + Inverter**
  - $V_{PCC}$
  - $I_{PCC}$
  - $Q_{PCC}$
  - $V_{gen~ref}$
  - $Q_{ref}$

**Diagram notes:**
- Squirrel-Cage IG
- Doubly-Fed IG
- Direct Drive SG

**Technische Universiteit Eindhoven**
Model of the Direct Drive Wind Turbine
Aim of the Measurements

• Check wind turbine performance during grid disturbance

• Check compatibility with E.on curve

• If necessary adjust parameters of controllers

• Challenge: perform measurement with minimal distortion of other connected customers
Explanation of Measurements

- Sub station
- Reactor 1
- Reactor 2
- Direct drive wind turbine
- U,I measurement
- I measurement
Grid current: measured vs analytical fitting

- Current from grid
- Analytical fitting
Estimated short-circuit contribution from turbine side
Conclusions

- During the test the wind turbine did not meet the E.on curve
- Readjustments of control parameters were necessary to meet the requirements of E.on Curve
- Measurement scheme is suitable to do live tests with minimum disturbance to customer
Questions?