Overview of Interconnection
Requirements for Wind Power Plants

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Agenda

- Introduction - Why relevant for WPP’s
- Interconnection requirements – an overview
- Problems / challenges
- An idea of the European Wind Industry – harmonization of grid code requirements
- Conclusion and outlook
Introduction – Interconnection of WPP’s

- There is a number of reference points for each WPP (e.g. to verify reactive power capability, FRT requirements, power quality, ...)

- Which reference points apply?
Introduction – Interconnection requirements

- Set of rules – connection and operation for generating plants
- In general applicable for all kind of generating plants as well as WPP's
- Requirements – apply normally at a defined reference point of the generating plant
Interconnection requirements – challenges

Problems for the wind industry (e.g. manufacturers, developers, operators):

- Requirements changing quite frequently (e.g. updates and drafting of new rules)

- Requirements are diverse and contain sometimes technical gray zones

- It must be fully clear what is required and what has to be fulfilled by the WPP at which reference point

- A common specification language is missing
### Introduction – Interconnection requirements relevant for WPP’s respectively WT’s - why??

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</thead>
<tbody>
<tr>
<td>FRT</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>X</td>
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<tr>
<td>Voltage range</td>
<td>-</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>(X)</td>
<td>-</td>
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<tr>
<td>Reactive power support</td>
<td>-</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>(X)</td>
<td>-</td>
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<tr>
<td>Reactive power at no Wind</td>
<td>-</td>
<td>X</td>
<td>X</td>
<td>-</td>
<td>X</td>
<td>X</td>
<td>-</td>
<td>(X)</td>
</tr>
<tr>
<td>Active power control</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>X</td>
<td>Delta</td>
<td>-</td>
</tr>
<tr>
<td>Frequency control</td>
<td>(X)</td>
<td></td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>X</td>
<td>FSM</td>
<td>X</td>
</tr>
<tr>
<td>Fast frequency response</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>-</td>
<td>X</td>
<td>X</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td>&gt; 25 m/s</td>
<td>X</td>
<td>(X)</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Blackstart</td>
<td>-</td>
<td>(X)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>-</td>
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</tr>
</tbody>
</table>
Interconnection requirements – overview

Connection requirements can be split into different groups:

- General requirements (e.g. definitions, MW size limits, reference points)
- Req. on steady state operation (e.g. operation ranges, power quality)
- Req. on dynamic performance -- different control schemes
  -- during grid faults
- Communication (e.g. SCADA), protection and verification (e.g. protection
  settings at WT, WPP level)
- Req. on simulation models / validation
- Compliance of WPP with requirements(type tests, compialce tests / monitoring)
- "Additional requirement"

Ancillary services (e.g. fast frequency response, black start, ....)
General requirements

Definitions:

- Generating unit (e.g. WT)
- Generating plant (e.g. WPP)
- Reference point, Current, Frequency, Voltage, .... (e.g. pos. sequ., RMS, inst. values)

High diversity in definitions!

Specification of reference points (e.g. point of connection (POC))

- Must be clear at which reference points requirements apply
General requirements – challenges

- Missing and unclear definitions in grid codes
  rise time, response time, detection time, settling time, voltage, ....
- What are the reference values (e.g. active power) for the different requirements?
  maximum capacity, registered power, actual active power, ..... 
- Reference point for different requirements (e.g. reactive power requirements, FRT requirements, POI, PCC, IP, CP, GEP, ....)
Steady state operation (1)

Operation range

- Voltage (kV) – continuous operating range (e.g. 0,9 Un – Un – 1,1 Un)
- Frequency (Hz) – continuous operating range (e.g. 49,0 Hz – 51,0 Hz)
- Rate of change of frequency (ROCOF) withstand capability (e.g. 2 Hz/s)

Source: ENTSO-E
Steady state operation (2)

Reactive power capability – various requirements world wide – trend towards 0.9 lead / lag

Ontario: 0.95 / 0.94 lag

IRL: 0.95 / 0.95

UK: 0.95 / 0.95

EON: 0.925 lead / 0.95 lag

FR: 0.94 lead / 0.92 lag

SP: 0.97 / 0.97 (bonus if < 0.95 / < 0.95)

NZ: 0.9 lead / 0.95 lag

AU: 0.93 / 0.93
Steady State operation (3)

Reactive power capability $P(Q)$ diagram – at and below rated active power

Where?
Voltage range?

Source: TenneT
Dynamic – controls (1)

Requirements for active power control:

- Start-up ramp up rate [MW/min]
- Active power controlability via SO set points
- Ramp down and ramp up rates during normal operation [MW/min]
- MW control schemes

Definition of power base important
Dynamic – controls (2)

Requirements for frequency control:

- P reduction in case of over frequency
- Frequency control

Requirements for reactive power control:

- Voltage control
- MVAR control
- Power factor control

Source: Energinet.dk. Eirgrid, National Grid
Dynamic – controls – example frequency control

Demand on compliance tests and validation:

- For controls at WPP level tests are required
- Requirements for verification of WPP controls
- Simulation models and studies usually done

Source: Siemens
Fault Ride Through (FRT) profiles in case of under voltage events

- Which voltage is shows
- What are the pre-fault and post-fault conditions (U, Q, SCR)
Fault Ride Through (FRT) profiles in case of over voltage events:

- Requirements specified where?
- Simulation studies are necessary

<table>
<thead>
<tr>
<th>Overvoltage (p.u.)</th>
<th>Minimum time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 ≤ V ≤ 1.10</td>
<td>Extended²</td>
</tr>
<tr>
<td>1.10 &lt; V ≤ 1.15</td>
<td>300 seconds</td>
</tr>
<tr>
<td>1.15 &lt; V ≤ 1.20</td>
<td>30 seconds</td>
</tr>
<tr>
<td>1.20 &lt; V ≤ 1.25</td>
<td>2 seconds</td>
</tr>
<tr>
<td>1.25 &lt; V ≤ 1.40³</td>
<td>0.10 second</td>
</tr>
<tr>
<td>V &gt; 1.40³</td>
<td>0.033 seconds</td>
</tr>
</tbody>
</table>

1 – Positive-sequence voltage on high-voltage side of switchyard
2 – Up to several hours, depending on time needed to bring grid back to normal state, i.e., within steady-state voltage range (see Section 5.1)
3 – Though temporary blocking is allowed for facilities using power electronics when the voltage exceeds 1.25 p.u., normal operation must resume once the voltage drops back below 1.25 p.u.

What is the highest voltage

Source: Eskom, Hydro Quebec
Dynamic – during grid faults (4)

Different requirements for fast acting voltage control during grid faults:

- Injection of prioritized active current or reactive current
- Injection of reactive current during grid faults (pos. sequ. or pos./neg. sequ.)
- Demands on rise- and settling time (e.g. \( t_r = 30 \text{ ms} \); \( t_s = 60 \text{ ms} \))

Source: Energinet.dk; VDE FNN, ENTSO-E, State Grid
Dynamic – during grid faults - challenges

Level of details of the requirement – vs. room for different technologies:

- Injection of what kind of current (active vs. reactive current, pos. sequ. / neg. sequ., absolute vs. additional reactive current)

- How to verify rise and settling time (based on pos. sequ. current)

- Post fault reactive current behaviour

- Verification of these requirements – FRT tests at WT level

2/3 of add. reactive current within 10 ms

2) The Power Park Module (ARTICLE 54 (2) (b) point 1) option a.) or the individual units of the Power Park Module (ARTICLE 54 (2) (b) point 1) option b.) shall be capable of providing at least 2/3 of the additional reactive Current within a time period specified by TEIAS which shall not be less than 10 milliseconds. The target value of this additional reactive Current defined by ARTICLE 54 (2) (b) point 1) shall be reached with an accuracy of 10% within 60 milliseconds from the moment the Voltage deviation has occurred as further specified according to ARTICLE 54 (2) (b) point 1).
More requirements and ancillary services

There are much more requirements for WPP’s

- New requirements (services)
- Existing requirements which become more demanding (models, compliance)
- Regulatory aspects (market schemes...)

<table>
<thead>
<tr>
<th>General requirement</th>
<th>Specification</th>
<th>UK</th>
<th>Comments</th>
<th>Reg. at WT yr.</th>
<th>Market tendency</th>
<th>Ireland (incl.)</th>
<th>Comments</th>
<th>Reg. at WT yr.</th>
<th>Market tendency</th>
</tr>
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<tbody>
<tr>
<td>Steady state requirements</td>
<td>Frequency response (in certain voltage range)</td>
<td>High</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Dynamic performance (control)</td>
<td>Frequency response (in certain frequency)</td>
<td>High</td>
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<td>Regulatory aspects (market schemes...)</td>
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New services (ancillary services)
- Frequency response
- Load change
- Storage
- Certification
- Regulatory aspects
- Other aspects

Interfaces

Modelling
- Model requirements (study)
- Validation
- Complexity of overall requirements
- Ancillary services

KPIs

Certification
- Voltage level

Regulatory aspects
- Feed in tariffs
- Market design

Other aspects
- Versus Grid
- Service related requirements

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Modern WT’s support the different requirements and can provide required control functionalities:

- Low voltage fault ride trough
- Active power control
- Ramp control, limitations etc.
- Reactive power control
- Voltage control
- Frequency control, including fast frequency response

But there are much more requirements to WPP’s (power quality aspects, damping requirements, provision of validated simulation models, ....)
European Wind Industry – harmonization of requirements (1)

European Wind Energy Association (EWEA) – TF Grid Codes:

- EWEA TF on GC set up – 2006, group of wind turbine manufacturers, component manufacturers, developers, consultants and associations

- TF works on present grid code topics (harmonisation, NC RfG)
European Wind Industry – harmonization of requirements (2)

2 Steps – first structure (e.g. figures, units) and second technical items (e.g. values, ranges)

4.11. Fault ride-through – FRT

132 Fault ride-through description

Used for general description. Statistics of number and type of grid faults should be specified.

133 FRT voltage profile for under voltages

The voltage / time FRT-profile (at POC) for the lowest phase RMS voltage or phase to phase RMS voltage shall be available for both balanced and unbalanced faults.

If voltages are specified in pu it shall be clear what 1 pu is referring to.

Furthermore, where applicable, the proceeding of the fault process from a higher level system bus down to a given POC point – shall be clearly specified.

134 FRT voltage profile for over voltages

The voltage/time FRT-profile (at POC) for the highest phase RMS voltage or phase to phase RMS voltage shall be available for both balanced and unbalanced faults.

If voltages are specified in pu it shall be clear what 1 pu is referring to.

Furthermore, where applicable, the proceeding of the fault process from a higher level system bus down to a given POC point – shall be clearly specified.

In general this aspect is related to grid strength, protection settings, insulation coordination, voltage control, islanding and the voltage level actual in a given case.

Source: EWEA
Summary and conclusion

- High diversity in requirements worldwide which brings challenges for WT manufacturers

- Interconnection requirements contain technical gray zones – leads to misunderstandings – projects getting more expensive!

- Interconnection requirements for WPP – is a combination of wind turbines, wind farm controls and other devises/controls!

Compliance with Interconnection Requirements is essential to connect WPP’s! But there are usually many obstacles on the path!
Thank you for your kind attention!
Further information:
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