Grid Codes – part 1

a module of the
Grid Connection and Integration of Wind Power

part of the
DTU Online Master’s Programme

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Learning objectives

After this module you should be able to:

- List the different grid connection requirements
- Identify the operational ranges of wind power
- Explain the need for reactive power control
- Understand the principles of fault-ride-through control
Grid codes – some definitions and history

• A grid code is a technical specification which defines the parameters a facility connected to a public electric network has to meet to ensure safe, secure and economic proper functioning of the electric system. The facility can be an electricity generating plant, a consumer, or another network.

• Historically, network requirements very favourable for wind power. Mostly technical specifications, generally requiring wind turbines to disconnect from the grid during abnormal voltage and frequency events.

• First grid code for wind power in Denmark in 1999; many countries have one today.
Why grid codes

• Ultimately, each project is unique and the technical requirements for connecting to the network will depend on the specifics of the project, the local conditions, etc.

• However, by nature wind power is a distributed generation resulting in a massive number of projects

• Need for standardization!

• First country wise, but quickly this also became laborious → at regional level (European)

• Grid codes are legal documents, not technical guidelines → (sometimes) difficult to read

Source: Danish Energy Authority, System Integration of Wind Power, Experiences from Denmark, 2015
ENTSO-E Network Code – Requirements for Generators

• Harmonization of the requirements across Europe

• Adopted as an EU law – much harder to modify!

• Timeline

Drafting, consultation and adoption

TSOs

OEMs

2011 2016 2018 2020
Synchronous areas

Europe
- RG Continental Europe
- RG Nordic
- RG Baltic
- RG UK
- RG Ireland

North America
- Western Interconnection
- Eastern Interconnection
- Texas Interconnection

Quebec Interconnection
ENTSO-E NC RfG – Main characteristics

• Applicable to all generators – technology agnostic

• However different requirements based on the installed capacity

<table>
<thead>
<tr>
<th>Synchronous areas</th>
<th>Limit for maximum capacity threshold from which a power-generating module is of type B</th>
<th>Limit for maximum capacity threshold from which a power-generating module is of type C</th>
<th>Limit for maximum capacity threshold from which a power-generating module is of type D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continental Europe</td>
<td>1 MW</td>
<td>50 MW</td>
<td>75 MW</td>
</tr>
<tr>
<td>Great Britain</td>
<td>1 MW</td>
<td>50 MW</td>
<td>75 MW</td>
</tr>
<tr>
<td>Nordic</td>
<td>1,5 MW</td>
<td>10 MW</td>
<td>30 MW</td>
</tr>
<tr>
<td>Ireland and Northern Ireland</td>
<td>0,1 MW</td>
<td>5 MW</td>
<td>10 MW</td>
</tr>
<tr>
<td>Baltic</td>
<td>0,5 MW</td>
<td>10 MW</td>
<td>15 MW</td>
</tr>
</tbody>
</table>
Requirements structure

• Operational ranges:
  – Frequency
  – Voltage

• Reactive power capabilities

• Fault-ride-through requirements
Operational ranges

- Power Generating Modules are required to remain connected and operational during specifically defined variations in frequency and voltage at the Connection Point. The grid code specifies this range, with minimum times specified before the generator is allowed to disconnect, depending on the frequency and voltage deviation from the nominal value.

- The values depend on the characteristics of each power system

- The ENTSO-E grid codes give minimum times for each synchronous area, but permit, in some cases, that the relevant TSO can locally demand longer durations
Operational frequency range

Operational Frequency Range

- Continental, Nordic, Baltic
- Ireland
- Great Britain
Operational voltage range

Operational Voltage Range (U<300kV)

Operational Voltage Range (U≥300kV)
Reactive power capabilities

• Essential for controlling the voltage locally

• Voltage changes in a node can be compensated by modifying the reactive power injection or absorption

• Grid codes require reactive power control capabilities from large generators to contribute to voltage stability

• The required capabilities are defined as functions of voltage (U-Q) or active power (P-Q) profiles

• ENTSO-E NC defines an outer envelope, with a specific requirements being defined by the relevant TSO
**U – Q and P – Q profiles**

- **black dash** line from ENTSO-E NC RfG and **blue** line from TenneT grid code for Offshore Power Park Modules.
Fault Ride-Through

- Fault-ride-through (FRT) is the capability of electric generators to stay connected in short periods of abnormal electric network voltage.

- If FRT not present, generators are susceptible of tripping (disconnect) when a fault occurs, leading to loss of generation → frequency collapse → blackout.

- The concept – FRT – applies equally to all generators, but the power electronic interface makes the FRT behavior of wind power fully dependent on control.

- The capability is required for both under-voltage (LVRT) or over voltage (OVRT).
No Fault Ride-Through

Under-voltage ride-through capability

Source: Jan Wenske, Ulrich Beckert, Voltage-induced stresses during Low Voltage Ride Through (LVRT) in the drive train of wind turbines with DFIG, ICREPQ’12, Spain
Under-voltage ride-through capability
Fault ride through – DFIG with crowbar

DFIG system – control and protection

Aerodynamics

Drive train with gearbox

Pitch angle control

Wind turbine

Control mode:
- normal operation
- fault operation
Crowbar effects

- On voltage dip:
  - RSC overcurrents
  - Crowbar activates / RSC disconnects
  - DFG behaves as IC (no control)
  - GSC can still be used as a STATCOM

- Effect of increased crowbar resistance:
  - Improves the torque characteristic
  - Reduces reactive power demand
  - Improves dynamic stability of the generator
Summary

• What is a grid code and why is needed

• Operational ranges – frequency and voltage

• What is fault ride-through requirement