GRID CODE FOR RENEWABLE ENERGIES INTEGRATION IN THE ELECTRIC GRID

2 June, Rabat, Morocco
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The Spanish Grid Code
1. Justification for grid codes & standardization
2. Grid codes-RES challenges
3. Grid code requirements
4. Conclusions
Justification for standardization

• Context
  • Large scale *wind/PV integration* getting more and more interest
  • Need felt by new players for *harmonized* interconnection standards and grid codes
    • Most renewable energy plant will have the capability to generate and/or absorb *reactive power* (MVAr)
    • However, that does *not* mean they will be *grid code compliant*.

• Grid integration effort - purpose
  • Develop electrical interconnection *guidelines and standards* with the aim of building *consensus* among stakeholders on Distributed Energy Resources (DER) and renewable energy system (wind, photovoltaic) *interconnection* to the grid
Why Grid Codes?

• Permit the development and operation of an efficient and economical power system whilst ensuring security of the network as a whole

• Since transmission networks in different parts of the world have different characteristics - the grid code should be developed to meet the needs of that network

• Guarantee the right performance of the electrical system
Standards and practices

- Generally applicable standards (IEEE, IEC,…): design, performance and testing; connection requirements

- Specific standards (wind turbines, photovoltaic,…): design, performance and testing; connection requirements, electric and mechanical performance
  • ENTSO-E = umbrella organisation for European Transmission System Operators (TSOs)

- Utility interconnection regulations (issued by regional grid operators as conditions for connecting DER to the transmission or distribution grid)
The Situation in Spain

- **Geography:** Pensinsula
- **Grid structure:** Low capacity interconnection with European grid
- **Installed renewable power vs. installed total power:**
  - $5 \text{ GW}_{PV}$
  - $24 \text{ GW}_{\text{wind}}$
  - $29 \text{ GW}_{\text{renewable}}$
  - vs. $100 \text{ GW}_{\text{total}}$
- **Maximum load:** $45 \text{ GW}$
Some are specific for RES generation:

- PO 3.7: Controllability of non-manageable RES generation
- PO 12.3, “Requirements for response to voltage dips of production facilities under the special regime”: Voltage dip ride-through capabilities of wind generation

At draft stage:

- PO 12.2, “Technical requirements for wind power and photovoltaic installations and any generating facilities whose technology does not consist of a synchronous generator directly connected to the grid”, P>10 MW. In effect since 2011
- PO 7.5: Voltage control by RES
Grid codes – RES challenges

• As incentive to supply reactive power a bonus or penalty that ranges from -4% to 8% and is calculated as a percentage of a reference tariff (78.441 €/MWh) for a power factor dependent on the demand profile

• During peak load, there is an incentive to supply capacitive power, during off-peak load there is an incentive to supply inductive power

<table>
<thead>
<tr>
<th>Power factor</th>
<th>Bonus (+) or penalty (-) as percentage of reference tariff</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Peak load</td>
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<tr>
<td><strong>Inductive power</strong></td>
<td></td>
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<tr>
<td>&lt; 0.95</td>
<td>-4%</td>
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<td>0.95 – 0.96</td>
<td>-3%</td>
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<td>0.96 – 0.97</td>
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<td>0.97 – 0.98</td>
<td>-1%</td>
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<tr>
<td>0.98 – 1.0</td>
<td>0%</td>
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<tr>
<td>1</td>
<td>0%</td>
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<tr>
<td><strong>Capacitive power</strong></td>
<td></td>
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<tr>
<td>1.0 – 0.98</td>
<td>0%</td>
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<tr>
<td>0.98 – 0.97</td>
<td>+2%</td>
</tr>
<tr>
<td>0.97 – 0.96</td>
<td>+4%</td>
</tr>
<tr>
<td>0.96 – 0.95</td>
<td>+6%</td>
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<tr>
<td>&lt; 0.95</td>
<td>+8%</td>
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</tbody>
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Grid codes – RES challenges

- The installation must remain connected for a certain amount of time according to the following voltage vs. frequency zones.
- The nominal frequency is 50 Hz and it allows a wide continuous frequency range of 48 – 51.5 Hz.
- Wind farms may stay coupled to the grid for frequencies below 48 Hz for no more than 3 seconds.
- The disconnection time for over frequencies (>51.5 Hz) has to be agreed with the TSO.
- The installation must not be disconnected under frequency deviation of ±2 Hz/sec.
- 0,95 ≤ V ≤ 1,05 pu installation: ability to deliver/absorb reactive power in a minimum range to collaborate in the maintenance of the voltage.
- Grid stability: Network response to voltage dips
¿Wind farms subject to unexpected voltage variations?

Voltage dips are voltage drops due to a fault incident (symmetrical or asymmetrical)

- Short-circuits generate instabilities in the grid and/or power disconnections

Impact of 400kV 3ph Fault in Spain: **640km from fault voltage dropped to 360kV (0.9pu)**
Grid codes – RES challenges

- Grid disturbances like voltage sags or swells may lead to tripping of wind and PV power plants.

- Grid codes requirements for RES usually involve the following:
  - Stay connected to the grid even if the voltage drops down to zero for up to 150 ms.
  - Contribute to voltage recovery by injecting reactive current.
  - Rise up the active power after the fault clearance.
  - Low Voltage (LVRT) and High Voltage Ride-through (HVRT) – this is the ability to remain connected to the system following a system event.
  - P & Q limitation during faults and recovery.
  - Reactive current injection (RCI) for voltage support during fault and recovery.
Grid codes – RES challenges

- Do not comply with P.O.12.3 and have to disconnect during voltage dips

- New installations of DFIM include a complete control system supports voltage sags

¡FACTS devices compensate for the reactive power requirement during voltage dips!

- Wind farms with synchronous generators coupled to full converters can tolerate voltage perturbations and rapid voltage dips
Grid code requirements

• Voltage support during dips

The “grid code” (PO 12.3) establishes the required level for Low Voltage Through Capability for mainly wind power plants without disconnection.

Voltage limiting curves at the grid connection point for PVs.
Grid code requirements

• Fault Ride Through Capability: LVRT and HVRT

• No disconnection is allowed within the black area for 1/2/3-phase faults

• No disconnection is allowed within the grey area for 1- and 3-phase faults

• During the whole transient regime, the facility must be able to inject to the grid at least the nominal apparent current
Grid code requirements

• P & Q requirements

• Momentary active or reactive power consumption (< 0.6 pu) is allowed during just the first 40 ms after the start of the fault and the first 80 ms after the clearance of balanced (three-phase) faults

• Momentary active or reactive power consumption (< 0.4 pu) is allowed during just the first 80 ms after the start of the fault and the first 80 ms after the clearance of unbalanced (single-phase and two-phase) faults
Grid code requirements

• Reactive power control

• Similar to AVR in conventional generators

• PV and wind power plants need to supply reactive current for voltages <0.85 pu

• They should not consume reactive power within the operation limits of 0.85 ≤ V ≤ 1.15 pu
Grid code requirements

• Active power control

• Active power injection limited within the grey area
• The active current limitation is a function of the active power before the fault and the voltage level

![Diagram showing active power control](image)

• For voltage levels below 0.5 pu, the active power may be reduced to zero
• For voltages higher than the normal operation, the facility will try to maintain the active power level prior to the disturbance
• The gain of the active current controller should ensure a dynamic response (90% increment) in less than 40 ms for lower voltage figures of $V < 0.85$ pu and 250 ms for $V > 0.85$ pu
Frequency response capability
Generators may be required to automatically adjust power output \( P \) to support grid frequency – increasing power at under-frequency (U), and/or reducing power at over-frequency (O)
Grid codes – analysis and comparisons

Generally similar requirements with variations on:

- Power factor: variable, within the range 0.95 lead to 0.95 lag
- Voltage range - continuous operation: variable, within the range 90 % to 110 %
- Voltage range - transient operation - tripping: variations in levels and durations
- Frequency range – continuous operation: variable, widest 47.5 to 51.5 Hz
- Frequency range – transient operation - tripping: variable in levels and duration
Conclusions

Lessons learnt

• Mature markets with a high penetration of distributed generation yield mature requirements already known from classic generation plants, i.e. **PV is growing up**

• Specific local conditions lead to specific local requirements

• Need for harmonized requirements and reasonable transition periods to provide sustainable growth and increase the DER integration

• The challenge is to adapt the older installations that cannot face the voltage dips and fulfill the new requirements
¡Thank you for your attention!