Integration of Variable Renewable Energy

March 13, 2018
Agenda

- Plan for the week
- What are your primary areas of focus in grid integration of RE?
- Introduction to System Impact Studies
Plan for the week

- Day 1: Understanding your needs and data gathering
- Day 2: Workshop on System Impact Study for the integration of variable renewable energy (VRE), Part 1
- Day 3: Workshop on System Impact Study for the integration of variable renewable energy (VRE), Part 2
- Day 4: Technical standards for interconnection of VRE
- Day 5: Develop coordinated work plan for conducting system impact study and development of interconnection standards
What are your areas of focus?

- Enhancing capacity for system impact study
- Jointly conducting a system impact study of the entire grid with VRE
- Jointly conducting a system impact study for a specific VRE project
- Setting up technical working group (TWG) for developing interconnection guidelines
- System operations and scheduling of VRE
- VRE forecasting
What is different about Renewable Energy?

<table>
<thead>
<tr>
<th>RE production is variable</th>
<th>RE production is uncertain</th>
<th>RE plants behave differently</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Hourly, daily and seasonal variation of energy output</td>
<td>• The energy output of plant depends on weather hence cannot be predicted with high accuracy</td>
<td>• Not synchronous</td>
</tr>
<tr>
<td>• Variations are not synchronized with load, they are independent of load</td>
<td></td>
<td>• Uses power electronics</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Others</td>
</tr>
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</table>
What are the implications of RE variability and uncertainty?

Conventional generators manage load variability/uncertainty with spinning and other reserves.

With RE generation, conventional generators have to manage load + RE production variability and uncertainty.

Conventional generators need flexibility to manage the combined variability and uncertainty.
What are the implications of generator type?

RE generators are unlike conventional generators because they are nonsynchronous.

RE generators do not provide inertia* to grid.
RE generators use power electronics, which leads to injection of harmonics.

Sufficient amount of conventional generation should be dispatched to ensure there is sufficient inertia.
Solutions to Grid Integration of RE

- Fortunately, with over 30 years of experience, solutions to grid integration issues have been found.
- Grid integration issues have been resolved through a combination of solutions:
  - Interconnection requirements for RE generators
  - Upgrades to the conventional grid
  - Upgrades to system operations
## RE Penetration Levels

<table>
<thead>
<tr>
<th>Country/State</th>
<th>RE Penetration (%)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Denmark</td>
<td>33%</td>
<td>97% (wind + solar)</td>
</tr>
<tr>
<td>Germany</td>
<td>12%</td>
<td>74% (wind+bio +solar+hydro)</td>
</tr>
<tr>
<td>Spain</td>
<td>21%</td>
<td>54%</td>
</tr>
<tr>
<td>Portugal⁴</td>
<td>21%</td>
<td>93% (wind)</td>
</tr>
<tr>
<td>USA</td>
<td>4.5%</td>
<td></td>
</tr>
<tr>
<td>USA/Texas</td>
<td>9.9%</td>
<td>38.5% (wind)</td>
</tr>
<tr>
<td>USA/Colorado</td>
<td>13.8%</td>
<td>60.5% (wind)</td>
</tr>
</tbody>
</table>

System Impact Study for Interconnection of RE Projects

- Power systems modeling and analysis:
  - Study the behavior of an existing power network—steady state and stability
  - Predict the behavior of the power network with RE projects—steady state and dynamic
  - Design and plan changes to the existing power network with the goal of:
    - Improving reliability of the network for current and future growth conditions
    - Ensure the system is safe and cost effective
Range of Power Systems Studies

- **Load flow**
- **Short-circuit**
- **Stability studies**
- **System operations**

Typically conducted during system impact study

- **Relay coordination**
- **Variety of special studies:** Harmonics, grounding, etc.

Typically conducted during detailed design of RE power plant
Software Tools

- Load flow
- Short-circuit
- Stability studies
- System operations

- Relay coordination
- Variety of special studies: Harmonics, grounding, etc.

- DIgSILENT, ETAP, PSS, others
- PLEXUS, others
- DIgSILENT, PSS, ETAP, others
Power Systems Model Classifications

Steady state model
- Load flow
- Short-circuit
- Relay coordination
- Harmonic analysis

Time-dependent model
- Transient stability
- Dynamic stability
- Electro-magnetic transient
- Sub-synchronous resonance
- Dispatch studies
- Other types of temporal simulations

Power the Future, Central Asia
Steps in the Analysis Process

1. Data Collection and Quality Check
2. Development of Assumptions
3. Develop scenarios and study cases
4. Create model of the grid
5. Power System Stability Analysis
6. Steady-state: Load flow & Short-circuit analysis
7. Assess Impact
8. Develop Recommendations
Scenarios for System Impact Studies

- Typically the following scenarios are studied, 4 extreme cases:

<table>
<thead>
<tr>
<th></th>
<th>High Load</th>
<th>Low Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Wind/Solar</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>No Wind/Solar</td>
<td>x</td>
<td>x</td>
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</tbody>
</table>

- In each case the bus voltages are computed and checked against allowable range
- Real and reactive power flows are computed, along with losses in transformers, transmission line, generators and other components
Thank You

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