Workshop on
ANALYZING AND MANAGING THE IMPACT OF VARIABLE RENEWABLE ENERGY ON THE GRID WORKSHOP
Tashkent, September 4-5, 2019

What studies should be performed to assess the impact of VRE on Reliability and Stability of the Network?

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Agenda

- Purpose of the study
- Process
- Inputs and outputs
- Questions answered
Purpose of Study 2 (Steady-State) & Study 3 (Dynamic Stability)

• The steady-state analysis is performed to study the flow of active and reactive power flows in a power system network.
  – The output of the analysis includes: bus voltages, active and reactive power generated and consumed, active and reactive power flows through the branches, active and reactive power losses in various elements, loading of conductors, flow of current (magnitude and angle), and other parameters.
  – The analysis is conducted for different scenarios that reflect the operations of the power system under stress.

• The objective of the power system dynamic stability study is to determine the response of the power system to a variety of transient disturbances.
  – Transient stability study examines rotor angle swing, voltage and frequency in response to large disturbances
Study 2: Steady-State Analysis of the Power Network

- Purpose of study 2 is the analysis of impact of VRE on the steady-state operations of the network under normal, N-1 and N-2 contingencies

- The impacts analyzed include:
  - Line loading
  - Voltage levels
  - Active and reactive power flows
  - Short-circuit requirements
  - Harmonics and voltage flicker

- Study 2 is comprised of three sub-studies:
  - Study 2.1: Load flow study
  - Study 2.2: Short-circuit study
  - Study 2.3: Power quality study
Study 2.1: Power Flow Analysis

Also called Load Flow Analysis or Steady State Analysis

- Single line diagram of Network
- Loads: Real and Reactive
- Generation Capabilities
- Voltage magnitude and angle at buses
- Real and Reactive power at generators
- Real and Reactive Power flow in T-lines
• Single-line diagram is developed of the network

• SLD is bus centric representation of the network

• LFA/Steady-state solution is for an instant
  – Generation and loads are specified at each bus
  – Impedances are specified for links between buses
  – For n-bus system the following is modeled--
  – Normally, at (n-1) buses generation and loads are known, and V and δ are variables
  – At the slack bus, V and δ are known, and P and Q are variables

• It is a system of non-linear equations

• Solution methods include: Newton-Raphson, Gauss-Seidel and others
Scenarios for PFA

- Typically the extreme cases are modeled as scenarios:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>High Load</th>
<th>Low Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Wind, No Solar (Basecase)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>High Wind, No Solar</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>High Wind, High Solar</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>No Wind, High Solar</td>
<td>x</td>
<td>x</td>
</tr>
</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
Study 2.2: Short-Circuit Analysis

Short-Circuit Analysis

Load flow analysis
Generator $X'_d, X''_d$
Fault impedances

Fault MVA
Fault current
Post-fault bus voltage
Short-Circuit Analysis

• Faults occur due to short-circuit to earth or between live conductors or broken conductor

• Reasons are lightning, insulation failure, human error, etc.

• Types of faults:
  – 3-phase balanced fault
  – Unbalanced faults: Single line to ground, line-to-line and line-to-ground

• SCA computes the maximum available fault current at the buses or short-circuit power at the buses

• Fault current is used determine the rating of various protection components like circuit breaker relays and fuses. This is to ensure that the protection system can safely withstand and interrupt the increased current flow

• Fault current is also used to determine ratings of panels, switchboards, motor starters and other components. This is to ensure that these components have the rating to withstand fault currents
Study 2.3: Power Quality Study

Power Quality Analysis

- Background harmonics of grid
- Harmonics of VRE plant
- Total Harmonic Distortion
Purpose of study 3 is the analysis of impact of VRE on the dynamic operations of the network under a variety of large disturbances.

The impacts analyzed include:

- Frequency response
- Rotor angle
- Fault ride through

Study 3 is conducted by modeling a variety of disturbances:

- Loss of largest generator
- Loss of largest VRE generator
- Loss of transmission line near the critical VRE interconnection points
- Loss of largest load

Result of the analysis is recommendations for increasing the amount of inertia and primary frequency response (governor controls) to accommodate the proposed amount of VRE.
Study 3: Transient Stability Analysis

- Load flow analysis
- AVR, Governor Control model of Generators
- Transients of components, Fault impedances
- Time variation of Voltage
- Time variation of Frequency
- Time variation of Swing Angle
Transient Analysis

- Disturbances occur constantly in a power system
- Power systems possess inertia to absorb the shock of a disturbance
- Generators have variety of control systems to respond to voltage and frequency changes—Automated Voltage Regulation (AVR) and Governor
- Transient analysis provides an understanding of how inertia, AVR, governor and other components act in response to disturbance
- The results are used to determine critical clearing time of protection systems
Two additional conditions: Each scenario above is studied for two types of clearing of fault: Clearing (after 9 cycles, which is 180ms) and no clearing.

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>NW-NS-HL</th>
<th>NW-NS-LL</th>
<th>HW-HS-LL</th>
<th>NW-NS-LL</th>
<th>NW-HS-HL</th>
<th>NW-NS-HL</th>
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<td>Generation loss of wind plant</td>
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<td>Generation loss of solar plant</td>
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<td>Partial load loss at buses</td>
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<td>Bus fault</td>
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<td>Transmission line fault</td>
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</tbody>
</table>
Result Variables: Illustration with loss of T-line

- Voltages—Generator terminal, bus
- Frequency—Bus
- Active Power—Generator, Transmission line
- Reactive Power—Generator, Transmission line
- Rotor angle—Generator
Study 3 Cost Assessment

1. Assimilate data about grid upgrade requirements caused by VRE from Studies 2 and 3
2. Estimate cost of upgrades required
3. Delineate costs attributable to VRE
4. Finalize cost of VRE integration
Study 2 & 3: Data Requirements from VRE Plants

• Physical data about the plant: Location, capacity, type of generators, number of generators, name of manufacturer and model of generator, physical properties of generator (hub height and rotor diameter for wind generator, panel size and number of panels for solar generator), point of interconnection, type of interconnection, planned commissioning date

• Electrical data about the plant: Generator capability curve (P-Q curve), transformer properties

• Control model and dynamic properties of VRE plant in DIgSILENT Power Factory, or any other software that would be used by PLN to conduct the study. This model should be obtained from the turbine or inverter manufacturer

• Resource data: At least one year of projected 10-minute wind speed, wind direction and generation data
What kinds of questions does Study 2 & 3 answer?

- Is static and dynamic stability maintained?
- What kinds of upgrades will be required to transmission network, including at points of interconnection of VRE, conventional plants and substations:
  - Higher transmission capacity
  - Reactive power compensation
  - Governor controls, AVR, PSS
  - Balancing capacity
  - Protection system
- What kinds of upgrades will be required to control systems like AGC, active and reactive power control of conventional and VRE plants, and other elements of the grid?
- How should generation be made flexible: Procurement of new flexible generation, retirement of old inflexible plants and retrofits of existing plants
- Should planned VRE plants be delayed or relocated because of balancing and other issues?
- What should be the changes to PPA and grid code to clarify issues like active and reactive power control, synthetic inertia, fault ride through and power quality issues?
Develop Recommendations

The final step is to develop recommendations in the following areas:

• Upgrade to the network—increase of transmission capacity on certain lines, reactive power supply at certain nodes, protection system at nodes near VRE plants

• How to maintain sufficient inertial and governor response in the grid

• Grid code and interconnection guideline changes pertaining to power quality
Thank You

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