Western Electricity Coordinating Council
Modeling and Validation Work Group
Renewable Energy Modeling Task Force

Development of Planning Models for Solar PV Systems

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Utility Industry Modeling Needs

• The not-so-distant future

<table>
<thead>
<tr>
<th>Utility</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCE</td>
<td>1350</td>
<td>2822</td>
<td>1540</td>
<td>2180</td>
</tr>
<tr>
<td>NV Energy (S)</td>
<td>469</td>
<td>776</td>
<td>484</td>
<td>980</td>
</tr>
</tbody>
</table>

• Reasonable concerns
  – Within a few years, inverter-based PV generation will displace a non-trivial amount of conventional generation
  – WECC likely to see higher penetration, larger projects
  – Need models for interconnection studies & regional planning
  – NERC reliability standards (MOD)
in the next several slides a slash is needed between Utility/Industry
Utility Industry Modeling Needs

• Planning models are needed for interconnection studies and transmission planning
  – Steady-state power flow (thermal, voltage)
  – Dynamic (transient stability)
  – Short circuit (interrupting capacity, system protection)

• With very few exceptions, utility simulation tools don’t include standard-library models for PV systems
  – At best, project developers provide insufficiently validated, manufacturer-specific, proprietary, user-created models
  – Worse yet, modeling short cuts (e.g., load netting) are used without adequate technical basis
Utility Industry Modeling Needs

• NERC Integration of Variable Generation Task Force (IVGTF) has identified the lack of planning models as major barrier to variable generation integration

“Validated, generic, non-confidential, and public standard power flow and stability (positive-sequence) models for variable generation technologies are needed. Such models should be readily validated and publicly available to power utilities and all other industry stakeholders. Model parameters should be provided by variable generation manufacturers and a common model validation standard across all technologies should be adopted. The NERC Planning Committee should undertake a review of the appropriate Modeling, Data and Analysis (MOD) Standards to ensure high levels of variable generation can be simulated.”

# Type of Planning Models

<table>
<thead>
<tr>
<th>Type</th>
<th>Main Application</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power flow, unbalanced</td>
<td>Power flow (static) simulation of distribution networks. Software also does motor start, protection coord., etc.</td>
<td>FeederALL, SynerGEE, EasyPower</td>
</tr>
<tr>
<td>Power flow, positive sequence</td>
<td>Large-scale power flow simulations of bulk transmission systems</td>
<td>PSS/E, PSLF, ETAP, Power World</td>
</tr>
<tr>
<td>Dynamic, positive sequence</td>
<td>Large-scale dynamic simulations of bulk transmission systems</td>
<td>PSS/E, PSLF, ETAP</td>
</tr>
<tr>
<td>Transient, three phase</td>
<td>Detailed analysis of power system electromagnetic/mechanical and control interaction and performance</td>
<td>PSCAD, Matlab, EMTP-RV</td>
</tr>
<tr>
<td>Short Circuit</td>
<td>Fault analysis protection coordination</td>
<td>Aspen, SynerGEE,</td>
</tr>
</tbody>
</table>
WECC Renewable Energy Modeling Task Force

NERC

WECC

PCC

TSS

Other WGs

Other Standing Committees

REMTF

Other TF

Wind

Solar

Other Sub Comm.
REMTG Mission Statement

• The mission of the REMTF is to achieve the following objectives: (for discussion)
  
  – Develop and validate generic, non-proprietary, positive-sequence power flow and dynamic simulation models suitable for representation of solar and wind generation in large-scale simulations in WECC
  
  – Issue model documentation and recommendations for proper representation of solar and wind systems in large-scale power system simulations
  
  – Coordinate with stakeholder groups to further the technical objectives and disseminate information
PV System Power Flow Models

• Large PV systems
  – Single generator representation
    • Requires “equivalencing” of PV collector system
    • Explicit representation of station transformer
    • Based on WECC Modeling Guide for Wind Generation
  – Use conventional generation with proper reactive limits and reactive control mode
    • Constant PF, constant reactive power, voltage regulation

• Distributed PV Systems
  – Approach TBD
PV System Power Flow Models

• For utility-scale PV
PV System Power Flow Models

• For distributed PV

Model feeder impedance for dynamics (e.g., WECC Composite Load Model)
PV System Dynamic Models

• Basic Specifications *(for discussion)*
  – Approximate aggregate dynamic response of multiple grid-connected inverters in a PV plant
  – Suitable for simulation of during grid events *with constant irradiance*
    • 3-phase faults (up to 9 cycles), 1-phase faults (up to 30 cycles), frequency events, oscillatory events
  – Numerically stable with time steps of ¼ to ½ cycle
  – Includes set of existing and emerging control options & capabilities
    • Volt/Var control options, power control (ramp rate, output limit), frequency support
PV System Dynamic Models

• Basic Specifications (continued)
  – Has user-settable parameters (gains, time constants, etc) for representation of manufacturer-specific hardware
  – Initializes from power flow without special scripts
  – Validated!

• Strong interest in simulating PV output variability in dynamic simulations
  – A module separate from the dynamic model could be used to inject PV power profile (similar to PSLF GENCLS)
    • User-specified P,Q vs. time series
    • User-specified Irradiance vs. time series (user needs to account for effect of tracking, size of plant, etc)
PV System Dynamic Models

• Model Validation
  – Critical part of model development
  – Need to demonstrate that models can match
    • Field recordings
    • Laboratory test
    • Manufacturer high-order (EMTP-type) models
  – Need assistance from manufacturers

• User experience and model testing should guide model improvements over time
A Potential Implementation

• Basic Assumptions
  – PV array is voltage- and irradiance-dependent current source
    • Temperature impacts can be neglected
    • Current response to voltage or irradiance transient is instantaneous (algebraic)
  – Inverters are high-frequency PWM, current-regulated, voltage-source
    • With ¼ cycle time step, current regulator and modulator dynamics may be neglected... perhaps
    • Primary dynamics are due to inverter dc capacitor bank, dc voltage regulator and ac phase lock algorithms
    • Additional dynamics may be introduced to influence real and reactive power ramp rates
A Potential Implementation

- Model connectivity

- PV Array Model
  - DC Voltage
  - DC Current

- Inverter Model
  - D- and Q-Axis Voltage
  - D- and Q-Axis Current
  - Desired Q-Axis Current

- Reactive Power or Voltage Regulator Model

- Network Model (implemented in PSS/E or PSLF)
  - Solar Irradiance
  - Desired Reactive Power or Voltage

A Potential Implementation

- PV array model – represent algebraically (can we really ignore MPPT dynamics for grid disturbances?)

![Graph showing the relationship between array voltage (pu) and array current (pu) with increasing irradiance.](image)
A Potential Implementation

- Inverter model – Similar to WT4 generic wind model
Questions and Discussion