Advanced Power Control of Wind Turbine Generators for Improved Power system Dynamic Performance

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GE W I N D - 1.5 / 1.5s / 1.5sl Series

Main Data:

- **Tower options:**
  - GE Wind 1.5: 67.4/80/85 m
  - GE Wind 1.5s: 67.4/80/85/100 m
  - GE Wind 1.5sl: 61.4/80/85/100 m
  (201 to 328 ft)

- **Rotor diameter options:**
  - GE Wind 1.5: 65.0 m
  - GE Wind 1.5s: 70.5 m
  - GE Wind 1.5sl: 77.0 m
  (213 to 253 ft)

- **Generator capacity:** 1500 kW, 50/60 Hz

- **Control:** Pitch

- **Rotor Speed:** Variable 11-20 rpm

- **Swept area:** 3318/3902/4657 m²
GE Wind Technology

**GE W I N D  -  3.6 Offshore**

Main Data:

- **Tower options:** 100 - 140m (328 to 459 ft)
- **Rotor diameter:** 104 m (341 ft)
- **Generator capacity:** 3600 kW
- **Control:** Pitch
- **Rotor speed:** 8.5 – 15.5 Rpm
- **Swept area:** 7854 m²
2.3 2.5 2.7 Wind Turbines

<table>
<thead>
<tr>
<th>Wind Regime</th>
<th>2.3</th>
<th>2.5</th>
<th>2.7</th>
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</thead>
<tbody>
<tr>
<td>Rated Power</td>
<td>2.3 MW</td>
<td>2.5 MW</td>
<td>2.7 MW</td>
</tr>
<tr>
<td>Hub Heights</td>
<td>100,120m</td>
<td>85m</td>
<td>58, 70m</td>
</tr>
<tr>
<td>Avg Wind Speed</td>
<td>7.5 m/s</td>
<td>8.74 m/s</td>
<td>10.0 m/s</td>
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Design Objectives:

- Common platform IEC I, II, III
- Common 50/60 Hz design
- Best in class energy capture, COE
- Market rollout throughout 2004
Interconnection Issues – Dynamic Performance

- Stability
  - Maintaining Synchronism
  - Damping
- Fault Tolerance/Low-Voltage Ride-Through
- Voltage Regulation
  - Steady-state reactive power capability
  - Dynamic voltage response
  - Flicker
- Variable Power

Problems are particularly challenging for large radially connected projects with low short-circuit ratio systems
Basic Components of a GE Wind Turbine Generator
New projects in Western US illustrate challenges and controls needed for successful system integration

Colorado Green 162 MW

Taiban Mesa 204 MW

~ 2500 km
Low Voltage Ride-Through
- Requirements driven by system needs

Fault # 1 (1-phase-g)
Fault # 2 (3-phase)

Guadalupe 345
34.5 kV
Guadalupe 40+65 MVAR Reactors

Taiban WindFarm
136 x 1.5 MW

Blackwater 200 MW HVDC

230 kV SPS Equiv

~300 km
Low Voltage Ride-Through Factory Test
Unbalanced faults present equipment design and simulation challenge:

- Good dynamic performance for severely unbalanced fault
- High fidelity simulations

Unbalanced faults

GE 1.5 MW Wind Generator

Simulation - vs - Test

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Crisp voltage regulation in weak systems is essential.

Compensation for long cable runs including charging is required.

~20 km 75 km

Individual WTG

Collector Bus

Utility Transmission Bus (POI)

SCR ~3.5
Basic Stability Models - Overall Structure and Data Exchange
Utility System Variables

- Utility Transmission Bus Voltage (pu)
- Total Wind Farm Power (MW)
- Total Wind Farm Reactive Power (MVAr)
- WTG Wind Speed (m/sec)

Volatges and Flows at Utility Point-of-Interconnection:

GE’s Wind Volt-Ampere-Reactive supervisory control, WindVAR, meets system requirements

Comparison: with (red) vs. without (black)

Very clean voltage on the host utility grid bus
Colorado Green Measurements April 28, 2004
Model Philosophy (for Stability Models)
- Simple, but of sufficient detail for utility grid integration studies
- Similar level of detail established in standard practice for other types of power generation
- Avoid multiple model structures.
- Structure and data transportable across simulation platforms (e.g. PSLF and PSS/e)
- Open documentation (structure and data)
- Confirmation from GE Wind on specific projects
Substation transformers usually have FOA rating roughly equal to total MVA of WTGs. Substation collector bus *may* have additional shunt reactive compensation to augment machine var capability.

Unit Transformers are normally 1.75 MVA, 5.8% leakage reactance delta-wye connected padmounts.

The collector system may cover several miles, and have different topologies. Provide an approximate equivalent R & X. Be sure to include charging, if collector system is cable.

For most systems of $N$ machines, model an equivalent transformer and machine as $N$ times one.
The supervisory control will instruct individual machines to adjust their reactive power output in order to regulate system voltage; normally at the point-of-interconnection.

GE 1.5 MW machines have steady-state reactive power capability at their terminals of:
- 0.95 pf overexcited (delivering 490 kVARs to the system)
- 0.90 pf underexcited (drawing 730 VARs from the system)
Summary: Model Development, Validation and Benchmarking

• Development is ongoing
  • GE Wind is committed to providing up-to-date, appropriate fidelity models
  • Equipment and features continuing to evolve quickly
  • Neither model structure nor data are fully mature
• Validation of PSLF model
  • Detailed models validated against equipment tests
  • Excellent agreement with detailed, validated models
    • Generator, converter, and controls
    • Mechanical system and controls
  • Model sufficiently accurate for grid studies
    • Accuracy comparable with models of other power system equipment
  • Model available to all licensees now
• Validation of model on other software platforms enabled by benchmark case documentation
• GE Energy Consulting is committed to implementation of models for other WTGs into PSLF
Conclusions

Transmission owners and operators have legitimate concerns about potential adverse impacts of wind generation on the grid.

Many of those concerns are well addressed by the latest wind technologies.

Proper system engineering and cooperation with the host grid owners and operators will limit problems for individual projects.

Wind technology must continue to evolve to meet an expanding spectrum of power system needs.