Grid Interface for Wind
- Advanced Functions

ARPA-e
Green Electricity Network Integration Workshop

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Renewables Growth – Where we are

Global Wind & PV annual installations

- Solar PV
- Wind

Last decade .... key drivers

Technology
- Reliability & Efficiency ↑

Cost
- ↓ 85% in last 25 years

Policy
- EU: 20% renewables by 2020
- US: PTC, ... 33 states have RPSs
Renewables – Where we want to go

UK: 20% Renewables by 2020

Germany: 20% Renewables by 2015

Spain: 20 GW Wind by 2011

EU: 20% Renewables by 2020

China: 30 GW Wind by 2020

India: 12 GW Wind by 2012

Japan: 3 GW Wind by 2010

Targets in 73 countries

US: 33 states have Renewable Portfolio Standards
California: 33% Renewables by 2020.

DOE Study: 20% wind energy by 2030
Wind Integration Challenges Are Broad

Longer time scale problems – grid dispatchability

Shorter time scale - dynamics and transients (power electronics)
Challenges for Wind Integration

• **Interconnection**
  • Performance through voltage sags
  • Variable power – freq reg, ramp rates, curtailment...

• **Intermittency**
  • Must be overcome with dispatchable energy assets
  • Unit commitment based on day-ahead forecasts
  • Regulation costs

• **Lack of Inertia**
  • Penetration of wind displaces conventional assets with inertia

• **Non-collocation with load**
  • Long-distance T&D makes economics more challenging
State-of-the-Art for Wind Integration

Application Characteristics

<table>
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<tr>
<th>Single WTGs</th>
<th>Large Farms</th>
<th>Multiple Farms</th>
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<tbody>
<tr>
<td>Low Penetration</td>
<td>High Penetration</td>
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Performance Requirements

Basic

- Anti-islanding
- O/U Voltage
- Overcurrent
- O/U Frequency
- Voltage control (old DVAR)

Advanced

- Zero-Power Voltage Control
- Coordinated Voltage Control (WindVAR, WFMS)
- PF control
- None

Protection

- Active Anti-islanding, Torsional, others
- Coordinated Voltage Control (WindVAR, WFMS)
- Voltage control (old DVAR)
- None

Volt/VAR Control

- None

LVRT

- LVRT with controlled current injection
- Zero VRT – no trip (e.g. Quebec, Western Australia)
- LVRT – no trip (e.g. Taiban, E-ON)
- None

Active Power Control

- Inertia
- Frequency Regulation
- Curtailment
- None
GE Wind – Grid Integration Features

Focus Areas:

Security
• Grid fault tolerance and recovery

Operability
• Voltage regulation
• Active power controls

Planning
• Assessment and planning tools
Voltage Regulation

- Regulates Grid Voltage at Point of Interconnection
- Minimizes Grid Voltage Fluctuations Under Varying Wind Conditions

Measurements: 162MW wind plant

Wind Turbine
Generator

kW

Converter Control

kVAR

Transformer

34.5kV

Substation

Main Transformer

POI

45 mi.

230kV

WFMS

kW

kVAR

Wind Plant Power Output

Average Wind Speed

Voltage at POI

Wind Plant Voltage

Average Wind Speed

Voltage Regulation
Like A Conventional Power Plant
Voltage Ride - Through Capabilities

- Remains on-line and feeds reactive power through system disturbances
- Meets present and emerging grid requirement with Low/Zero Voltage Ride Through (LVRT/ZVRT) capability
- Meets transmission reliability standards similar to thermal generators

Fault Recovery

- Voltage recovery better than conventional generator

Synchronous generator swings dramatically

Power recovers to pre-disturbance level in <200ms

3-Phase, 200ms, Zero Voltage Fault from WINDTEST report WT5491/06

Voltage at Point of Interconnection (Percent)

Time (seconds)

Fault Recovery

- Voltage recovery better than conventional generator

Synchronous generator swings dramatically

Power recovers to pre-disturbance level in <200ms

3-Phase, 200ms, Zero Voltage Fault from WINDTEST report WT5491/06
Active Power Controls

Typical Grid Requirements

- Ramp rates
- Power curtailment
- Power droop w/ frequency
Future Challenges and Directions
High Penetration Grid Dispatchability

Wind Plant...
- Coordination with grid controls
- Effective use of forecasting

+ Balancing Generation...
- Highly maneuverable
- Fast start/stop
- Good heat rates at partial load

+ Energy Storage Technologies...
- Variable speed pumped hydro
- Compressed Air, Batteries, Flywheels

+ Load Participation
- Create new loads during low load/high wind periods such as water desalination/purification
Power Conversion: Migration to Higher Voltage

- **Current Wind Turbines**
  - 690 V electrical system
  - Significant Cabling Weight/Cost
  - Large filters

- **High frequency, High voltage conversion**
  - lighter cables
  - big benefit in offshore applications
  - need HV SiC devices?

**Present**

- 690 Vac, Var. Freq.
- 35 kVac, 60 Hz

**Future?**

- High Frequency Conversion
- 690 Vac, Var. Freq.
- 35 kVac, 60 Hz
Power Conversion: DC interface for offshore wind

Present

- Reduce power conversion steps
- Higher efficiency + Lower cost
- Technical challenges: Power Electronics, Insulation, Protection
Enabling Technologies
- Advanced Power Semiconductors & Passives

Si IGBT assembly, 10 kV, 120 amps
Conduction drop > 12 V, Switching time > 2 μs

SiC Module, 10 kV, 120 amps (Cree, Powerex)
Conduction drop < 6 V; Switching time < 100 ns

220 kVA, 60 Hz dry-type xfmr

DARPA/ONR HPE program: 10 kV Silicon Carbide MOSFETs, 20 kHz Magnetics
ARPA-e ADEPT program: on-going program for 15kV IGBTs, ...

Can enable ->
More Efficient & Reliable, Compact Power Electronic Interface for Renewables!
Looking Ahead

• Tremendous control flexibility through power electronics – goal should be for a grid that is more stable with renewable energy sources

• EVs/ PHEVs .. potentially radical impact on the grid

• Great challenges & opportunities in grid integration of renewables and new loads through power electronics