The Roles of Power Electronics in Renewable Energy Deployment

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Credit: NREL – pix library
Outline

• Introduction
• Renewable energy resources
• Grid integration
• Power electronics control
• Environment
Introduction

• Applications
  ➢ mW or MW level
  ➢ Isolated or grid connected

• Variability of the source
  ➢ Temporal (seconds, hour, day, week, season)
  ➢ Spatial (continental, local, plant)

• Large area coverage – Diversity (resource and electrical characteristics)

• Operation
  ➢ Normal/abnormal
  ➢ Balanced/unbalanced
Introduction

PV Plant (5~50 MW)

Rooftop PV (1~30 kW)

Mobile 9-kW PV System

Bechler Meadows Ranger Station

Yellowstone National Park
Wind Resource – Midwest

**Spring Peaking**

Wind Resource – West Coast

**Summer Peaking**

24-Hour Wind Resource

- **Low Output**: 8 a.m. – 14 p.m.

24-Hour Solar Resource

- **High Output**: 8 a.m. – 12 p.m.
Resources

U.S. Wind Resource

Offshore Wind Resource

Solar Resource

Wind Speed at 90 m

Synchronous Generator (left) vs. Wound Rotor Induction Generator (right)

What will happen if there is a sudden disturbance in the transmission network?

To power AC-DC-AC power converter to operate WTG in variable speed
**Conventional Power Plant vs. Renewable Energy Power Plant**

*Generator Sgen 4,000-W (Siemens) 1,300 to 2,235 MVA*

*Wind Turbine Generator 1-6 MW*

*Plant Diversity*

[Image of a modern steam turbine generator](http://www.energy.siemens.com/hq/en/)

[Image of wind turbines](Credit: David Hicks / NREL / 18454)

[Diagram of grid connections](Credit: Wikipedia)
**Type 1 Wind Turbine Generator (1% Slip)**

- Wind Rotor
- Gear-Box
- Squirrel Cage Induction Generator
- Soft Starter
- Transformer
- PFC Capacitors

**Type 2 Wind Turbine Generator (10% Slip)**

- Wind Rotor
- Gear-Box
- Wound Rotor Induction Generator
- Soft Starter
- Control Signal
- External resistors
- Transformer
- PFC Capacitors

**Type 3 Wind Turbine Generator (+30% Slip)**

- Pitch Controlled Wind Rotor
- Gear-Box
- DFIG
- Power at super-synchronous speeds
- Power at sub-synchronous speeds
- Control Signal
- Crow-bar
- Power/Frequency Converter
- Transformer
- Grid

**Type 4 Wind Turbine Generator (Full Conversion) (100% Slip)**

- Pitch Controlled Wind Rotor
- PMSG
- Power/Frequency Converter
- Transformer
- Grid
Examples of Renewable Energy Resources
Credit: Dennis Schroeder / NREL / 27806

10 modules per string at 3 kW; 380-430Vdc
2 strings per row at 6kW

380-430Vdc

165 kVA 3 phase 60Hz 208Vdc

300Vdc 150kWdc

Inverter

DC side

AC side

Representing 89 Nodes

66 MVA 3 phase 60Hz 34.5kV/110kV

PV + MPPT

Inverter

AC–480V

PV + MPPT

Inverter

AC–34.5kV

660 kVA 3 phase 60Hz 480V/34.5kV

165 kVA 3 phase 60Hz 208/480Vdc

3 phase AC 60Hz Grid

25 rows at 150kW

3 phase AC 60Hz Grid

650 kVA 3 phase 60Hz 480V/34.5kV

PV Array

DC–DC Converter As MPPT

PV + MPPT

Inverter

660 kVA 3 phase 60Hz 480V/34.5kV

PV + MPPT

Inverter

165 kVA 3 phase 60Hz 208/480Vdc

PV + MPPT

Inverter

N1
Grid Integration

- Interconnection
- Operation
- Standards – Grid codes
- Ancillary services (inertial response, frequency and governor response, reserves)
Transmission to other utilities
115kV and higher

Utility Scale Wind Farms (above 10 MW)

Small Wind Farm (less than 10 MW)

Single Large Wind Turbine

Small Wind Turbine

Step-up transformer

Step-down transformer

Subtransmission Customers

Distribution Customers

120-480 V

Wind Farm Interconnections

Distributed Interconnections per IEEE-1547

Credit: NREL’s TGIG presentation archive.
Real and Reactive Power Balance
(To Keep Frequency and Voltage Constant)

- Base Loads
- Adjustable Loads
- Variable Loads
- Power Losses
- Reserves
- Storage
- Freq $^{\text{UP}}$
- Freq $^{\text{Down}}$
- Real Power
- Inductive Load
- Induction Motors/Generators
- Switched Capacitors
- Synchronous Generators/Condensers
- Line Inductance
- Line Capacitance
- Reactive Power
- Voltage $^{\text{UP}}$
- Voltage $^{\text{Down}}$
- Static Compensation

Real and Reactive Power Balance
(to keep frequency and voltage constant)
Fault Ride-Through Capability

- Wind power plants should be able to stay online under transient faults/disturbances.
- The voltage should tolerate 0 p.u. for 15 ms (9 cycles).
- Wind power plants should be able to regulate the power factor between 0.95 leading/lagging.
- Wind power plants should have a SCADA system to allow remote access and monitoring.

Voltage vs. Maximum Clearing Time as Described in IEEE 1547

<table>
<thead>
<tr>
<th>Voltage range (% of base voltage(^*))</th>
<th>Clearing time (s)</th>
<th>Clearing time: adjustable up to and including (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V &lt; 45</td>
<td>0.16</td>
<td>0.16</td>
</tr>
<tr>
<td>45 ≤ V &lt; 60</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>60 ≤ V &lt; 88</td>
<td>2</td>
<td>21</td>
</tr>
<tr>
<td>110 ≤ V &lt; 120</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>V ≥ 120</td>
<td>0.16</td>
<td>0.16</td>
</tr>
</tbody>
</table>

\(^*\) Under mutual agreement between the EPS and DR operators, other static or dynamic voltage and clearing time trip settings shall be permitted.

\(^b\) Base voltages are the nominal system voltages stated in ANSI C84.1-2011, Table 1.
Power Electronics Control

- Generator level
- Plant level
- Transmission level
Maximize Energy Capture

Load Control

Gearbox Preservation

Provide Active Damping to Power System Network

Pitch Controlled Wind Rotor

Inertial Response

Spinning Reserve

Short/Long-Term DC Distributed Storage

At the Generator Level

Power Quality

Real and Reactive Power Control

Transformer

Grid

DFIG

Control Signal

Power at super-synchronous speeds

Power at sub-synchronous speeds

Crow-bar

Power / Frequency Converter
Maximize Energy Capture

Virtual Inertia Spinning Reserve

Provide Active Damping to Power System Network

3 phase AC 60Hz Grid

Real and Reactive Power Control

Short/Long-Term DC Distributed Storage

At the Generator Level

650 kVA 3 phase 60Hz 480V/34.5kV
• Many (hundreds) of wind turbines (1 MW to 5 MW each)
• Prime mover: Wind (wind turbine) – Renewable (free, natural, pollution free)
• Controllability: Curtailment
• Predictability: Wind variability based on wind forecasting, influenced more by nature (wind) than humans, based on maximizing energy production (unscheduled operation).
• Located at wind resource; may be far from the load center.
• Generator: Four different types (fixed speed, variable slip, variable speed, full converter) – Non-synchronous generation
• Types 3 and 4: Variable speed with flux-oriented controller (FOC) via power converter. Rotor does not have to rotate synchronously.

At the Plant Level
Inertial Response from a Wind Turbine

At the Plant Level
Variability

At the Transmission Level

Wind Power Generator

Storage

ΔP, ΔQ

VAR Compensation to Help Regulate Voltage

Δδ, ΔV

Other Generators

Δδ, ΔV

(Load Center)

Wind
Transmission Constraints

Thermal Limit (Thin Wire)

Stability Limit (High Impedance, Long Distance, Weak Grid)

At the Transmission Level
Environment
Lightning Protection


Conclusions

• Cost reduction in the past 20 years
• Many and diverse opportunities for Power Electronics
  ➢ Generation, transmission, and distribution
• Know the limitations
  ➢ Thermal, magnetic, electric (voltage, current) etc.
• Know the applications
  ➢ Environment: Ocean, land-based, isolated, clusters
  ➢ Opportunities to work in parallel (PV – Wind – CSP)
• Leverage existing and future technologies
  ➢ Other industries (drives, transportation, ship building)
  ➢ Modern technologies (smart control, wireless, condition monitoring, cyber physical and security, synchrophasor, market driven)

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