Technology (continued)
Hubs
Drive Trains
Generators
Towers
Foundations
Lightning Protection
Obstruction Marking

Paul Gipe, wind-works.org
Hubs
Struts & Stays

Blade with stays, windmill A

8 m  12 m

Blade, windmill B

Paul Gipe, wind-works.org
Hubs
Teetered-Delta 3-Butterfield

Paul Gipe, wind-works.org
ESI 80, Palm Springs, CA
Hubs
Teetered-Pitch Linked

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Windflow 500
Gebbies Pass, NZ
Hubs
Cantilevered

Paul Gipe, wind-works.org
Hubs
Fixed (But Adjustable) Pitch

Paul Gipe, wind-works.org
Hubs
Variable Pitch

Paul Gipe, wind-works.org
Hub (Blade) Bolts

Paul Gipe, wind-works.org
Drive Trains
Traditional Danish

- Front Bearing
- Main Shaft
- Gearbox
- Generator
Drive Trains
Main Shaft-Traditional

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Drive Trains
Integrated (Small-Medium)

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Drive Trains
Integrated (Large)

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Drive Trains
Dual-Output Gearboxes

Paul Gipe, wind-works.org
New Drive Trains

Paul Gipe, wind-works.org
New Drive Trains

Fuhrlander 2 MW
Drive Trains
Multiple-Output Gearboxes

© Clipper Wind

Paul Gipe, wind-works.org
Buffalo, New York
Drive Trains
Direct-Drive Permanent Magnet

Paul Gipe, wind-works.org
Generators

- DC Generators
- Alternators
- Induction (Asynchronous) Generators
- Wound-Rotor or Doubly-Fed Induction Generators
- Direct-Drive Ring Generators
- PMG
  - Small
  - Large
Generators
Dual-Induction

• Dual Speeds
• Simple
• Rugged
• Cheap

Paul Gipe, wind-works.org
# Generator Pole Switching (RPM)

<table>
<thead>
<tr>
<th></th>
<th>50 Hz</th>
<th>60 Hz</th>
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<tbody>
<tr>
<td>4-pole</td>
<td>1500</td>
<td>1800</td>
</tr>
<tr>
<td>6-pole</td>
<td>1000</td>
<td>1200</td>
</tr>
</tbody>
</table>

Paul Gipe, wind-works.org
Generators
Wound-Rotor (Doubly-Fed)

Paul Gipe, wind-works.org
Generators
Direct-Drive (Large)
Generators-Variable Speed

- Better Performance
  Mostly Hype
- Lower Loads
  Major Plus in Large Turbines
- Ability to Correct Power Factor
- More Expensive
- More Complex
- And, Don’t Forget the “Patent”
Generators-Variable Speed

- “Opti” Slip (10%)
- Doubly Fed Generators
  Widely Used in Germany
  Inverter Handles Only a Portion of Power
- Full Variable Speed
  Inverter Handles Full Power
  Full Benefits of Variable Speed
  Enercon, Lagerwey, & PMGs

Paul Gipe, wind-works.org
Towers

- Guyed
  - Small Turbines
  - Large Turbines
- Freestanding (Cantilevered)
  - Lattice
    - Small Turbines
    - Large Turbines
  - Tubular
  - Concrete
- Hinged

Paul Gipe, wind-works.org
Towers-Guyed Small Turbines

Paul Gipe, wind-works.org
Towers-Guyed Lattice
Small & Medium Wind Turbines

Paul Gipe, wind-works.org

© Vergnet
Towers-Guyed Large Wind Turbines

Paul Gipe, wind-works.org
Towers-Freestanding
Small Turbines

Paul Gipe, wind-works.org
Towers-Lattice

Paul Gipe, wind-works.org

© Nordex
Towers-Lattice

Paul Gipe, wind-works.org
Towers-Tubular Small Turbines

Paul Gipe, wind-works.org
Towers-Tubular Medium & Large Wind Turbines

Paul Gipe, wind-works.org
Towers-Concrete

© Risø

Paul Gipe, wind-works.org
Towers-Hinged Small Turbines

Paul Gipe, wind-works.org
Hydraulic Tower

Paul Gipe, wind-works.org
Hydraulic Tower

Paul Gipe, wind-works.org
Towers-Hinged Medium Turbines

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Towers-Novel

- Octahedron
- Farm Silos
- Roof Tops
- Trees

Yes, Really

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Towers
Pendant Cables & Raceway

Paul Gipe, wind-works.org
Foundations

- Piers
  - Lattice Towers
- Spread Footing
- Monopile
  - Solid
  - Hollow with Fill

Paul Gipe, wind-works.org
Foundation Monopile Hollow with Fill

Paul Gipe, wind-works.org

© Neal Emmerton
Foundation Bolts

Paul Gipe, wind-works.org
Foundation Bolts

Paul Gipe, wind-works.org
Lightning Protection

- Receptors at Blade Tip
- Cabling Through Blade
- Nacelle Lightning Rod
- Slip Rings & Jumpers
- Grounding (Earthing)
  Some Areas Require Ground Net
- Large Turbines will be Hit Periodically
Lightning Protection
Nacelle Lightning Rod

Paul Gipe, wind-works.org

© Nordex
Lightning Protection
Tower Section Jumpers

© Lagerwey

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Lightning Protection

Windflow 500
Gebbies Pass, NZ

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Obstruction Marking

- **Height Limits**
  - 200 ft USA
  - 100 m Europe

- **Lights**
  - Red (night?)
  - Strobe (Day)
  - Impacts

- **Painting**

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Obstruction Marking

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Operations & Maintenance

• Large Turbines
  Formerly by Quarter
  Now Once/year

• Small Turbines
  Once/year

• Large Turbines
  Complex & Rotating Schedules
  Visual Inspections
  Moving Parts

• Electronic Controls
  Largest Single Cause of “Nuisance” Trips

Paul Gipe, wind-works.org
Good Housekeeping

• Little Items Make a Big Difference on a Million-Dollar Wind Turbine!
Operations & Maintenance
Check Welding

© Lagerwey

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Operations & Maintenance

- Condition Monitoring
  Large Turbines
- w/o Condition Monitoring, No Insurance
- w/o Insurance, No Financing
- Enercon “Partner” Program
  Other Manufacturers Following Suit

Paul Gipe, wind-works.org
**Operations & Maintenance**

As Percentage of Total Investment

<table>
<thead>
<tr>
<th></th>
<th>Years 1-10</th>
<th>Years 10-20*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>150-300 kW</strong></td>
<td>1-3%</td>
<td>4-7%</td>
</tr>
<tr>
<td><strong>500-600 kW</strong></td>
<td>1-2%</td>
<td>4-5%</td>
</tr>
</tbody>
</table>

*Includes prorated 20% reinvestment after year 10.
Source: IEA, EMD 2001

Paul Gipe, wind-works.org
Fall Protection

- Body Harness
- Shock-Absorbing Lanyard
- Double-Acting Snap Hook
- Positioning Belt is Only for Positioning

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Safety

- Helmet
- Gloves
- Harness
- Radio

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Aerial Lifts

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Ladder Fall Protection

- fall protection device
- climbing cable
- lock
- hook

© Lagerwey

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Ladders

Paul Gipe, wind-works.org
Steps

Paul Gipe, wind-works.org
Secure Rotor Locking

Rotor Hub

© Lagerwey

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Secure Rotor Locking

Paul Gipe, wind-works.org

© Nordex
Secure Rails & Attachments

© Nordex

Paul Gipe, wind-works.org
Access Doors

© Nordex

Tararua, NZ

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Secure Access Doors

It’s Windy Out There

- **Lock to Prevent Unauthorized Access**
- **Latch to Prevent Door Closing**
- **Interior Release To Prevent Confinement**
- **Ventilation Louvers**

© Lagerwey
Safety...

- Anti-Climb Guards
- Shaft Guards
- Two-Person Crews
- Regular Reviews
- Myth Busting
  - “Never Fall Ascending”
  - “Want to Jump Free”