Wind Energy 101: The Power in Wind

Virginia Center For Wind Energy
at JAMES MADISON UNIVERSITY.
Wind Basics

Wind is actually solar energy!

Wind is the flow of gases on a large scale resulting from the heating and cooling of Earth and its atmosphere as well as the planet’s rotation.

Types of Wind

- Global-Scale Winds
- Synoptic-Scale (Regional) Winds
- Mesoscale (Local) Winds
Global Winds

Areas of rising and sinking vertical air motions that set up the semi-permanent pressure zones.

- the subtropical high pressure cells
- inter-tropical convergence zone
- sub-polar lows

Major bands of horizontal winds that direct the movement of air masses.

- including the polar easterlies
- mid-altitude prevailing westerlies
- easterly trades of the tropics
Regional – Air Masses

• The mix of land and water on Earth's surface leads to the regional production of air masses with differing characteristics.

• Air masses are large, relatively uniform “blocks” of air that have taken on the characteristics of the underlying surface.
Regional Fronts & Jet Streams

Polar front jet stream, average summer position (60 km/hr)

Polar front jet stream, average winter position (125 km/hr)
Local - Lake and Sea Breezes

Sea Breeze Summer Scenario

- Early morning
- Mid morning
- Late morning
- Noon
- Early evening
- Late evening/night

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Local - Mountain and Valley Breezes

Bernoulli Principle

Decrease in fluid pressure means increase in fluid speed.
Power is a reference to the potential instantaneous output of a device measured in Kilowatts (kW).

Energy is a reference to the output of a device over time measured in Kilowatt Hours (kWh).

The power in wind can be described using the following equation:

\[ P = \frac{1}{2} \rho A v^3 \]

- \( \rho \) = Air Density
- \( A \) = Area
- \( v \) = Wind Velocity/Speed
The Power in Wind

Air Density

• Changes with air temperature.
• Changes with pressure.
• Density will decrease with increased humidity.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Temperature (°F)</th>
<th>Density of Dry Air (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>95</td>
<td>1.1455</td>
</tr>
<tr>
<td>30</td>
<td>86</td>
<td>1.1644</td>
</tr>
<tr>
<td>25</td>
<td>77</td>
<td>1.1839</td>
</tr>
<tr>
<td>20</td>
<td>68</td>
<td>1.2041</td>
</tr>
<tr>
<td>15</td>
<td>59</td>
<td>1.2250</td>
</tr>
<tr>
<td>10</td>
<td>50</td>
<td>1.2466</td>
</tr>
<tr>
<td>5</td>
<td>41</td>
<td>1.2690</td>
</tr>
<tr>
<td>0</td>
<td>32</td>
<td>1.2920</td>
</tr>
<tr>
<td>-5</td>
<td>23</td>
<td>1.3163</td>
</tr>
<tr>
<td>-10</td>
<td>14</td>
<td>1.3413</td>
</tr>
<tr>
<td>-15</td>
<td>5</td>
<td>1.3673</td>
</tr>
<tr>
<td>-20</td>
<td>-4</td>
<td>1.3943</td>
</tr>
<tr>
<td>-25</td>
<td>-13</td>
<td>1.4224</td>
</tr>
</tbody>
</table>
Area is proportional to the power available in wind. Increasing the area by a factor of 2 will increase the available power by a factor of 2!
The Power in Wind

Wind Speed: As wind speed increases, power increases by a factor of 3.

\[ P = \frac{1}{2} \rho A v^3 \]

Example: Consider two sites. One site with a wind speed of 10 mph and another site with a wind speed of 12 mph.

\[
\frac{P_2}{P_1} = \left(\frac{V_2}{V_1}\right)^3 \quad P_2 = \left(\frac{12}{10}\right)^3 P_1
\]

\[
P_2 = (V_2/V_1)^3 P_1 \quad P_2 = 1.73 P_1
\]

There is only a 20% increase in wind speed, but a 73% increase in available power between the sites.
The Power in Wind

**Height:** Wind speed, and therefore the power in wind, is affected by height.
The Power in Wind – Turbulence

- Obstacles create turbulent wind
- Decreased performance – breaks lift
- Increased wear and tear (maintenance costs)
- Rule of thumb: install turbine 20 - 30 ft higher than anything within 500 ft
Wind Energy 101: Wind Turbines

Virginia Center For Wind Energy
at JAMES MADISON UNIVERSITY
**Wind Turbine Terminology**

- **The Industry**: defines by generating capacity
  - Small wind < 100 kW, Large wind > 100 kW

- **The Public**: defines by physical size
  - How big/tall is it? How many turbines?

- **Net-metered**

- **Grid-connected, grid-tie**

- **Nameplate capacity**: rated maximum output

- **Capacity factor**: Ratio of energy generated by system over potential the system could have generated if it ran at 100% nameplate capacity over the same period.

- **Efficiency**: Ratio of energy generated by a system over the potential the system could have generated if it captured 100% of the available resource.
**How does it work?**

**Wind Turbines:** A wind turbine captures the kinetic energy in wind converting it to mechanical energy via the spinning rotor and then to usable electrical energy by way of the alternator.

<table>
<thead>
<tr>
<th>Component</th>
<th>Rotor</th>
<th>Gearbox</th>
<th>Generator</th>
<th>Converter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>45-52%</td>
<td>95-97%</td>
<td>97-98%</td>
<td>96-99%</td>
</tr>
</tbody>
</table>

**Betz Limit:** The theoretical maximum amount of kinetic energy that can be captured by a wind turbine is 59.3%.
### Types of Turbines – Size & Capacity

<table>
<thead>
<tr>
<th>Category</th>
<th>Nameplate Capacity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onsite</td>
<td>≤ 10 kW (residential) ≤ 500 kW (commercial)</td>
<td>These systems are small, either stand-alone or net metered, and would probably involve only 1 turbine.</td>
</tr>
<tr>
<td>Community</td>
<td>≤ 10 MW</td>
<td>Community-scale projects are typically either net metered or connected to the local distribution network, but could be connected to transmission. These projects are typically owned by and serve the community. They would probably involve less than 5 turbines. In the Midwest, there are community wind systems that are also “utility scale” using our definition.</td>
</tr>
<tr>
<td>Utility</td>
<td>&lt; 50 MW</td>
<td>Industrial-scale wind power projects are most often developed by a company that either will own or sell the project for the purpose of realizing a return on their investment.</td>
</tr>
<tr>
<td></td>
<td>≥ 50 MW</td>
<td>An industrial-scale wind power project equal to or greater than 50 MW nameplate capacity is subject to the full approval process by the Commonwealth’s State Corporation Commission.</td>
</tr>
</tbody>
</table>
Types of Turbines – Size & Capacity
Types of Turbines – Drag vs. Lift

Drag

Lift

Tip Speed Ratio: The ratio between the rotational speed of the blade tip and the actual speed of the wind.
Types of Turbines – HAWTs & VAWTs

Horizontal Axis Wind Turbine

• Efficient
• Durable
• Proven Design
• Require a Yaw System

Vertical Axis Wind Turbine

• Innovative/Modern
• Quiet
• Less affected by turbulence
• Can be installed on roof or short tower
• Easy to access electronics/generator
• Lower cut-in speed
• Accepts winds from any direction
• Aesthetically pleasing, “Sexier”
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Types of Turbines – Upwind vs. Downwind

**Upwind**

- Eliminates potential for tower shading.
- Require a yaw mechanism to orient into the wind.
- Rotors must be more rigid.
- Over-speed protection generally by “furling,” mechanical braking, or electromagnetic braking, or blade pitching.

**Downwind**

- Can have influence of tower shading.
- Orient themselves into the wind via coning.
- Rotors can be more flexible
- Over-speed protection generally by mechanical braking, electromagnetic braking, or blade pitching.
Types of Turbines – Active vs. Passive Yawing

Active Yaw Control

Utilizes an electrical yawing mechanism using data acquired from onboard sensors and computers to automatically or manually orient into the wind.

Passive Yaw Control

Orients itself into the wind via mechanical system built into the design and engineering of the turbine.
Types of Turbines - Over-speed Protection

**Furling**

**Blade Pitching**

**Electromagnetic & Mechanical Braking**
Types of Turbines – Number of Blades

• Cheaper
• Less frequent flickering
• Lower noise
• Balance Issues

• Can generate more lift
• Balanced Rotor
• More blades costs more $$$
• Possible wake effects
• Heavier

The Compromise
What Turbine Goes Where

Onsite Systems

A 1-kW Bergey in Floyd, VA
Height: ~ 45 ft

A 20-kW Westwind in Ireland
Height: ~ 60 ft
What Turbine Goes Where

Community Wind Systems

A 100-kW Northwind in MA
Height: ~ 120 ft

A 50-kW Atlantic Orient in VT
Height: ~ 80-90 ft
What Turbine Goes Where

Community Wind Systems

A 660-kW community system in Hull, MA, less than 10 miles from Boston.
What Turbine Goes Where

Utility Wind Systems

Bear Creek Wind Power Project near Wilkes-Barre, PA, as seen from the PA Turnpike. These are 2.0 MW Gamesa Turbines.
What Turbine Goes Where

Utility Wind Systems

Wind Farm in West Texas
What Turbine Goes Where

Utility Wind Systems

Middelgrunden Offshore Wind Farm - Denmark
Wind Energy 101: Siting
Phases of Wind Project Development

- **Prospecting Phase**
  - Early Preliminary Analysis on potential sites.
  - Lease Blocks (Offshore)

- **Planning Phase** *(1 – 5+ years)*
  - Project Proposals
  - Permitting
  - Environmental Assessment
  - Wind Resource Assessment
  - Financial Planning
  - Project Layout
  - Interconnection Agreements
  - Time in this phase differs depending on scale of project.
    - Community Outreach/Acceptance

- **Construction Phase** *(1 – 2 years)*

- **Operations and Maintenance**

- **Decommissioning**
  - Dismantle or Refurbish equipment at end of typical life cycle.
How Do You Site a Turbine

- Wind resource
- Current land use
- Environmental impacts
- Government regulations
- Cost of wind farm
  - Distance to nearest transmission source and nearest load
  - Road access
- Economic payback
- Community opinion
  - Aesthetics
- Noise
- Flicker issues
- Spacing of turbines
- Much, much more!

Mountaineer Wind Energy Center, WV
www.communityenergy.com
### What Turbine Goes Where

<table>
<thead>
<tr>
<th>Wind Class</th>
<th>Potential for Wind Development</th>
</tr>
</thead>
</table>
| Class 1 or 2 | • Marginal for onsite  
                  • Unsuitable to marginal for community-scale  
                  • Unsuitable for utility-scale               |
| Class 3     | • Appropriate for onsite  
                  • Marginal to appropriate for community-scale  
                  • Generally unsuitable for utility-scale     |
| Class 4     | • Appropriate for onsite or community-scale  
                  • Marginal for utility-scale                   |
| Class 5+    | • Appropriate for all scales                        |

Class 1 = 0.0 – 5.6 m/s  
Class 2 = 5.6 – 6.4 m/s  
Class 3 = 6.4 – 7.0 m/s  
Class 4 = 7.0 – 7.5 m/s  
Class 5 = 7.5+ m/s
Finding your Wind Resource – Real Data

- Meteorological Tower, Personal Weather Station, Sodar, Lidar

- Archived Weather Data/Airport Data
  - http://windenergy.cisat.jmu.edu/SBALP/
  - http://www.ncdc.noaa.gov/oa/ncdc.html
Siting Issues – Shadow Flicker

- can occur when any moving object comes between a viewer and a light source to create recurring shadows.
- In the case of wind turbines, this can happen each time a blade passes in front of the sun.
- In general, shadow flickering occurs for only a few minutes near sunrise and sunset.
- Significant difference in shadow flickering between utility-scale wind turbines and small wind energy systems.
  - Smaller towers
  - Faster RPM

[Image: Illustration of a house with shadows from a wind turbine]
Siting Issues - Noise

- Ambient Noise
  - the combined noise from all sources both near and far.
  - Considered “normal.”

- Intrusive Noise
  - any noise that exceeds the ambient noise level at a given location.

- What makes a noise intrusive?
  - Time of day
  - Situational circumstance
  - Sensitivity of the listener

- Decibels
  - $10 \times$ intensity of 0 decibels = 10 dB
  - $100 \times$ intensity of 0 decibels = 20 dB
  - $1000 \times$ intensity of 0 decibels = 30 dB
  - Etc...

- What is “noisy” is relative to the observer
**Siting Issues – Birds & Bats**

- Wind Turbines are known to kill birds as well as bats.
- Important to consider the types of birds being impacted.
- Ongoing research investigating impacts and mitigation techniques at existing facilities.
- Bat impacts not as well understood at this time.
- Siting is key for new facilities!
- Not the same for small wind turbines!
  - Shorter towers
  - Smaller rotor diameter
  - Faster RPM
  - Wind Turbines are known to kill birds.
Other Siting & Environmental Challenges

- Do wind farms cause habitat fragmentation?
  - Depends on location and species considered.
  - Not necessarily just avian life.

- Can wind farms have indirect effects on wildlife?
  - Depends on location and species considered.
  - Recent research implies effects aren’t necessarily negative.

- Do Wind Turbines/Wind Farms effect property values?
  - 2009 study by Lawrence Berkley National Laboratory

- Transmission Lines
  - If nearest transmission is > 10 miles to be profitable

- Road Access
  - Particularly an issue with mountain sites.

- Ice Throw
  - Exaggeration

- Land Use
  - Protected Lands
  - National Parks
  - Shipping Lanes
  - Military Operations
**Offshore vs. Onshore**

- More wind
- Less complex terrain
- Bathymetry (depth)
- Sea bed geology
- Selection of turbine and foundation structure
- Wind farm design and cable laying
- Reduced social impacts (visual, noise, shadow flicker, etc)
- Increased cost
- More maintenance
- Both onshore and offshore development required
Wind Farm Layouts
Environmental Impacts

- An Environmental Impact Statement (EIS) as defined by the National Environmental Policy Act (NEPA) is necessary to ensure minimal impact to the marine environment.

- Marine and coastal habitats of importance
  - Sandbanks
  - Mangroves
  - Seagrasses
  - Coral reefs
  - Large shallow inlets and bays
  - Submerged or partially submerged sea caves

- Birds, bats and marine life – noise and vibration during construction phase

- Destruction of important habitats for birds, bats and marine life

- Marine life – noise and vibration during operation phase

- Effects of EMFs from subsea cables on marine life

- Other
Other Impacts and Marine Traffic Related Barriers

- Bunkering Zones
- Military – impact on radar and navigation and other operations
- Port Approaches and Shipping Lanes
- Nature Reserves
- Restricted Areas
- Fishing and Fish Farming
- Archaeological sites, shipwrecks and areas of historical significance
- Boating, yachting and other tourism and recreational activities
- More expensive than conventional sources of energy and onshore wind
- Driving factors behind cost
  - Distance to shore – more cabling, deeper waters
  - Foundation structures
  - Offshore substations
  - Cost to upgrade ports, build roads, upgrade electrical infrastructure onshore