An overview of Wind Power development in the Midwest

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Wind is one of the fastest growing Renewable energy sources in the world

Annual Wind Turbine Installations Worldwide (MW)

Worldwide installed capacity (2001): 24,000 MW
(~ 12.6 million homes @ 5,000 kWh/home and 30% wind capacity factor)

8,100 MW Germany
3,175 MW Spain
4,240 MW U.S.
2,417 MW Denmark

45,000 MW predicted by 2005

Source: Danish Wind Turbine Manufacturers Association & BTM Consult
Windmills?

- Early application of wind was for grinding grain (Wind-Mill)
  - and pumping water (Windmill?)
- Making Electricity
  - Wind Turbine
  - Wind Energy Conversion System (WECS)

Components of a WECS

- Gearbox
- Tower
- Rotor
- Foundation
- Controls
- Generator
Where does the wind come from?

Solar heating of the earth’s surface

High pressure vs. Low pressure systems

Circulation Cell patterns
  • Hadley Cell (trade winds)
  • Ferrel Cell
  • Polar Cell

And where does it go?

Local Winds

- Sea Breezes
  - Result of the seas ability to maintain temperature
  - Daytime land heats, sea is cool
  - Nighttime land cools faster than sea

Local Winds

- Mountain Breezes
- Wind concentration in mountain passes
- One of the first ‘wind farms’ in the US was in Livingston, Montana

Wind Engineering Basics

- Machine Dynamics: How Much Power?
  - Wind to energy conversion
  - Wind machine power curves
  - Mechanical Protection or: Will it break?
- Wind Dynamics: How much Energy?
  - Time Patterns of wind speed
    - Daily, Monthly
  - Spatial Wind Patterns
    - Tower Height
    - Local scale wind disturbances

Energy in Wind

- Kinetic Energy $= 0.5 \text{ m}^2 \text{V}^2$
  - $m =$ mass (kg)
  - $V =$ velocity (m/s)
  - Energy (Joules) $= \text{kg m}^2 / \text{s}^2$
- Energy in a finite mass of air moving at a certain velocity

### Power in Wind

- Kinetic Energy of a finite mass of air = \(0.5 \, m \, V^2\)
- Energy (Joules) / time = power (Watts)
- Mass of air going through the hoop per second
  - \(\rho A V\)
  - \(A = \) cross sectional area of the hoop
  - \(\rho = \) air density (mass/volume)
- Power of a mass of wind blowing through a HOOP at a certain rate (velocity)
  - \(0.5 \, \rho \, A \, V^3\)

### Conversion Efficiency

- We can not convert all of the power in the wind to Mechanical (then electrical) power
- Maximum theoretically power conversion efficiency (wind to mechanical)
  - Betz Limit = 0.59
  - Maximum mechanical power extracted from wind blowing through a HOOP at a certain rate (velocity)
    - \(0.59 \times 0.5 \, \rho \, A \, V^3\)
- Losses caused by
  - Some of the wind goes around (not through) the hoop
  - You cant slow the outgoing wind to zero velocity
  - Aerodynamic drag
  - Frictional losses from high velocity wind / turbulence


Early Designs

- First evidence of wind turbines 4000 years ago
- Differential resistance
- Vertical Axis
- Drag type
- Blade cannot go faster than the wind
  - Screened
  - Clappers
  - Sails
  - Cups


Modern Machines

Lift Type

- Lift forces perpendicular to the direction of the wind.
- Drag force parallel to the wind direction

Vertical Axis Wind Turbine

VAWT

- Use wind from any direction without need for positioning device
- Generator on the ground
- Difficult to manufacture special curved blades
- Need to be started spinning to develop sustained lift
- Overall efficiency is low
Optimum number of blades depends on rotational speed (output torque)


Efficiency ratings of modern wind turbines

Power coefficient for various turbine designs. Figure 24.3.3 from Duffie and Beckman, Solar Engineering
Over-speed / High Wind Protection

- Turn blade axis out of the wind
  - windmill tails
- Feather Blades
  - change angle of attack to kill lift - stall
- Aerodynamic brakes flaps

Wind Machine Design Challenges

- High efficiency at low wind speeds without flying apart at high wind speeds (tornados?)
- Challenges of going up to capture more energy
  - High Towers
  - Long blades
- Fatigue failure of ‘flapping’ blades
- ICE!
- Ultra-high reliability requirements
  - 8760 hours / year = 400,000 miles/year on your car
**WECS Power Curve defines performance over a range of wind speeds**


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**Incorporating Wind Energy into Building Design**

- Potential to use urban planning to create “Venturi” effect with architecture, or building placement, creating higher-winds
- Can use smaller cheaper turbines with wind concentration
Environmental Impacts

- **Positive Impacts**
  - Reduction of air pollution for energy production
  - Requires no water for waste heat removal
  - Reduced carbon emissions

- **Negative Impacts**
  - Noise
  - Electromagnetic interference
  - Visual Impact
  - Flickering of light during sunset/rise
  - Bird collisions

![Average Life Cycle Carbon Emissions](chart.png)
Noise

- Wind turbine noise has been greatly reduced in modern turbines
- Much quieter than many other public sources of noise
- Two sources of wind turbine noises
  - Mechanical—gearboxes/bearings
  - Aerodynamic noise

Noise and the Impact on Wind Power Development

- Most turbines undergo noise testing during manufacturing to establish distances turbine should be used from habitation.

- Serious issue, if careful consideration is not taken to work with those around the site, it can cause major setbacks.

Electromagnetic Interference

- Rotating turbines between transmitter and receiver distort signals.
- Depends mainly on:
  - Blade material
  - Shape of the tower
- Non-metallic blades absorb signal (as opposed to reflect it) and fix problems.
- TV signals can be distorted, affected viewers need to be serviced with cable.
- Complex airplane controls signals can be interfered with, appropriate siting is required.
Bird Collisions

- Avian mortality greatly reduced with large turbines
  - Average 1-2 bird deaths per turbine per year
  - Worst case was California
    - Smaller faster turning turbines
    - High concentration of raptors
    - Sited in known flyways
    - Many perching areas nearby

Bird Collisions

- Some facts for comparisons
  - California is the worst example of bird mortality in the world, killing 500 birds/year
  - Exxon Valdez spill killed 500,000
  - Estimated in the USA each year 57 million birds are killed by cars
  - More than 97 million through collisions with glass windows
**Visual Impacts**

- Often depends on a variety of more complex social and psychological parameters
  - Opposition to change in surroundings
  - Understanding technology
  - Individuals involvement in project
- Wisconsin opinion survey found marked preference for onshore over offshore

**Off-Shore Wind Energy**

- Capital costs of off-shore wind is generally higher
  - Experimental Station off-shore of Denmark show capital costs 85% higher
  - As experience is gained in off-shore construction, costs are expected to decrease
Off-Shore Wind

- **Methods of decreasing capital costs**

  This ship has 6 legs that will hydraulically lift the boat to create quick, stable crane platform for installing off-shore wind turbines.

Off-Shore Wind Energy

- Off-shore wind speeds are generally higher and steadier allowing greater energy production
  - At Denmark experimental off-shore wind far energy production was 20% - 30% greater than models predicted
  - Winds are actually higher farther off-shore
  - Availability has been around 98%
Off-Shore Wind Energy

- Favorable sites:
  - Up to 30 m to 50 m water depth
  - At least 5 km from shore
- Some studies show an increase in flora and fauna around off-shore wind farms
  - Underwater supports offer reef-like structure
  - Higher yields reported from fisherman in the area

Off Shore wind in the USA

- Long Island Power Authority
  - Bids were accepted starting May 2004

Table 2: Planned Offshore Farms in North America

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>Total capacity (MW)</th>
<th># of turbines</th>
<th>Size of turbine (MW)</th>
<th>Hub height (m)</th>
<th>Rotor dia. (m)</th>
<th>Spacing (m)</th>
<th>Water depth (m)</th>
<th>Distance from shore (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CapeWind</td>
<td>Cape Cod, MA</td>
<td>468</td>
<td>130</td>
<td>3.6</td>
<td>79</td>
<td>100</td>
<td>533 x 800</td>
<td>~15</td>
<td>~24</td>
</tr>
<tr>
<td>Winergy</td>
<td>MA, MD= 21 sites</td>
<td>976</td>
<td>271</td>
<td>3.6</td>
<td></td>
<td></td>
<td></td>
<td>18</td>
<td>~24</td>
</tr>
<tr>
<td>LIPA (in pre-proposal)</td>
<td>Long Island, NY</td>
<td>100-140</td>
<td>23-50</td>
<td>2.0-4.0</td>
<td>~80</td>
<td>79-100</td>
<td>690</td>
<td>~21</td>
<td>5-10</td>
</tr>
<tr>
<td>Nai Kun</td>
<td>British Columbia</td>
<td>700</td>
<td>350</td>
<td>~2</td>
<td>80</td>
<td>72</td>
<td></td>
<td></td>
<td>15</td>
</tr>
<tr>
<td>AIM PowerGen</td>
<td>Lake Erie, Prov. Of Ontario</td>
<td>400</td>
<td>200</td>
<td>~2</td>
<td></td>
<td></td>
<td>600 - 760</td>
<td></td>
<td>15</td>
</tr>
</tbody>
</table>
Potential off Wisconsin shores

- Southern Lake Michigan
- Green Bay
- 6 MW onshore
- 3 MW offshore

Public Concern about purity of Viewshed
Useful Wind Web Sites

- American Wind Energy Association
  - www.awea.org/
- National Renewable Energy Lab
  - www.nrel.gov/wind/
- Wind Powering America
  - www.eere.energy.gov/windandhydro/windpoweringamerica/