ECE 333 – GREEN ELECTRIC ENERGY

4. Wind as an Energy Resource

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TRANSPORTATION OF A LARGE WIND TURBINE BLADE

As wind turbines continue to grow in size, project developers will face greater challenges in transporting components. This 80-meter blade is being transported to a 7-MW test turbine in Scotland.

WIND RESOURCES

- Wind is becoming a significant source of generation in the US and Europe
- Today’s over 500 GW of global wind capacity contributes to lowered $CO_2$ emissions
- The technological advances over the past two decades have dramatically reduced the costs of wind generated electricity
- In this set of lectures on wind, we explore its key characteristics, its physical limitations and the economics of wind generation

HARNESSING WIND POWER

- Many early wind turbines were used to grind grain into flour and thus the term “windmill”
- We do not use the term windmill for machines that pump water or generate electricity
- There are various terms used today for generators that convert wind into electricity; terms include “wind-driven generator”, “wind generator”, “wind turbine”, “wind-turbine generator ($WTG$)”, “wind energy conversion system ($WECS$)”
- We, typically, use the term wind turbine in ECE 333
One way we categorize wind turbines is in terms of the axis around which the turbine blades rotate:

- Large wind turbines are virtually all horizontal axis wind turbines (HAWTs).
- Some smaller turbines have blades that rotate around the vertical axis and are called vertical axis wind turbines (VAWTs).

Groups of wind turbines are located in what is called either a “wind farm” or a “wind park”.
WIND TURBINE CLASSIFICATION

- The **HAWTs** are either
  - upwind machines that directly face the wind; or
  - downwind machines that have their rotors behind the wind
- A key design decision is the number of blades – either 2 or 3; virtually, all large wind turbines have 3 blades

VAWT

- The only vertical axis machine with any commercial success is the **Darrieus rotor**
- The wind hits the rotor blades – so-called aerofoils – and obtains lift to put the blades in a spin
- Blades are, typically, closer to ground where wind speeds are lower

Source: http://reuk.co.uk/Darrieus-Wind-Turbines.htm
### VAWT

- A VAWT requires no yaw – rotation about vertical axis – control to keep the blades facing into the wind
- The nacelle contains the heavy generator and the gearbox and is located down on the ground and so is easily serviced
- The lightened tower need not be as strong as those for HAWTs; in some land installations, guy wires may be used

### HAWT

**upwind**

![Wind](image1)

**downwind**

![Wind](image2)
UPWIND *HAWT*

- Most modern wind turbines are of the **upwind** *HAWT* type
- An upwind *HAWT* requires a somewhat **complex** yaw control to keep the blades facing into the wind
- Upwind *HAWTs* operate more smoothly and deliver more power than downwind turbines

DOWNWIND *HAWT*

- A downwind *HAWT* requires **no yaw control** to regulate the left–right motion as it naturally orients itself in line with the wind direction
- A downwind *HAWT* suffers from the **shadowing effects of the tower**: when a blade swings behind the tower, the wind it encounters is reduced over a brief period and the blade flexes; such blade flexing increases blade noise, reduces power output and may, eventually, lead to **blade failure**
The first known wind turbine for electricity production was developed in 1888 by Charles F. Brush, in Cleveland, Ohio. The 12 kW turbine electricity was used to charge the batteries in the cellar of the owner’s mansion. The first wind turbine to generate electricity was built in 1891 by Poul La Cour in Denmark.

La Cour used the electricity generated by his wind turbines to electrolyze water to produce hydrogen for the gas lights in the local schoolhouse. In the US, the first wind-electric systems were built in the late 1890’s.
WIND POWER DEVELOPMENT: BRIEF HISTORY

- By the 1930’s and 1940’s, hundreds of thousands of small–capacity, wind–electric systems were in use in rural areas not yet served by utilities.
- As the transmission grid expanded, interest in wind power waned, since inexpensive electricity became widely available.
- The oil shocks of the early 1970’s created a new interest in wind power and large wind farm developments were set up in California.

WIND FARMS
WIND POWER DEVELOPMENT:
BRIEF HISTORY

- The *US* government termination of tax credits put a stop for nearly a decade to the installation of new wind developments
- The renewed interest started in the mid 1990’s
- Various wind turbine technology development projects were undertaken in Denmark, Spain, and Germany that led the continual reductions in the cost of wind–produced electricity
- China has become the leading nation in wind electricity installations

1998 – 2017 **US Annual and Cumulative Installed Wind Capacity**

![Bar chart showing annual and cumulative installed wind capacity from 1998 to 2017.](chart.png)


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2017 **US Wind Power Project Status**

![Map showing 2017 US wind power project status.](map.png)

Note: each number on a state gives the cumulative installed wind capacity; each number in brackets gives the capacity added in 2017.

### 2017 WIND CAPACITY ADDITION AND CUMULATIVE WIND TOTAL

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<thead>
<tr>
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<th>annual capacity in MW</th>
<th>cumulative capacity in MW</th>
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<tr>
<td>China</td>
<td>19,660</td>
<td>188,392</td>
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<td>United States</td>
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<td>rest of the world</td>
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<td>total</td>
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### LEADING NATIONS IN WIND ENERGY CONSUMPTION IN 2017

![Graph showing estimated wind generation as a percentage of electricity consumption, approximate additional wind penetration due to 2017 added capacity, and approximate wind penetration at the end of 2016.]

KEY COMPONENTS OF A WIND TURBINE

THE TREND TO LARGER WIND TURBINES

2005 – 2017 AVERAGE WIND TURBINE SIZE EVOLUTION


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WIND MAP FOR NORTH CENTRAL IL

Source: http://apps2.eere.energy.gov/wind/windexchange/maps_template.asp?stateab=il

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WIND RESOURCE MAP

Source: https://www.nrel.gov/gis/images/80m_wind/awstwspd80onoffbigC3-3dpi600.jpg

WORLDWIDE WIND RESOURCE MAP

Average Wind Capacity Factors in Calendar Years 2000 – 2017

Capacity factor based on estimated generation (without curtailment)
Capacity factor based on estimated generation (with curtailment)