Sustainable Energy

Lecture 15: Wind Energy

Wind Resources

- Table 15.1 summarizes the history of wind machine use.
- Wind power has been used for most of the agricultural and industrial periods of human cultural development.
- We are in the golden age of wind power generation now.

Table 15.1/Timeline of Wind Machines

Table 15.1. A Timeline of Wind Machine Milestones

Part I: The Historical Era

Dates	Events of Note
1	Hero (a.k.a. Heron) of Alexandria uses a wind machine to power an organ.
~ 400	Reference to wind-driven Buddhist prayer wheels
644, 915	References to pre-existing vertical axis windmills (panemones) in Persia
1137, 1274	References to pre-existing horizontal axis windmills in England and Holland, respectively
~ 1400	Smock (rotatable cap) mills originating in Holland supercede post mills (which turn on a vertical shaft).
1200–1850	Golden age of windmills in western Europe, totaling perhaps 10,000 in England, 18,000 in Germany, 9,000 in Holland, and 50,000 overall
1850s	Multiblade wind turbines for water pumping made and marketed in US
1769	James Watt granted a patent on his much-improved version of a steam engine
1877, 1893	Invention of the 4-stroke gasoline and the diesel internal combustion engines by Nikolaus Otto and Rudolf Diesel, respectively
1882	Thomas A. Edison commissions the first commercial electric generation stations in New York City and London
1900	Competition from alternative energy sources reduces windmill population to fewer than 10,000
1919, 1937	End of commercial operation of the last of the conventional old-style mills in Long Island (New York) and Denmark
1850–1930	Heyday of the small multiblade wind machine in the US midwest—as many as six million units installed
1936+	US Rural Electrification Administration extends the grid to most formerly isolated rural sites, which rapidly displaces wind machine use

Table 15-1 continued

Table 15.1 (continued). A Timeline of Wind Machine Milestones

Part II: The Modern (Electric) Era

Dates	Events of Note
1890–1893	LaCour in Denmark and Lewis Electric in New York state build wind machines to generate electricity
1933	Krasnovsky builds a 100 kWe wind machine in the Russian Crimea, near Yalta
1941–1945	The Smith-Putnam 1250 kWe wind turbine is installed and operated on Grandpa's Knob, Vermont
1973	The oil energy crisis inspires new interest in alternative energy sources
1974–1980	US Federal Large Wind Turbine Program
1976	US Energy Research and Development Administration (ERDA) small wind machine development program
1978	Public Utility Regulatory Policy Act (PURPA) requires that utilities purchase electricity from small producers at the utilities' "avoided cost"
1981–1993	Wind turbine boom times in California: more than 12,000 units installed, totaling some 1800 MWe
1982–1994	Record rating 4 MWe Hamilton Standard 4TS-4 unit operated in Wyoming
1985, 1986	US federal and California tax credits for wind projects expire, respectively
1988	Worldwide large wind turbine sales, R&D expenditures, market incentives bottom out due to decline in US
1991	First commercial offshore wind farm, Vindeby, Denmark
1992	National Energy Policy Act (NEPA) gives a 1.5 ¢/kWhr production tax credit for wind-generated electricity
1996	Kenetech Windpower (US Windpower), largest US and world manufacturer, declares bankruptcy. [assets sold to Enron Wind, then acquired by GE Wind]
1990–2000	Megawattage of installations in Europe grows at ~20%/year
1998–1999	European manufacturers open wind turbine factories in US and China
2001	US Department of Energy (DOE) announces goal and program to have 3¢/kWehr electricity from wind by 2012

Wind Machinery and Generating Systems

- There is a wide variation by region and locale in the availability of quality wind resources.
- Coastal areas are key locations for wind generation.
- The US great plains has extensive wind resources.
- If the resources of South/North Dakota were developed they could provide ½ of the energy use in the US.
- Constraints on use of wind power:
  - Winds vary in speed and the resultant energy flux daily is not necessarily in concert with the demand for energy.
  - Integration of wind power into the grid provides challenges since storage is not currently possible for peak periods of use.
  - There is no inexpensive way to store the excess wind generation capacity.
  - Grid infrastructure is currently lacking to take advantage of potential areas of high wind power generation capacity.
- The power provided by wind varies by the cube of the velocity of the wind. Double the wind speed and you have 8X the power!

Wind in the US

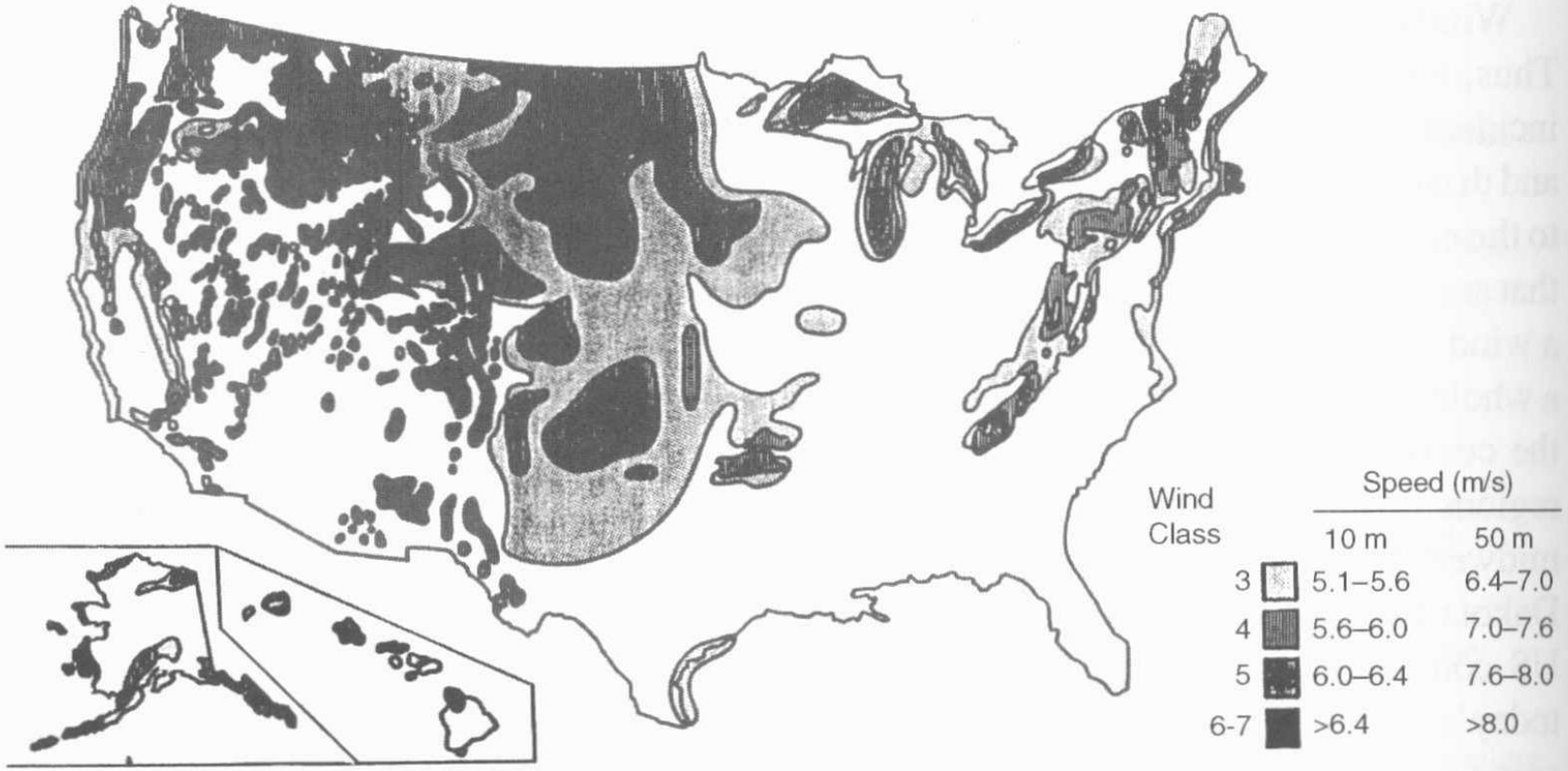

Figure 15.1. Annual average wind speed map of the US. Source: Pacific Northwest Laboratory (1986).

Worldwide Wind Areas

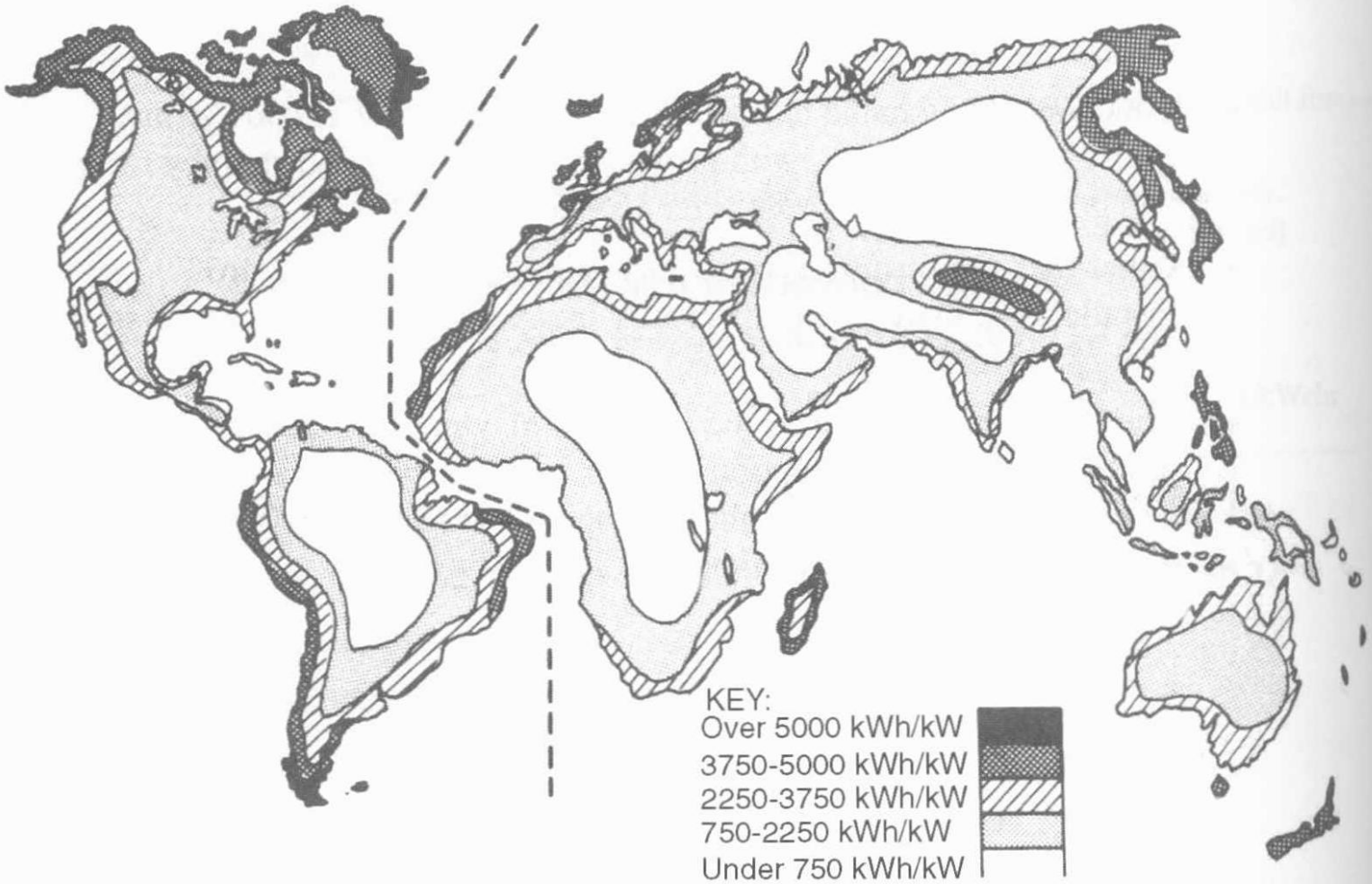

Figure 15.2. Worldwide available annual wind energy per rated Kilowatt. Source: Eldridge (1980). Reprinted with author's permission.

Wind machinery continued

- Average wind speed increases with the height to the 1/7 power; a wind turbine with a hub elevation of 50m will see an average wind speed of 7.6% higher than at 30m.
- Tower height is a major consideration of wind turbine design.
- Parts of a wind machine:
  - Rotor
  - Nacelle (contains gearing and electric generator)
  - Support tower and power conditioning system
- Rotor
  - Blades are similar in design to aircraft propellers
  - Two and three blade designs are common; there is a tradeoff between torque considerations at low speeds and cost. Efficiency is not effected by the number of blades.
  - Tapering of the hub to tip shape and twisting the angle of pitch in the horizontal plane allow for an increase in circumferential speed.
  - Lightweight composite materials are favored for construction materials.

Wind machines continued

- Tower
  - Steel lattice and tubular pole designs have been used; pole designs are the most common.
- Nacelle Components
  - Generators are normally AC run at a constant shaft speed to produce 60hz AC power.
  - Variable speed units are available and can operate at increased efficiencies.
  - Variable speed units require a power electronic converter to maintain proper frequency outputs.
- Efficiencies
  - Maximum theoretical efficiencies are at 40% for the machine.
- I recommend viewing this website for more details on wind machines design: http://www1.eere.energy.gov/windandhydro/wind_how.html#inside

Elements of a wind turbine

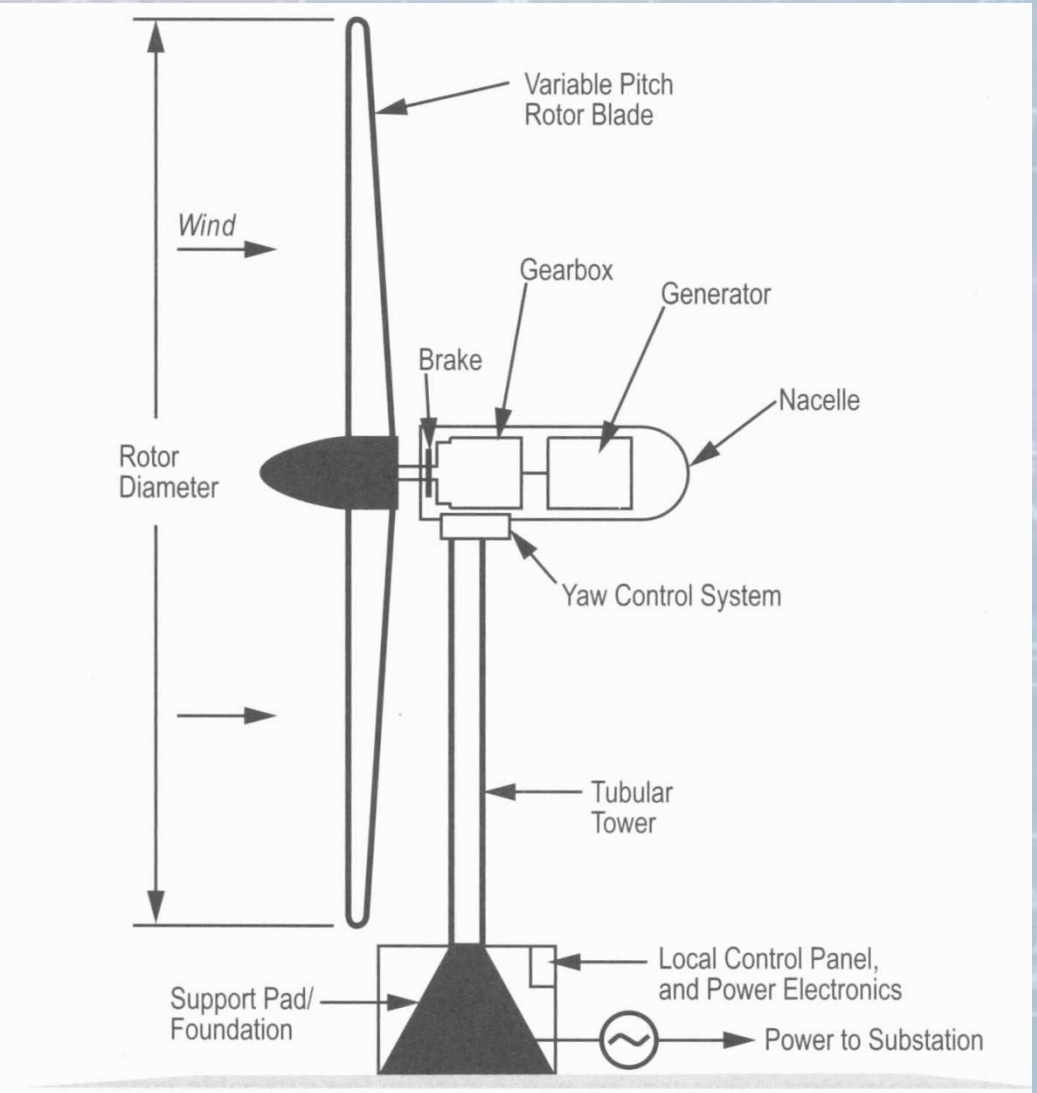

Figure 15.6. Principal elements of a wind turbine electric generator.

Wind Turbine Rating

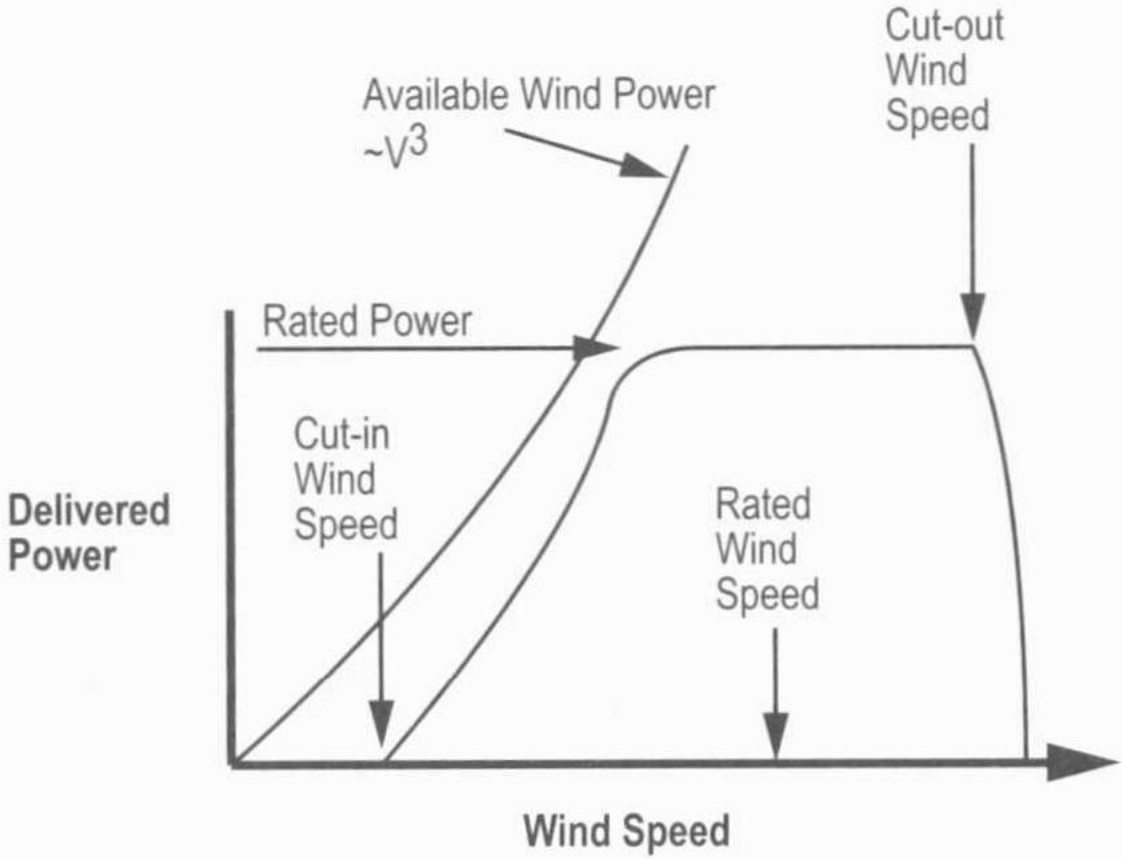

Figure 15.7. Generic wind turbine performance (variable pitch blades).

Wind Power Economics

- Wind turbines are the most competitive of the solar technologies to fossil-fired systems.
- The predicted lifetime-levelized cost in current valued dollars is 6.5 cents/kWe/hr
- This is approximately the same cost as nuclear, 10% higher than coal and 20% more costly than natural gas-fired combined cycle gas turbines (CCGT).
- The costs of externalities makes this an attractive energy source for the future.
- Wind machines can be up and running in 6 months to a year from purchase.
- Fuel costs are zero…while the costs of fossil fuels are sure to increase.
- Economies of scale will surely make this form of energy production increasingly attractive.

Measures of Sustainability

- Payback time is 0.9yr for wind turbines.
- Externalities
  - Impacts are primarily come from the steel used to produce the turbine tower.
    - Estimates are that 0.08C/kWe hr are due to this impact….very, very low.
    - If a carbon tax were assessed this estimate would be higher.
    - Wind power is responsible for only 2% of the impacts of a comparable fossil-fuel plant.
- Environmental Impacts
  - Aesthetics
  - Noise…you need about a 0.5km buffer zone.
  - Raptor kill
  - Interference with radio, TV and radar transmission.
  - Land use.
  - Maintenance worker hazards.
- Wind power is the fastest growing source of energy; wind power quadrupled between 2000-2006; current growth rates are estimated to be 21% per year worldwide.

Annual Wind Generation

Annual Wind Power Generation (TWh) / Total electricity consumption(TWh)[51][52][53][54]										
Rank	Nation	2005			2006			2007		
		Wind Power	%	Total Power	Wind Power	%	Total Power	Wind Power	%	Total Power
1	Germany	27.225	5.1	533.7	30.7	5.4	569.943	39.5	6.8	584.939[55]
2	United States			4049.8	26.3[56]	0.6	4104.967	32.14[57]	0.77	4179.908
3	Spain	23.166	9.1	254.9	29.777	10.1	294.596	29.4[58]	9.7	303.758
4	India			679.2			726.7	14.7	1.9	774.7
5	China			2474.7	2.7	0.1	2834.4	5.6[59]	0.172	3255.9
6	Denmark (& Faeroe Islands)	6.614	19.3	34.3	7.432	16.8	44.24			37.276
7	France			547.8	2.323	0.4	550.063			545.289
8	United Kingdom	0.973	0.2	407.365			383.898			379.756
9	Portugal			35	4.74	9.7	48.876			
	World total (TWh)			15,746.54[60]			16,790[61]			