

Wind Turbine Generation

Implications for Power Systems and Society

Dave Young (416) 207-6815

dave.young@kinectrics.com

September 17, 2003



KINECTRICS

Who is KINECTRICS?



KINECTRICS

Formerly Ontario Hydro Technologies

Now owned by AEA Technology

Over 85 years of experience solving the challenges
faced by Ontario Hydro and other North American
utilities

Now an independent company serving the needs of
North American government & energy sector clients

Over 250 employees, expertise in generation, T&D,
environmental and energy services

Consulting business in the field of energy and
environmental strategies

Linkages to Universities, Manufacturers, and
International "Centers of Excellence"

ISO 9001

KINECTRICS -

Transforming Ideas into Energy



Small-scale Wind Generators



Enertech 40 kW in Urban Locale



Bergey 10 kW in Remote Community

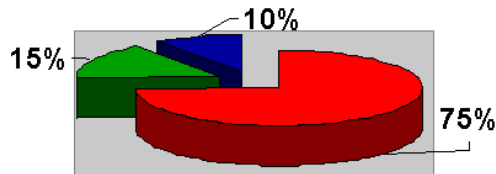


World Wind Generation



- Surpassed 31,000 MW installed capacity in 2002
- Average Output ~ 1/3 nameplate rating
- World wind generation at this moment is over 10,000 MW!
- Wind electricity now costs less than nuclear & gas, ~ = clean coal
- \$10B/yr new wind development increasing 25%/year

Total World wind power generation, by region
World total: 31,127 MW



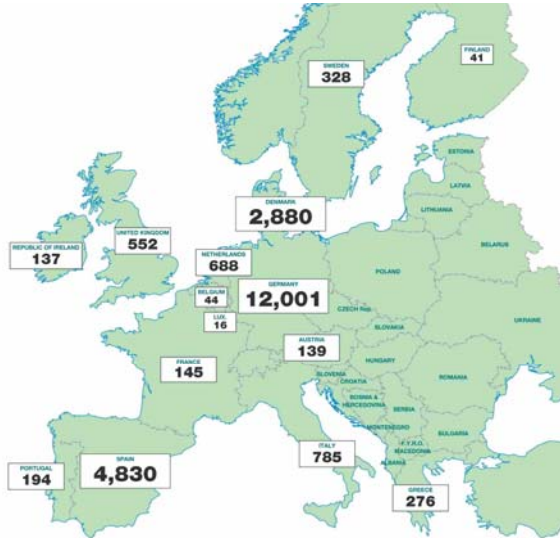
■ Europe (23,291 MW) ■ United States (4,685 MW) ■ Rest of World (3,151 MW)

European Union Wind Generation



Total EU Wind power
by the end of 2002:

23,000 MW

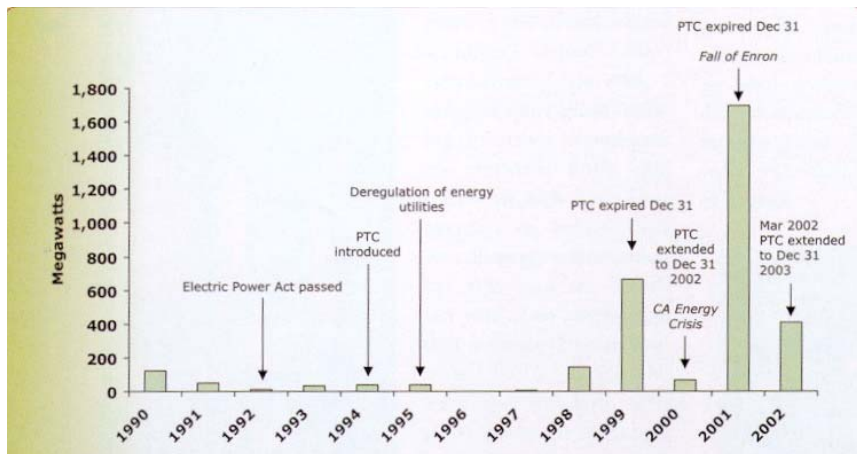


USA Wind Generation



Total USA Wind power
by the end of 2002: 4,700 MW

“boom-bust” federal PTC support cycle

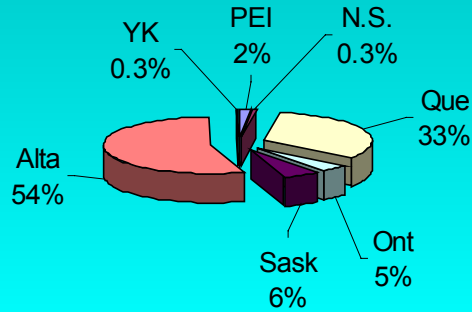


Canada's Wind Generation



Alberta's current total (170 MW) exceeds half Canada's capacity

Installed Wind Capacity (312 MW) - Canada







Wind Power Applications and Markets



	Private	Remote	NUGs	Gencos
Size Range	1 – 25 kW	50 – 200 kW	300 – 800 kW	1 – 2.5 MW
Installed Price (\$US/kW)	\$4000/kW	\$3000/kW (+ remote extras)	\$2000/kW	\$1000/kW
Market Segment	Private, self-installed	Remote Communities	NUG Consortiums	Gencos
Rotor Technologies	Fixed Pitch, Stall Regulated	Fixed Pitch	Fixed or Variable Pitch	Variable Pitch
Generator Technologies	Permanent-Magnet Variable-Speed Alternator	Induction Generator	Induction or Wound Rotor Generator or Salient Pole Gen.	Wound Rotor (slip recovery) Generator or Salient Pole Gens.
Grid Connect Technologies	DC to AC Inverter	Directly Connected	Fluid couplings and/or AC Cycloconverter	Slip Couplings and/or AC Cycloconverter

Wind Power Status and Issues

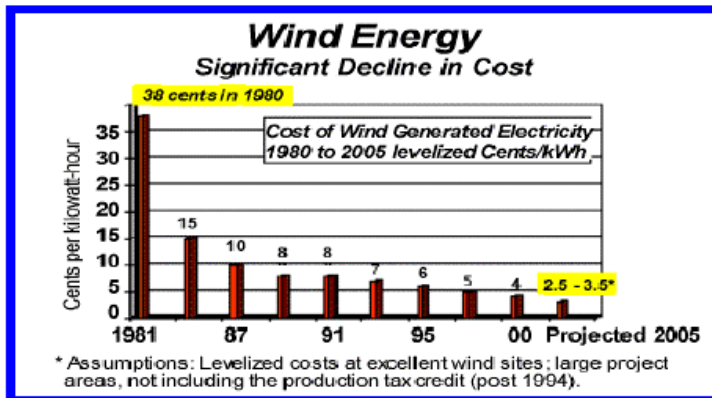


	 Private	 Remote	 NUGs	 Gencos
Gearbox	Direct Drive	Simple Planetary	Complex gearbox & hydraulics or Direct with salient pole generator and full power inverter	
Innovations	mature	Better control systems	Low wind regime blade options	
Ontario Sites	Anywhere	North	Lee Shores of the Great Lakes	
Groupings	Individual	One to four per site	Singles or Small Wind Farms	Major Utility Farms
Key Issues	Poor paybacks – enthusiasts and off-grid dwellings only	Maintenance. Telephone-based diagnostics	Salient pole, non-gearbox models not avail. due to US Patent fight	Move to salient pole, non-gearbox models. Low-wind versions needed for Ont.

Utility-scale Wind Power Costs



U.S.A. experience: Costs in US cents per kWh
Recent gas price increases make wind the lowest-cost generation



Wind Resources = Wind Strength



- WTG output increases with the cube of wind velocity
- 10% speed increase = 33% output increase
- Developers search for the strongest winds
- Earliest wind farms built in favourable mountain passes and ridges (California), and shorelines (Denmark)
- First WTGs were built for high average winds

Standard	Design criteria	Class I	Class II	Class III	Class IV
GL	Average wind speed	Max. 10 m/s	Max. 8,5 m/s	Max. 7,5 m/s	Max. 6,0 m/s
	50 year gust	65,1 m/s	55,3 m/s	48,8 m/s	39,1 m/s
	50 year wind	46,5 m/s	39,5 m/s	34,9 m/s	29,9 m/s
IEC	Average wind speed	Max. 10 m/s	Max. 8,5 m/s	Max. 7,5 m/s	Max. 6,0 m/s
	50 year gust	70,0 m/s	59,5 m/s	52,5 m/s	42,0 m/s
	50 year wind	50,0 m/s	42,5 m/s	37,5 m/s	30,0 m/s

Wind Turbine Evolution



Since 1980's:

- Enormous advances in WTG blade efficiency
- Longer Blades and Taller Towers open up low wind sites
- Low wind regimes (like Ontario) benefit from this evolution (i.e. DOE's "Low Wind Speed Turbine" project)

Rule: Whether a site is "**Developable**" depends more on the "**Hardware**" than on the **site**!

Ontario Wind Resource



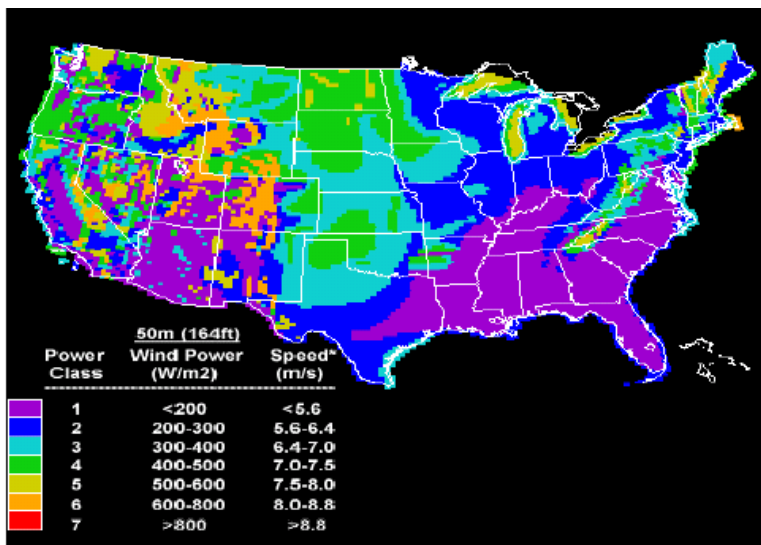
- Theoretically, wind potential far exceeds electrical use.
- Assumed “poor”, but Ontario’s winds are like Germany’s (world WTG leader) and we have more coastline.
- Ontario has significant Class 4, and some 5 & 6 zones

Wind Power Class	Wind Speed m/s	Notes
1	< 5.6	NOT COMMERCIALY VIABLE
2	5.6 – 6.4	
3	6.4 – 7.0	
4	7.0 – 7.5	COMMERCIALY VIABLE WITH TAX AND MARKET INCENTIVES
5	7.5 – 8.0	
6	8.0 – 8.8	COMPETITIVE WITH ALL ELECTRICITY GENERATION SOURCES
7	> 8.8	

Ontario Wind Resource (2)



Note wind “bump” along shoreline of Great Lakes.



Ontario Wind Resource (3)



- Ontario Renewable Energy Task Team estimates that at 400 MW/yr, the best regions of the province would take about 10 years to develop.

Region	Capacity
Lake Huron/Georgian Bay	800-2000 MW
Lake Erie onshore	300-600 MW
Lake Erie offshore	200-2000 MW
Lake Ontario onshore	300-600 MW
Lake Superior onshore	300-500 MW
Other highlands	200-500 MW
Total	2100 – 6200

Ontario Wind Resource (4)



BARRIERS

- Ontario municipal tax system places 0.3% working capital tax on generating assets.
- Wind power is capital-intensive & intermittent - a tax disaster

Type of generation (100 MW)	Typical capital cost	Annual capital tax at 0.3%	Typical capacity factor	Capital tax per unit of energy (MWh)
Wind power	\$150 million	\$ 450,000	33%	\$1.56
Waterpower	\$230 million	\$ 690,000	57%	\$1.32
Natural gas	\$100 million	\$ 300,000	90%	\$0.38

- In July, Ontario introduced regulations to exempt renewable energy generators from this tax, but only for 10 years, and only if constructed by December 2007.

Wind Power FAQs

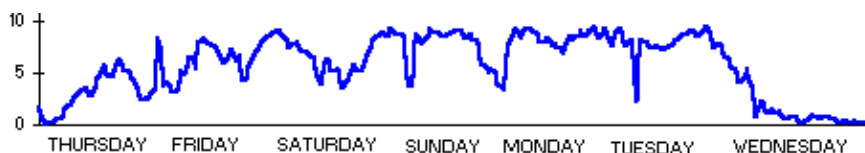


- ARE WTGs NOISY?
No. Visit a wind farm to prove it! At 350m, WTG=35-40 dBA, comparable to a quiet indoor room. Wind itself is noisy.
- WHAT IS A WTG's LIFETIME?
20-25 years. Maintenance includes overhauls and 2 blade sets.
- DO WTGs KILL BIRDS?
Studies conclude yes: 1 or 2 per year (same as average car or cat or living-room window). Replacing other generation with WTGs improves environment and survival rates of all species, birds included.

Wind Power is a Random Variable



- The output of multiple WTGs and distributed wind farms is very much smoother than a single turbine.
- However, the wind does not always blow (in Ontario).
- Wind forecasts based on "persistence" models (1-3 hours) and "met" models (1-2 days) are used by ISOs to predict wind capacity and availability.



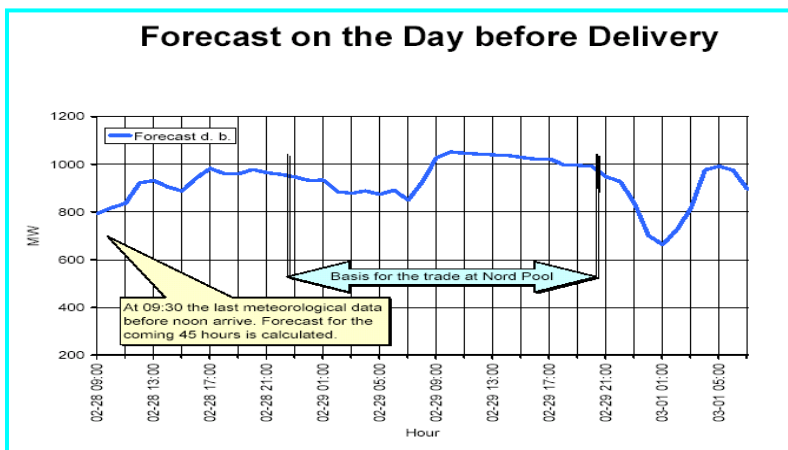
Wind Power must be Balanced by ..



KINETRICS

- The cost of dispatching other generation to “fix” wind projection errors is estimated at \$0.50 to \$2.50 / MWh of wind energy in a system with under 5% penetration.

Forecast on the Day before Delivery



High-penetration System Operations



KINETRICS

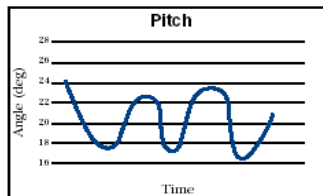
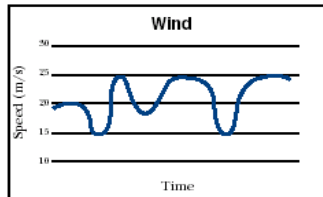
- ISOs in high-penetration jurisdictions (Denmark, Germany) are now prepared to:
 - back down thermal production
 - export unscheduled power
 - shut down excess wind generation through SCADA
- Denmark can have 1000 MW more wind generation than needed during low system load periods (weekends, holidays)
- Denmark has invested \$70M in grid upgrades to support their \$2B current wind infrastructure
- Centrally-dispatched heating schemes are being considered to use “excess” wind

MW-class WTGs are Utility-friendly



- Small cap technology not use in MW machines
 - no induction generators
 - no fixed-pitch blades
- Electronically-controlled generators with:
 - soft start
 - power smoothing
 - controlled PF (+/- 0.9)
- Variable-speed generator technology
 - wound rotor (doubly-fed async.)
 - full IGBT inverter on synchronou

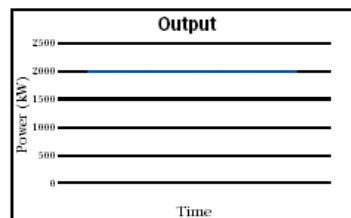
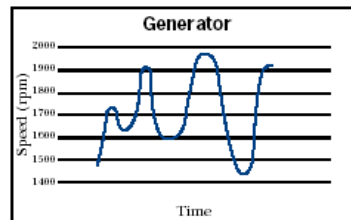
Vestas V80-2.0 MW turbine with OptiSpeed™



MW-class WTGs are Utility-friendly



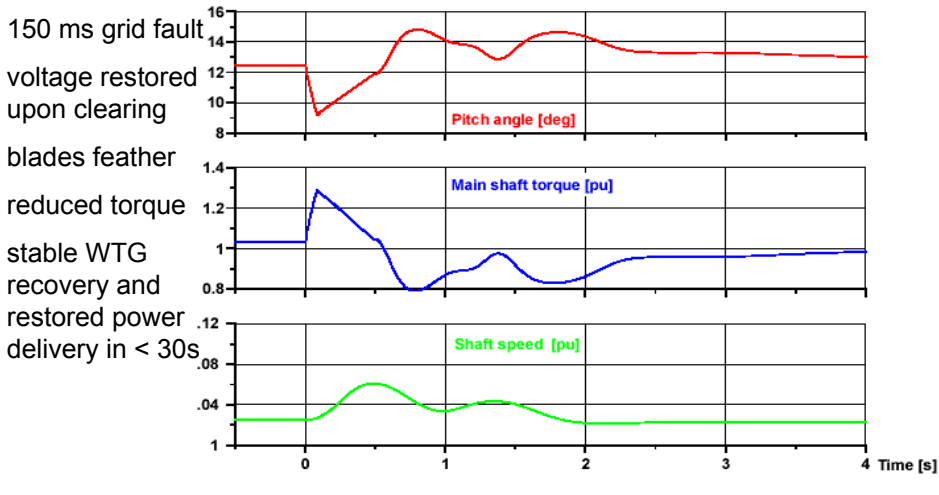
- Patent uncertainty hangs over variable-speed generator technology in N.A.
- Wide range of variable-speed manufactured in Europe, including direct drive
- Both gen types need electronics, but wound-rotor excitation inverts only 20-30% of the machine's power
- Some controllers maintain "reserve" by forgoing yield



MW WTGs & System Disturbances



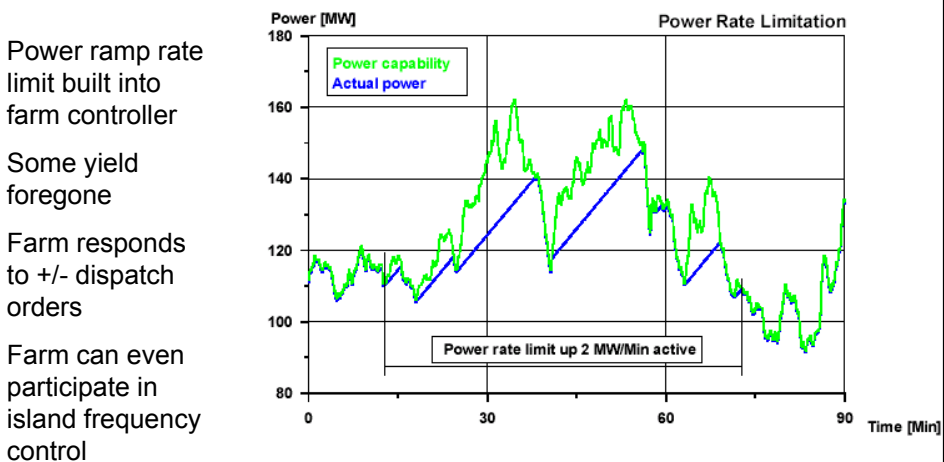
Current WTGs meet same grid standards as other generators



MW WTGs & System Disturbances



Current WTGs meet same grid standards as other generators

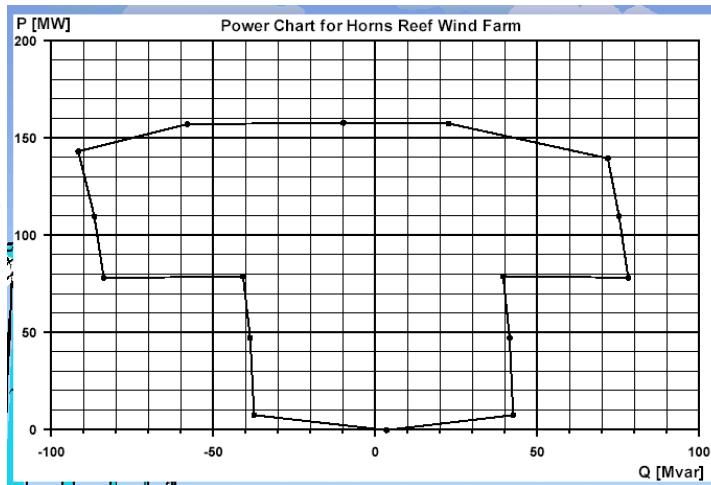


MW WTGs & VAR Support



Current WTGs meet same grid standards as other generators

Wound rotor induction machines have flexibility to absorb or produce reactive power



Canada's Largest Wind Farm



- Hydro Quebec's Le Nordais (on Gaspé Peninsula)
- 100 MW
- Similar capacity now being built in Alberta



Wind Farms in Special Areas



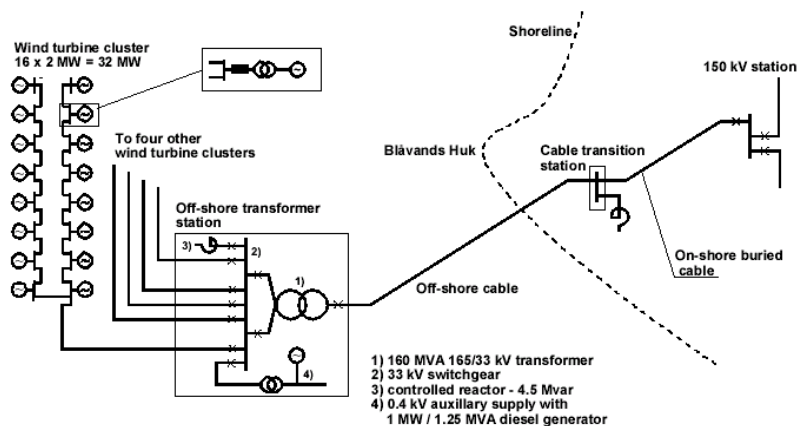
- California, near Palm Springs
- Annual cycle of thermally-driven winds
- Turbines as far as the eye can see!



Offshore Wind Farms in Europe



- Denmark's largest: 160 MW Horns Reef Project
- Grid interconnection costs: 15% of total budget
- Project cost ~ CAN\$2400/kW (double a land-based project)
- Offshore transformer station - fitted with helicopter deck



Offshore Wind Farms in Europe



- Denmark's largest: 160 MW Horns Reef Project



Storing Wind Energy



- Although storage developers often cite wind's intermittent output as a potential market, there is little evidence that modern wind farm equipment and controls need storage for system reasons.
- Storage will “swim or sink” based on system-wide needs and opportunities. The economics of electricity markets and arbitrage potential will dictate which storage schemes succeed. Their optimal location may be nearer to loads than to generation.
- Storage possibilities include: Compressed Air Energy Storage, Fly Wheels, Flow Batteries, Pumped Hydro, etc.

Distributed Wind Energy



JUST REMEMBER:

- Wind Power is coming to a highland wind farm or waterfront near you
- Wind Power makes people happy!

