Advancing Wind Power in Illinois Conference 2011

Guenter Conzelmann

Argonne National Laboratory

Hot Topics Plenary Panel Session
Advanced Drivetrain Concepts for Large Wind Turbines

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Advanced Drivetrain Concepts for Large Wind Turbines

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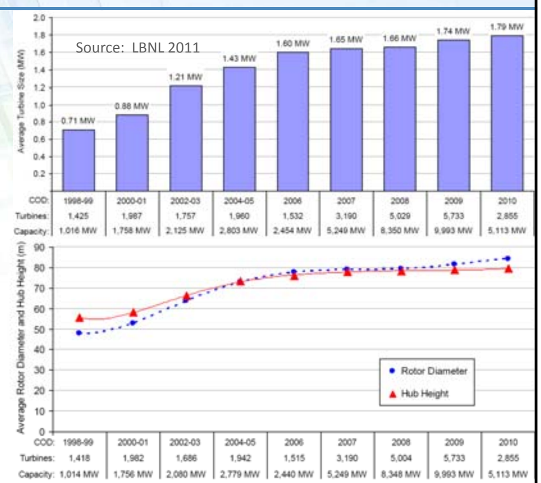
Guenter Conzelmann
Center for Energy, Environmental, and Economic Systems Analysis
Decision and Information Sciences Division (DIS)
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

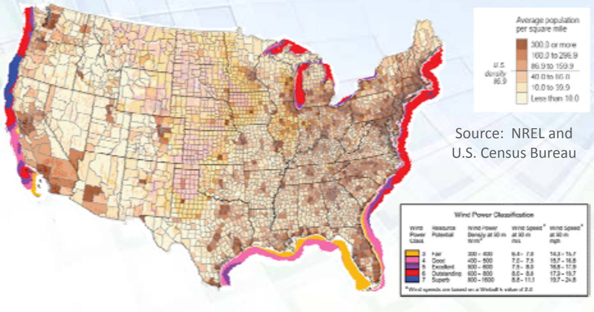
Average Turbine Size Continues to Increase

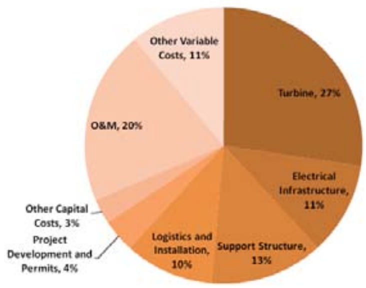
- More than ¼ of all turbines installed in 2010 were larger than 2.0 MW
  - Up from 0.1% in 2004-05
- Since 1998, hub heights have increased by 43% and rotor diameters by 76%



Offshore Wind Resources May Become a Major Contributor and Lead to more Changes in Turbine Size and Technology

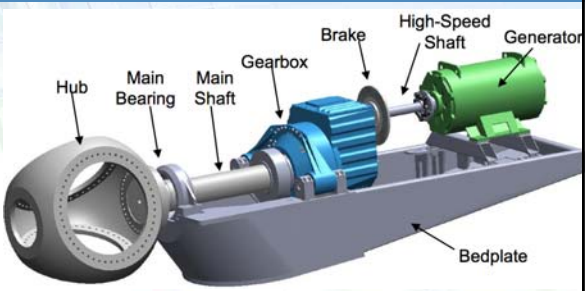
- Offshore resources are located close to major demand centers
  - Over 4000 GW gross resource; 740 GW in Great Lakes
  - 28 coastal states account for 78% of total electricity consumption
  - Coastal states have higher average electricity prices
- Offshore lifecycle cost structure favors larger turbines
  - Serviceability, logistics, infrastructure about 1/3
  - Turbine just over a quarter
- Size of turbines currently not constrained by shipping and lifting capacities of marine equipment and vessels


Source: NREL and U.S. Census Bureau

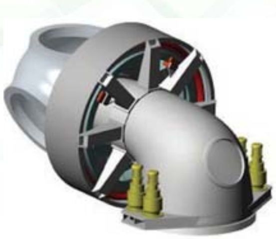


Current Drivetrain Configuration

- Modular configuration
  - Main bearing
  - Main shaft
  - Gearbox
  - Brake
  - High-speed shaft
  - Generator
- Direct Drive
  - Eliminates gearbox
    - Reduced losses
    - Reduced maintenance issues
  - Reduces number of components
  - Large generator diameter

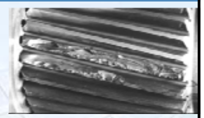



Multi-stage Gearbox


Direct-Drive Generator

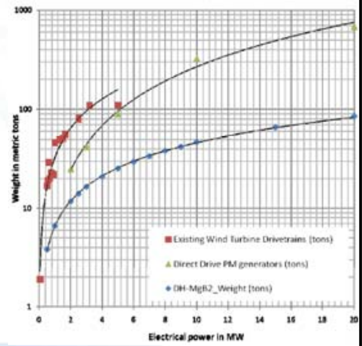
Source: DOE 2010; GE

Main Driver for New Drivetrain Technologies: Reduce Cost of Energy



- Drivetrain includes most expensive components (gearbox, generator); accounts for almost 50% of total turbine capital cost; accounts for majority of total energy losses in turbine
- Current drivetrains don't meet expected lifetime
  - Need to increase reliability
- New drivetrains could capture more of the available energy
  - Need to reduce losses and increase performance
- Current drivetrain technologies do not scale up well and lead to weight issues
  - Need to decrease investment costs

Current Design		New Design
7 year useful life		20+ year useful life
Unexpected component failures		Predictive condition health monitoring
High system weight		Increased energy capture to weight ratio
Variable mean time between failure		Improved management of maintenance activities
Variable downtime		Longer duration between planned outages
Relatively high cost		More attractive economics
Legacy technology from 80s and 90s		Innovative designs



Bringing Offshore Wind Cost of Energy to Competitive Levels Requires a Rampup in Turbine Size and New Technology

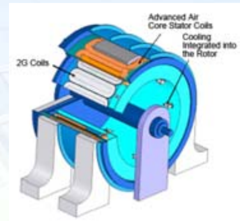
Year	2010	2015	2020	2025	2030
Component					
Installed Cap Cost/kW	$ 4,259	$ 3,900	$ 3,400	$ 2,900	$ 2,600
Fixed Charge Rate	20%	17%	14%	11%	8%
Turbine Rating (MW)	3.6	5.0	6.0	8.0	10.0
Rotor Diameter	107	126	136	156	175
Annual Energy Production / turbine	12276	17905	22029	31040	39381
Capacity Factor	38.93	40.88	43.67	44.29	44.96
Array Losses	10%	9%	8%	7%	7%
Availability	95%	96%	97%	97%	97%
Rotor Cp	0.45	0.46	0.47	0.49	0.49
Drivetrain Efficiency	0.9	0.9	0.95	0.95	0.95
Rated Windspeed (m/s)	12.03	12.03	12.03	12.03	12.03
Average Wind Speed at Hub Heights	8.8	8.91	8.96	9.09	9.17
Wind Shear	0.1	0.1	0.1	0.1	0.1
Hub Height (m)	80	90	95	110	120
Generator	Geared	Geared	DDPM	DDSC	DDSC
Cost of Energy ($/kWh)	**0.269**	**0.2057**	**0.1486**	**0.1035**	**0.0712**

DDPM: Direct drive permanent magnet
DDSC: Direct drive superconducting

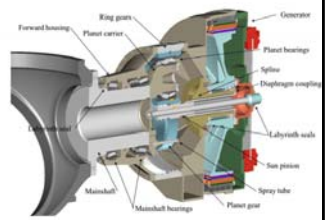
Source: DOE-WWPP

There are a Number of Advanced Drivetrain Technologies Under Consideration

- Superconducting direct drive generators
  - Low temperature and high temperature designs
  - Partially superconducting (rotor only)
  - Fully superconducting (rotor and stator)
  - Advantages: less mass, less volume, reduced load on tower, increased reliability (allowing a much larger air gap tolerance between rotor and stator as compared to permanent-magnet direct drive designs), no rare earth materials
  - Challenges: technical risks, scaling risks, perception risk



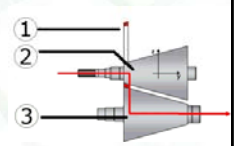
- Advanced permanent magnet generators
  - Permanent magnets with rare-earth mineral alloys in place of induction generators composed of wound electromagnets that require electricity to operate
  - Advantages: Already commercially available; increased power densities; lower parasitic losses; direct-drive permanent magnet configuration eliminates gearbox
  - Challenges: requires large-diameter generator which increase size, weight, use of rare earth material; design, manufacturing, operational challenges; synchronous generator requires extensive power electronics to allow variable speed operation



There are a Number of Advanced Drivetrain Technologies Under Consideration

- Continuously variable transmission
  - Can shift smoothly between infinite number of effective gear ratios (within a range), as opposed to conventional geared systems that offer a limited number of fixed gear ratios
  - Vary gear ratio seamlessly to ensure that the variable low-speed rotation of turbine rotor is always stepped up to exact high-speed rotation required for electricity generation
  - Operate at higher aerodynamic efficiencies over larger range of wind speeds
  - Frictional contact drives
    - Rolling traction (varies angle of contact between transmission components)
    - Belt/chain drives
  - Fluid drive systems
    - Hydrodynamic: use inertia of the fluid to transmit power
    - Hydrostatic: use static pressure to transmit power
- Others
  - Uptower DC generator
  - Ground-level generators
  - Tandem generator
  - Traction or rim-drive turbine
  - Complete uptower gearbox reparability

Source: Fallbrook



Source: RWTH Aachen

Earlier this Year, DOE Issued Awards to 6 Teams to Advance the State of the Art in Wind Turbine Drivetrains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June 28, 2011

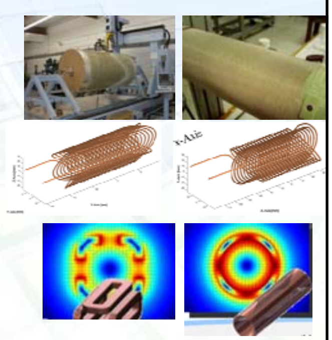
Department of Energy Awards Nearly $7.5 Million to Help Develop Next Generation Wind Turbines

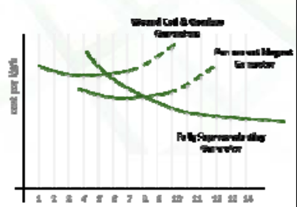
Washington, D.C. - U.S. Energy Secretary Steven Chu today announced that six projects in four states - California, Colorado, Florida, and New York - have been selected to receive nearly $7.5 million over two years to advance next-generation designs for wind turbine drivetrains. Drivetrains, which include a turbine's gearbox and generator, are at the heart of the turbine and are responsible for

- Selected projects will focus on reducing the cost of wind energy by increasing component reliability or redesigning drivetrains to eliminate the need for some components altogether
  - Five projects use direct-drive (gearless) drivetrain technology to increase reliability; 2 projects use superconductivity technology for increased efficiency and lower weight
- Project Leads include:
  - Advanced Magnet Lab (Palm Bay, Florida)
  - Boulder Wind Power (Boulder, Colorado)
  - Clipper Windpower (Carpinteria, California)
  - Dehlsen Associates, LLC (Santa Barbara, California)
  - GE Global Research (Niskayuna, New York)
  - National Renewable Energy Laboratory (Golden, Colorado)

Advanced Magnet Lab is Partnering with Argonne and Others to Develop an Innovative Superconducting Direct-Drive Generator

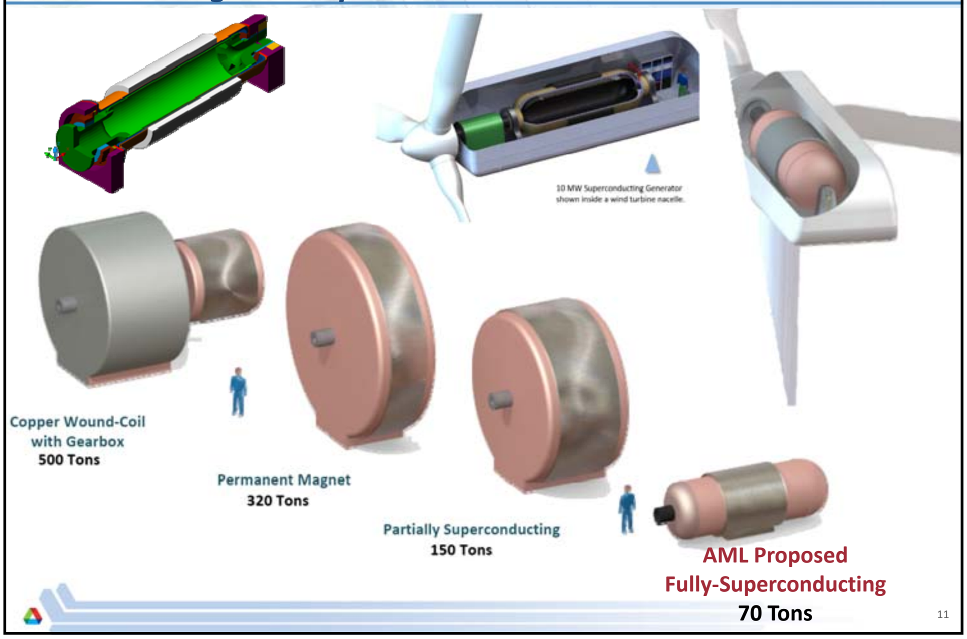
- Partners include: Advanced Magnet Lab (AML), Argonne National Laboratory, Ecomerit, and Emerson
- Uses AML's Double-Helix™ magnet winding technology
  - Uses superconducting rotor and stator: fully superconducting
  - Comes from the world of high energy physics
  - Creates homogeneous "pure" magnetic field, leading to less vibration and higher reliability
  - Uses commercially available magnesium diboride (MgB_2) as superconducting material and a highly reliable cryocooler (gaseous helium)
  - Better performance, higher specific power, less weight lead to lower cost of energy at higher power levels
  - Cost improvements could be well over 40% compared to conventional drivetrains
- Argonne will lead the optimization of the cooling system, based on experience with particle accelerator design and operations





Argonne | ECOMERIT | EMERSON | aml Advanced Magnet Lab

Superconducting versus Conventional: 10 MW Generator Size and Weight Comparison



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Other DOE Drivetrain Awards

- **Boulder Wind Power** will test an innovative permanent magnet-based direct-drive generator. Design requirements and optimization will also be documented for turbines up to 10 megawatts and for turbines deployed in offshore applications. The proposed generator design may operate at higher efficiencies than other permanent magnet generators
- **Clipper Windpower** will develop and test a unique drivetrain design that enables increased serviceability over conventional gearboxes and is scalable to large capacity turbines
- **Dehlsen Associates** will design and test components of an innovative direct-drive concept. The proposed drivetrain configuration eliminates the need for gearboxes, power electronics, transformers, and rare earth materials
- **GE Global Research** will design and perform component testing for a 10 megawatt direct-drive generator employing low-temperature superconductivity technology. The proposed generator employs a unique stationary superconducting component design that reduces the risk of fluid leakage
- **National Renewable Energy Laboratory** will optimize and test a hybrid design that combines the advantages of geared and direct-drives through an improved single-stage gearbox and a non-permanent magnet generator that reduces the need for rare earth materials. The technology developed will be scalable to 10 megawatts, and may be used to retrofit currently deployed 1.5 megawatt turbines

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Conclusions

- Innovative turbine drivetrains have the potential to lower the cost of wind energy
  - Improved reliability
  - Reduced weight and lower capex
  - Larger size and increased energy capture
- Continued technology R&D is needed to realize these cost reductions and position the U.S. as leader in advanced turbine technology