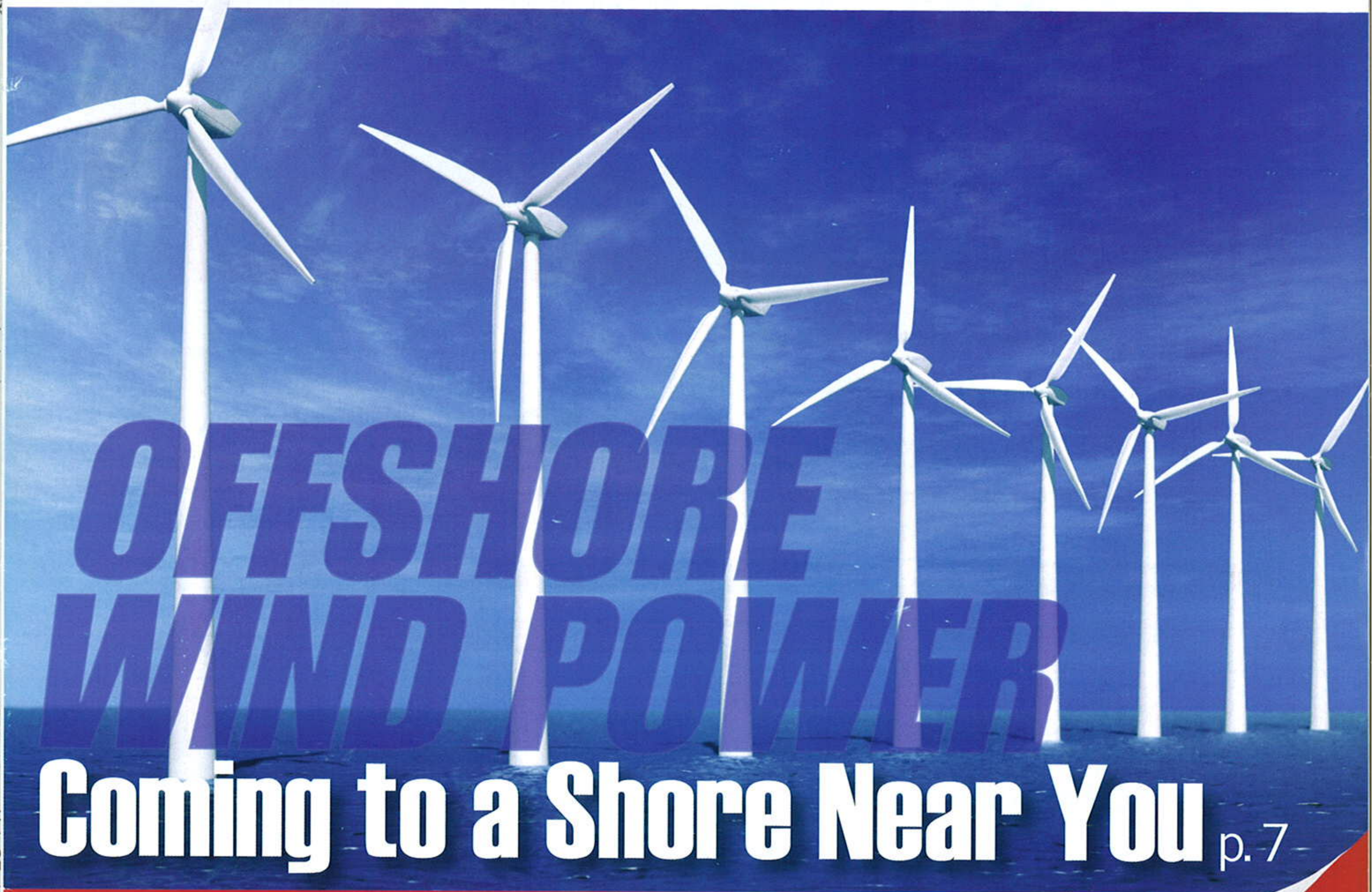
www.powerelectronics.com
APRIL 2011
Vol. 37, No. 4

POWER ELECTRONICS TECHNOLOGY®

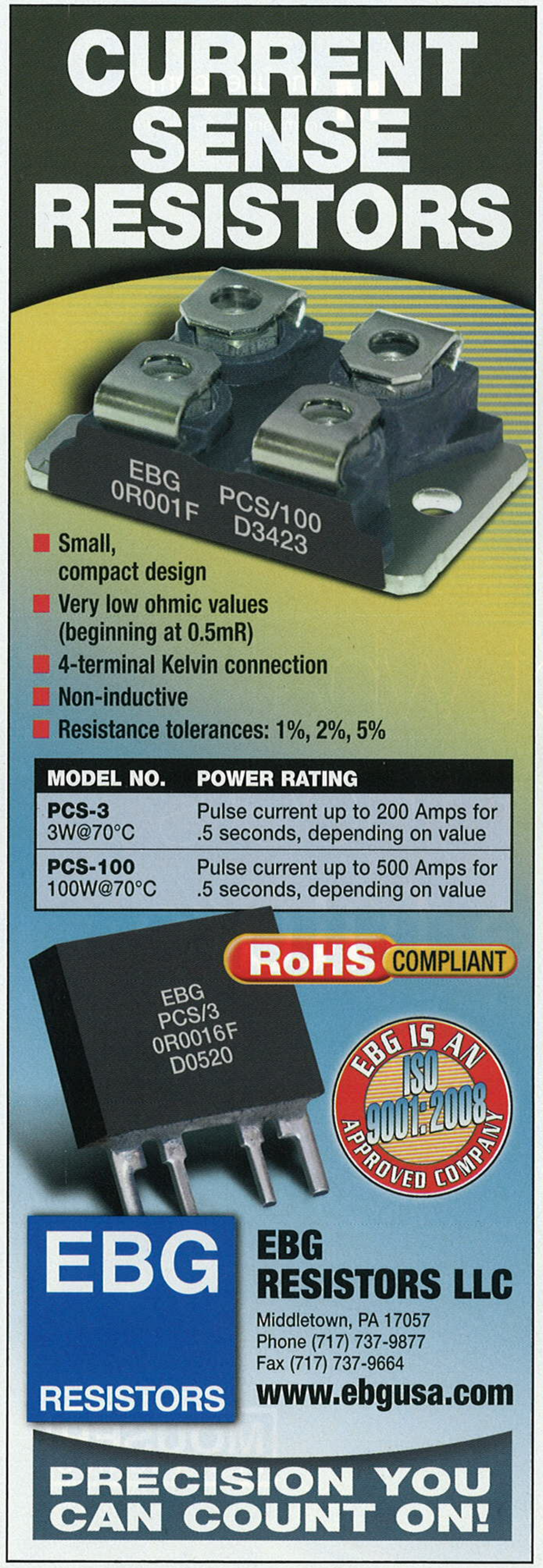
FOR DESIGNERS AND SYSTEMS ENGINEERS



OFFSHORE WIND POWER

Coming to a Shore Near You p. 7

A PENTON PUBLICATION



POWER ELECTRONICS TECHNOLOGY

www.powerelectronics.com

EDITORIAL

EDITOR IN CHIEF: **Sam Davis** (818) 348-3982 sam.davis@penton.com
ART DIRECTOR/GROUP DESIGN MANAGER: **Anthony Vitolo** (212) 204-4376 tony.vitolo@penton.com
MANAGING EDITOR: **Spencer Chin** sdchin@verizon.net
SENIOR ARTIST: **James Miller** (212)204-4371 james.miller@penton.com
STAFF ARTIST: **Michael Descul** michael.descul@penton.com

PRODUCTION

PRODUCTION DIRECTOR: **Vince Potochar** vince.potochar@penton.com
AD PRODUCTION COORDINATOR: **Kara Walby** kara.walby@penton.com
CLASSIFIED PRODUCTION COORDINATOR: **Linda Sargent** linda.sargent@penton.com

AUDIENCE MARKETING

AUDIENCE MARKETING MANAGER: **Michele Bartlett** michele.bartlett@penton.com
Free Subscription • Status of Subscription • Address Change • Missing Back Issues

SALES & MARKETING

GROUP PUBLISHER: **Bill Baumann** (201) 845-2403 Bill.Baumann@penton.com

GROUP SALES MANAGER: **Paul Milnamow** (312) 840-8462 Paul.Milnamow@penton.com

Northwest/Northern CA./Western Canada REGIONAL SALES REPRESENTATIVE: **Jamie Allen** (415) 608-1959 Jamie.Allen@penton.com

South REGIONAL SALES REPRESENTATIVE: **Bill Yarborough** (713) 636-3809 Bill.Yarborough@penton.com

Mid-Atlantic/Central, Southern CA. REGIONAL SALES REPRESENTATIVE: **Tracy Smith** (913) 967-1324 Tracy.Smith@penton.com

East Coast REGIONAL SALES REPRESENTATIVE: **Chuck Curley** (781) 762-2240 Charles.Curley@penton.com

EUROPEAN SALES: **Victoria Hufmann** 49 (0) 911 939764-42 victoria@hufmann.info

CLASSIFIED SALES REPRESENTATIVE: **Joanne Reppas** (201) 666-6698 Jrepfrangides@msn.com

LIST RENTAL: **Marie Briganti** (877) 796-6947 marie.briganti@meritdirect.com

Penton Electronics Group

CHIEF EXECUTIVE OFFICER: **Sharon Rowlands** sharon.rowlands@penton.com
CHIEF FINANCIAL OFFICER/EXECUTIVE VP: **Nicola Allais** nicola.allais@penton.com

Member Organizations: Power Sources Manufacturer's Association
Business Publication Audit of Circulation Inc.

SUBSCRIPTIONS AND BACK ISSUES: (866) 505-7173

REPRINTS: To purchase quality custom reprints or e-prints of articles appearing in this publication, contact Joel Kirk at (216) 931-9324 or joel.kirk@penton.com. Instant reprints and permissions may be purchased directly from our website; look for the iCopyright tag appended to the end of each article.

PHOTOCOPIES: Authorization to photocopy items for internal corporate, personal or instructional use may be obtained from the Copyright Clearance Center at (978) 750-8400. Obtain further information at copyright.com.

MAILING LISTS: Penton Media Inc. makes portions of our magazine subscriber lists available to carefully selected companies that offer products and services directly related to the industries we cover. Subscribers not wishing to receive such mailings should contact the Penton Media Inc. subscriber services at (866) 505-7173 (U.S.) or (402) 505-7173 (outside the U.S.).

PRIVACY POLICY: Your privacy is a priority to us. For a detailed policy statement about privacy and information dissemination practices related to Penton Media Inc. products, please visit our website at www.penton.com.

Power Electronics Technology Conferences/Seminars: (805) 389-6600

EDITORIAL OFFICE: Penton Media Inc., 249 West 17th St., New York, NY 10011 (212) 204-4368, www.penton.com

CORPORATE OFFICE: Penton Media Inc., 249 West 17th St., New York, NY 10011

SAM DAVIS, Editor-in Chief

Technology Solutions Are Key to Offshore Wind Power Benefits

Technology solutions for offshore wind power are challenging, but a successful result would improve U.S. energy independence. Engineering efforts will generally focus on making offshore wind technology economically feasible, reliable, and productive.

ACCORDING TO THE NATIONAL RENEWABLE ENERGY LABORATORY (NREL) the energy-generating potential of offshore wind in the U.S. is immense due to its lengthy coastline and the quality of the resources found there. Offshore winds blow stronger and more uniformly than on land, resulting in greater potential for electricity generation. Offshore wind resource data for the Great Lakes, U.S. coastal waters, and the OCS (Outer Continental Shelf) indicate that for annual average wind speeds above 7 meters per second (m/s), the total gross resource of the United States is 4,150 GW, or approximately four times the generating capacity of the current U.S. electric power system (M. Schwartz 2010). Of this capacity, 1,070 GW are in water less than 30 meters (m) deep, 630 GW are in water between 30 m and 60 m deep, and 2,450 GW are in water deeper than 60 m (*Fig. 1*). The scale of this theoretical capacity implies that under reasonable economic scenarios, offshore wind can contribute significantly to the nationís energy resources.

Wind is an alternative energy technology that has been used to generate electricity for both land- and offshore-based installations. Wind is a viable candidate as an alternate source of energy because it is produced continuously by:

- The sun's uneven heating of the atmosphere
- Earth's surface irregularities
- Terrain
- Bodies of water
- Vegetation
- Earth's rotation

Wind energy is a renewable resource, regardless of how much it is used today, there will always be a similar supply in the future. Wind energy is also a source of clean, non-polluting, electricity. Unlike con-

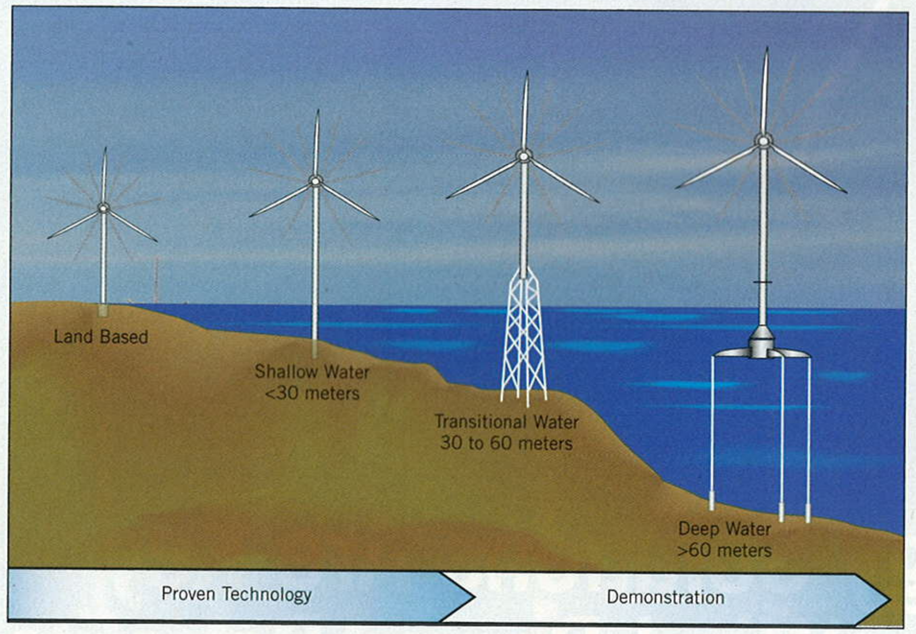


Fig. 1. Substructure technology classes for offshore wind power.

ventional power plants, wind plants emit no air pollutants or greenhouse gases.

Land-based wind power plants (*Fig. 2*) have relatively little impact on the environment when compared with fossil fuel power plants. Sometimes there is concern over the noise produced by the rotor blades (a constant hum when the wind blows), aesthetic (visual) impacts, and birds and bats having been killed by flying into the rotors. In addition, in colder climates they have a propensity to fling chunks of ice from their blades. Most of these problems have been resolved or lessened through technological development, or by properly locating wind farms.

Fig. 2 Biglow Canyon Wind Farm under construction by Portland General Electric in Sherman County, Oregon covers 25,000 acres and will eventually produce 450MW.

WIND TURBINES

Wind flow, or motion energy, activates wind turbines that generate electricity. In operation, wind turbines blades spin a shaft that connects to a generator and produces electricity for the utility grid.

Wind turbines come in a variety of sizes and power ratings. A large turbine can have rotors longer than a football field and can produce enough electricity to power 1,400 homes. Utility-scale offshore turbines range in size from 450 kW to 3.6 MW.

A wind turbine blade works like an airplane's wing. Blowing air passes around both sides of the blade. The shape of the blade causes the air pressure to be uneven - higher on one side of the blade and lower on the other. The uneven pressure causes the blades to spin around the center of the turbine.

Fig. 3 shows the internal components of a wind turbine, including:

Anemometer that measures wind speed and, along with a weather vane and other devices for measuring meteorological conditions, and feeds that information into the turbine's controller. The controller then corrects the turbine's direction, pitch and yaw to best harvest the available wind energy.

Blades are usually made of fiberglass or balsa wood. Most turbines have either two or three blades. The spinning rotor is connected to a shaft, which turns with the breeze. That's not nearly fast enough to generate electricity with a regular generator (50-60 Hz), so in most wind turbines a gearbox secures the correct speed (rpm) for the generator to produce electricity..

Brake is a disc type that can be applied aerodynamically, electrically, or hydraulically to stop the rotor in emergencies. A brake shuts down the turbine if the winds become strong enough to impact the turbine's internal components.

Controller starts up the machine at wind speeds of about 8 to 16 miles per hour (mph) and shuts off the machine at about 55 mph. Turbines do not operate at wind speeds above about 55 mph because that might damage them.

Gear box connects the low-speed shaft to the high-speed shaft and increases the rotational speeds from about 15 to 30 rotations per minute (rpm) to about 1000 to 1800 rpm, the rotational speed required by most generators (alternators) to produce electricity. This is an expensive and heavy part of wind turbines, so some are being replaced with a direct-drive generator tailored specifically to producing electricity from wind. Such generators rely on the permanent magnetic fields created by rare earth magnets, like neodymium.

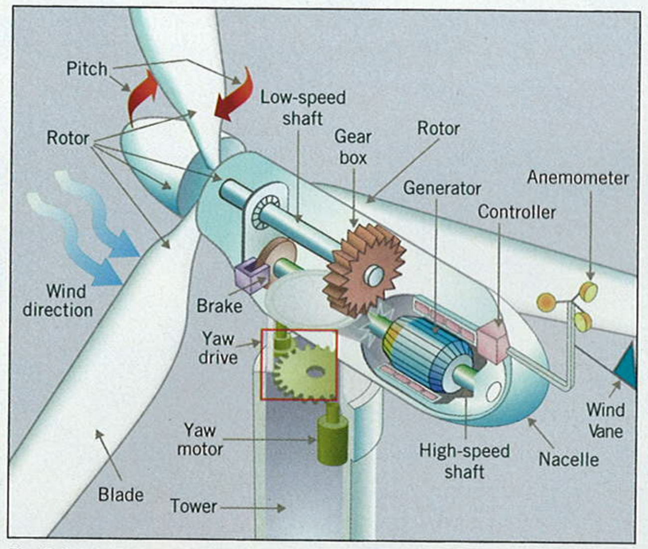


Fig. 3. Internal construction of a typical wind turbine assembly showing all the components.

Generator is usually an off-the-shelf induction generator that produces 60-cycle AC electricity.

High-speed shaft: Drives the generator.

Low-speed shaft: The rotor turns the low-speed shaft at about 15 to 30 rotations per minute.

Nacelle sits atop the tower and contains the gear box, low- and high-speed shafts, generator, controller, and brake. It is essentially the cover for the machinery that translates wind power into electrical power.

Pitch turns blades out of the wind to control the rotor speed and keep the rotor from turning in winds that are too high or too low to produce electricity.

Rotor includes the blades and the hub together. The blades spin the rotor, which is attached to a shaft that transfers the torque it creates into the gearbox. The rotor provides pitch regulation for power output optimization and control. Its speed is variable to maximize the aerodynamic efficiency.

Tower is usually made from tubular steel, concrete, or steel lattice. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity. Wind turbines are mounted on tall towers because the higher up you go, the windier it is, which means more electricity.

Wind direction shown is an "upwind" turbine, because it operates facing into the wind. Other turbines are designed to run "downwind," facing away from the wind.

Wind vane measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind.

Yaw drive in upwind turbines face into the wind. The yaw drive keeps the rotor facing into the wind as the wind direction changes. Downwind turbines don't require a yaw

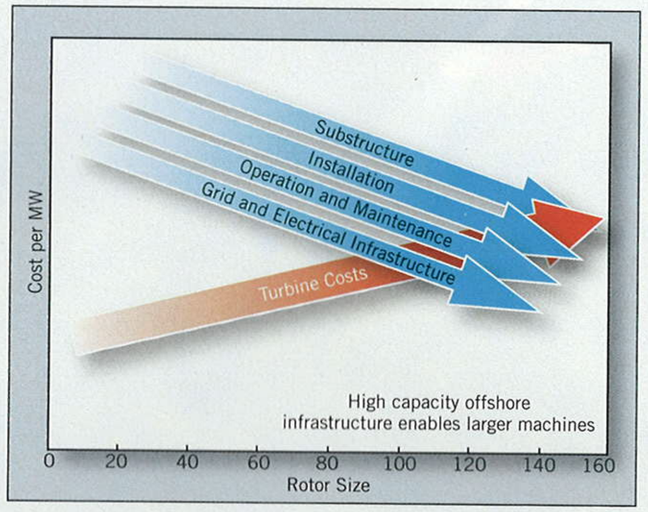


Fig. 4. Larger turbines could actually lower the cost per MW for wind power.

drive, the wind blows the rotor downwind.

Yaw motor powers the yaw drive.

TURBINE TYPES

Modern wind turbines fall into two basic groups: the horizontal-axis and vertical-axis design, Horizontal-axis wind turbines typically either have two or three blades. These three-bladed wind turbines are operated "upwind," with the blades facing into the wind.

Horizontal-axis wind turbines (HAWTs) have the main rotor shaft and electrical generator at the top of a tower, and must be pointed into the wind. Small turbines are pointed by a simple wind vane, while large turbines generally use a wind sensor coupled with a servo motor. Larger turbines capture wind energy more efficiently than smaller ones.

Since a tower produces turbulence behind it, the turbine is usually positioned upwind of its supporting tower. Turbine blades are made stiff to prevent them from being pushed into the tower by high winds. Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted forward into the wind a small amount. Most HAWTs are of upwind design.

Vertical-axis wind turbines (VAWTs) have the main rotor shaft arranged vertically. Key advantages of this arrangement are that the turbine does not need to be pointed into the wind to be effective. This is an advantage on sites where the wind direction is highly variable, for example when integrated into buildings. The key disadvantages include the low rotational speed with the consequential higher torque and hence higher cost of the drivetrain.

The speed and torque at which a wind turbine rotates must be controlled in order to:

- Optimize the aerodynamic efficiency of the rotor in light winds.
- Keep the generator within its speed and torque limits.
- Keep the rotor and hub within their centripetal force limits. The centripetal force from the spinning rotors increases as the square of the rotation speed, which makes this structure sensitive to overspeed.
- Keep the rotor and tower within their strength limits. Because the power of the wind increases as the cube of the wind speed, turbines have to be built to survive much higher wind loads (such as gusts of wind) than those from which they can practically generate power. Since the blades generate more downwind force (putting far greater stress on the tower) when they are producing torque, most wind turbines have ways of reducing torque in high winds.
- Enable maintenance; because it is dangerous to have people working on a wind turbine while it is active, it is sometimes necessary to bring a turbine to a full stop.

The major challenge to using wind as a power source is that it is intermittent and does not always blow when electricity is needed. Wind cannot be stored and not all winds can be harnessed to meet the timing of electricity demands. However, when the wind is not blowing the traditional utility grid can supply power.

A typical electrical circuit for a wind turbine installation includes generator, storage batteries, and a charge controller. The ac output normally goes to a local transformer station (that collects all the turbines' outputs); it is then transformed to a higher voltage and transmitted via a cable or overhead line to an infeed point (another transformer station), where the connection to the normal power grid is made. This voltage must be synchronized with the utility grid.

When the turbine is not producing power it consumes it from the grid. The power is used for:

- Dehumidifying in case of long idling periods
- Yawing the turbine into the wind when the wind comes back
- Control and lighting system
- The hydraulic pump used for pitching (turning) the blades into production position after eventually being in the stop position.

The power consumed by the turbine is very limited compared with what it produces when in its full production mode. The turbines also have small battery back up systems (UPSs) that power navigation lights, aviation warning lights as well as the turbine's control system.

OFFSHORE WIND POWER

Employing offshore wind technologies involve significant challenges. Turbine blades can be much larger without land-based transportation and construction constraints. But, new technology may be required to construct blades greater than 70-meters in length. However, these blades can be allowed to rotate faster offshore, because the noise is less likely to bother people. Faster rotors operate at lower torque, which means lighter, less costly drivetrain components.

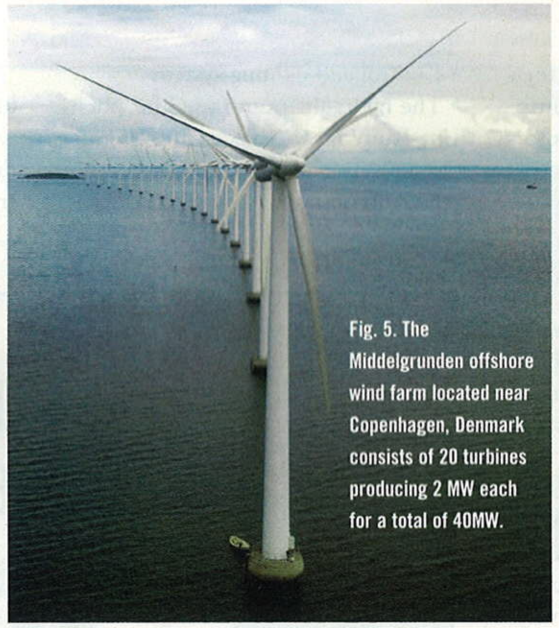


Fig. 5. The Middelgrunden offshore wind farm located near Copenhagen, Denmark consists of 20 turbines producing 2 MW each for a total of 40MW.

A major challenge for offshore wind energy is cost reduction. Developing the necessary support infrastructure implies initial costs for customized vessels, port and harbor upgrades, new manufacturing facilities, and workforce training. In general, capital costs are twice as high as land-based, but this may be partially offset by potentially higher energy yields - as much as 30% or more. As with land-based wind systems over the past two decades, offshore wind costs are expected to drop with greater experience, increased deployment, and improved technology. To make offshore wind energy more cost effective requires systems able to generate more electricity per turbine.

Offshore wind appears to be a leading contender to provide a substantial portion of a low-carbon energy supply for the U.S. In 2007, the European Union (EU) and the European Wind Energy Association (EWEA) established aggressive targets to install 40 GW of offshore wind by 2020 and 150 GW by 2030. In the United States, there are no offshore wind projects yet, but interest is growing with greater than 2,000 MW of offshore wind in the detailed planning, site development, and approval process.

Offshore turbines were originally derived from land-based wind turbines, which have realized a basic level of commercial maturity over the past decade. The evolutionary path taken by land-based designs is not optimum for offshore machines because of the following fundamental differences in the offshore environment, market, and infrastructure:

- Corrosive seawater exposure for towers
- Interference with shipping lanes
- Higher offshore construction costs
- Lightning protection
- Wave loading added to extreme wind and fatigue load
- Other external conditions (e.g., ice and hurricanes)
- Contrasting regulatory, construction, and operational risk profiles
- Greater distances from shore usually mean increased water depth, exposure to more extreme open ocean conditions
- Long distance electrical transmission on high-voltage submarine cables
- Turbine maintenance at sea
- Accommodation of maintenance personnel

Because of these differences, future trends may move toward significant divergences between offshore and land-based designs. Optimized offshore turbine designs may take advantage of innovations and design opportunities that were previously rejected for land-based turbines in order to meet strict noise requirements or to improve aesthetics. Most offshore turbines will be far enough from people that some noise sources, such as aerodynamic blade noise, may not propagate an appreciable distance outside the project perimeter. Low-frequency infrasonic noise should be treated separately, but has not been an issue for modern upwind turbines, even those relatively close to residences.

The cost of an offshore wind turbine (the tower plus the rotor nacelle assembly) is estimated to be less than one-half of the capital cost of the entire wind project. Because transportation and erection size limits are less constrained and costs are higher offshore, the optimum turbine size may be greater than the current sizes that evolved for land, and growth should continue until overall system costs are minimized. The optimized system could even allow for turbines that cost more per megawatt, as long as the life-cycle project costs for the offshore system decrease as turbine size increases. *Fig. 4* shows how offshore project economics favor large turbines. The non-turbine project elements trend toward lower cost on a dollar-per-megawatt basis as turbine size increases. *Fig. 5* shows the Middelgrunden offshore wind Power farm in Denmark.

Even though wind power cost has decreased dramatically in the past decade, it requires a higher initial investment than fossil-fueled generators. Roughly 80% of the cost is the machinery, with the balance in site preparation and installation. If wind generating systems are compared with fossil-fueled systems on a "life-cycle" cost basis (counting fuel and operating expenses for the life of the generator); however, wind costs are much more competitive with other generating technologies, because there is no fuel to purchase and minimal operating expenses.

An ongoing cost factor is the support for wind turbines that requires a local team of engineers that provide fault analysis, modifications and upgrades, retrofitting of turbines, optimization of maintenance procedures, turbine alarm handling, and warranty management. This is needed because a profitable system requires turbines to run at optimum capacity, which also means spare parts are available when needed. ⏻

NEXT GENERATION TURBINES FOR WIND POWER

PIONEERING THE DESIGN of the next generation of wind power turbines is a company appropriately called The Switch, headquartered in Finland. Its new style drive train (see sidebar figure) capitalizes on highly variable wind speeds for maximum energy capture and reliable delivery of high-quality power to the grid.

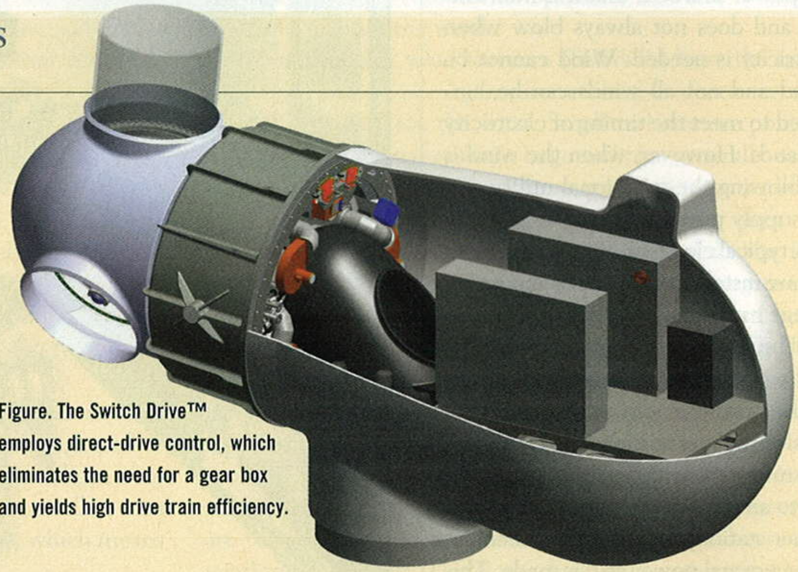


Figure. The Switch Drive™ employs direct-drive control, which eliminates the need for a gear box and yields high drive train efficiency.

Wind turbine manufacturers have long sought a drive train configuration that increases energy production with limited power losses. Responding to this need, The Switch developed The Switch Drive™. It utilizes an optimized permanent magnet generator (PMG) and full-power converter package that enables active power extracted from the turbine, as well as the reactive power produced, to be individually and precisely controlled over the entire operating speed range.

The PMG is a simple form of synchronous generator that requires no connections and energy feed to the rotor. Depending on the application, permanent magnets are placed on the rotor, for low-or medium-speed generators, or embedded in the rotor for high-speed generators.

By driving the generator with an optimal power factor using PMG technology, stator-side losses are also minimized. PMGs do not require any separate excitation systems, thereby reducing cost, simplifying the system, and improving system efficiency because it virtually eliminates rotor losses. Further, no slip rings are used, greatly reducing maintenance needs. Another benefit is that the optimized PMG electro-magnetic circuit reduces cogging and thus vibrations. This extends the lifetime of the turbine and reduces maintenance requirements.

The switch full-power converter is optimized to work with a range of PMG concepts. It features lightweight construction, modular power packs with liquid or air cooling. Customizable software can match all turbine designs and wind conditions, and a rugged design that provides greater fault tolerance and grid support through fault ride-through (FRT) functionality. It is not as sensitive to changes in the network as traditional converters, and offers control advantages for adapting to ever-changing operational conditions.

According to Panu Kurronen, PMG product specialist at The Switch, PMG efficiencies remain very high, close to nominal value, over a wide range of speeds. Wind turbines using the company's PMG and full-power converter exhibit up to 20% higher partial load efficiency, yielding more energy. Plus, PMG efficiency at partial speed is superior to that of conventional double-fed or squirrel-cage systems. Another advantage of The Switch Drive is its ability to tune itself to individual sites and seasonal conditions.

In the wind power industry, PMGs typically produce efficiency levels up to 98% at the rated point. When used in low-speed, direct-drive applications, generator efficiency is not quite as high, but it eliminates the need for a gearbox, creating excellent overall drive train efficiency.

Moreover, because it is designed for the highest level of performance to lower demands on the grid, the robust grid-side converter assures stable and high-quality electricity. For example, the converter was designed to assure low harmonics, which meet IEEE 519 requirements, resulting in extremely low flicker. These considerations allow for greater flexibility in selecting turbine sites.

REFERENCES

1. Large-Scale Offshore Wind Power in the United States Assessment Of opportunities and Barriers, September 2010, NREL/TP-500-40745.
2. A National Offshore Wind Strategy, Creating an Offshore Wind Energy Industry in the United States.