MODERN WIND GENERATORS

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INTRODUCTION

An exposition of the characteristics of modern wind generators designs from the leading manufacturers is advanced to show their components and their respective design characteristics.

Modern wind turbines design and production is a modern high-tech technology at the same level of airplane manufacture. Consider that the rotor blade span diameter of a 2.3 MW wind turbine is 93 meters; this is larger than the wingspan of a Boeing 747-400 Jumbo Jet, which measures only 70 meters.

We consider modern wind turbine designs from different manufacturers and discuss their prominent features and differences.

MAIN CHARACTERISTICS

Four major developments characterize modern wind machines. The first development was considered for a while as a trade secret and involves the almost universal adoption of flexible or teetering rather than rigid hub structures, preventing catastrophic failure under gust wind conditions.

The second development involves the use of the economy of scale with larger capacity turbines reaching the 5-7 MW level, particularly for offshore siting.

The third development is the use of variable speed turbines. Variable speed operation is a design feature that ensures that the turbines work at high efficiency, compared with fixed speed wind turbines which only reach peak efficiency at a particular wind speed. While constant speed rotors must deflect high wind gust loads, the variable speed operation absorbs the loads from the wind gusts and converts them into electric power.

The fourth development is the adoption of gearless wind turbines eliminating the gearbox as the weakest link in the chain in the design of modern wind turbines: gearboxes last for an average of 5 years failing probably due to misalignment during operation over the 20 years design lifetime or to severe strain and shape changes under sudden wind gusts. In addition, it eliminates the need for oil cooling avoiding one cause of fires and environmental pollution in the case of the lubricating oil spillage. Like small wind turbines, these have inverters instead of synchronous generators, that is to say, a separate controller that converts the AC electrical power generated into a form that the grid can be fed with. This last gearless feature has not yet been universally adopted like the flexible hub concept.

MAIN MANUFACTURERS

The main wind manufacturer percentage of the electrical installed capacity worldwide is shown in Table 1. There are 10-12 manufacturers of large utility scale systems; marketing 200 kW to 7 MW rated capacity systems of different configurations. These include three-bladed turbines with full span pitch control and two-bladed stall control machines with teetering hubs.

Table 1: Wind turbines manufacturers share of installed capacity as of 2005.

Manufacturer	Installed Capacity 2004 [MW]	Installed Capacity 2005 [MW]	Share 2005 [percent]
Vestas, Denmark	17,580	3,186	27.9
General Electric (GE), USA	5,346	2,025	17.7
Enercon, Germany	7,045	1,505	13.2
Gamesa, Spain	6,438	1,474	12.9
Suzlon, India	785	700	6.1
Siemens, Germany	3,874	629	5.5
Repower, Germany	1,169	353	3.1
Nordex, Germany	2,406	298	2.6
Ecotècnia, Spain	744	239	2.1
Mitsubishi, Japan	1,019	233	2.0
Japan Steel Works, JSW, Japan, and others	4,359	557	5.0
Total			100.0

In late 1996, the now defunct Enron Company in the USA purchased Zond Systems based in California, which used designs based on the Vestas Danish company. Enron was a mediocre steward of the Zond technology, which was apparently its only economically viable division. The General Electric (GE) company in the USA purchased it in 2003, in addition to the German manufacturer Tacke, consequently maintaining the USA's position visibility in the global wind turbine market.

VESTAS WIND GENERATORS

The Vestas V90 3.0 MW three blades wind generator uses carbon fibers as a structural material for the load bearing spars. Carbon fiber is intrinsically lighter than fiberglass used in other designs and its strength and rigidity also reduce the quantity of material needed, thus cutting overall weight.

The V90 has a swept area of 6,362 m^2 with blades with a diameter of 90 m. Their nominal revolution speed is 16.1 rpm with an operational interval of 9-19 rpm. Power regulation is through pitch/variable speed control. Its air brake is by full blade pitch by three separate pitch cylinders. The hub can be built on top of towers that are 65, 80, 90 or 105 m in height.

The cut-in wind speed is 4 m/s, with a nominal wind speed of 15 m/s. The cut-out wind speed is 25 m/s.

The generator is asynchronous with a converter rated at a nominal 3.0 MW at 60

Hz and 1 kV.

The gearbox consists of two planetary stages and one helical stage.

Control is achieved with microprocessor based control of all the turbine functions with the option of remote monitoring. Output regulation and optimization are via variable speed control and pitch regulation.

For a tower height of 105 m, the tower weights 275 metric tonnes (mt), the nacelle 68 mt, the rotor 40 mt, for a total of 383 mt.

The profile of the V90 blades optimizes the relationship between the overall load impact on the turbine and the volume of energy generated annually. The airfoil improves energy production, while making the blade profile less sensitive to dirt on the leading edge and maintains a favorable geometrical relationship between successive airfoil thicknesses. This translates into an increase in output combined with a decrease in load transfers.

To increase fatigue strength magnets are used to fasten the internal components to the tower walls.

Fig. 1: Vestas V90 3.0 MW wind generator. Source: Vestas.

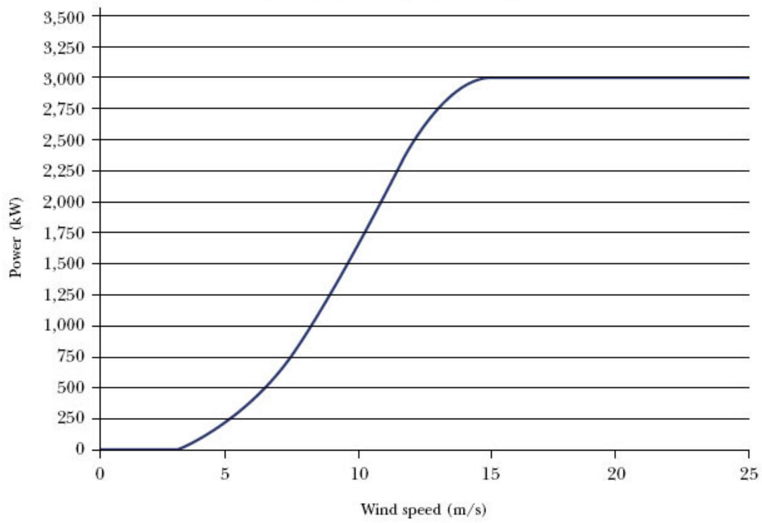


Fig. 2: Power curve of the V90 3.0 MW Vestas wind generator. Source: Vestas.

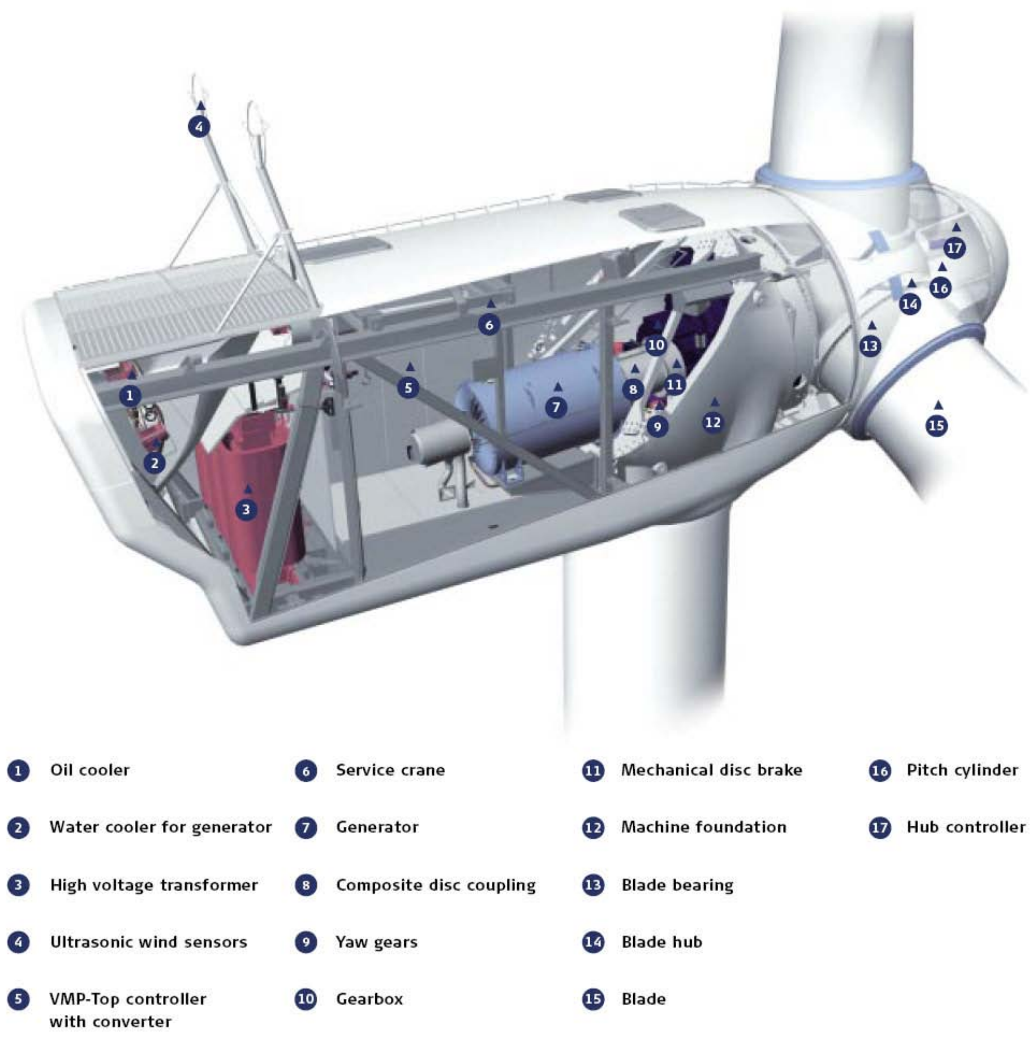


Fig. 3: The Vestas V90 3.0 MW wind generator nacelle components. Source: Vestas.

The nacelle integrates the hub bed plate directly into the gearbox, eliminating the main shaft and thus shortening nacelle length. The result is a nacelle that can generate much more power without any appreciable increase in size, weight or tower load.

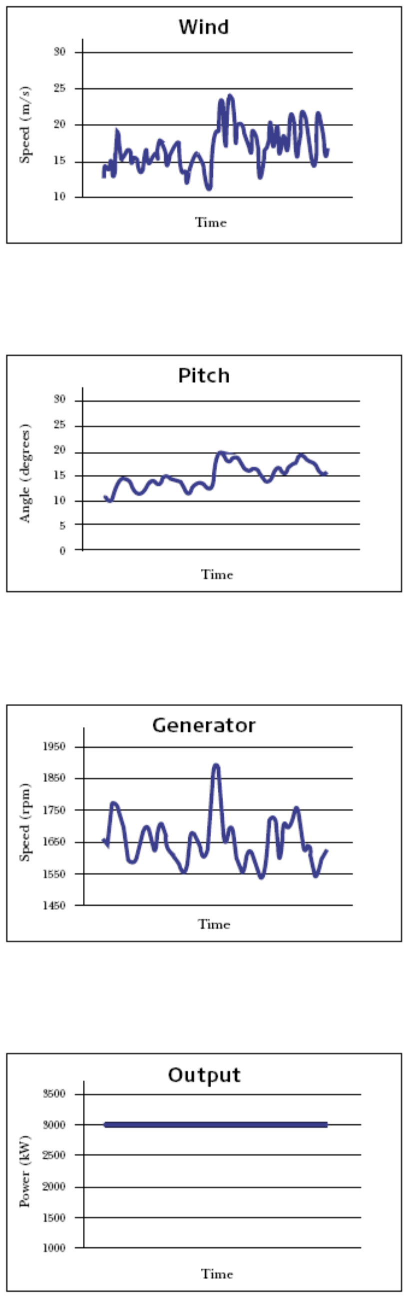
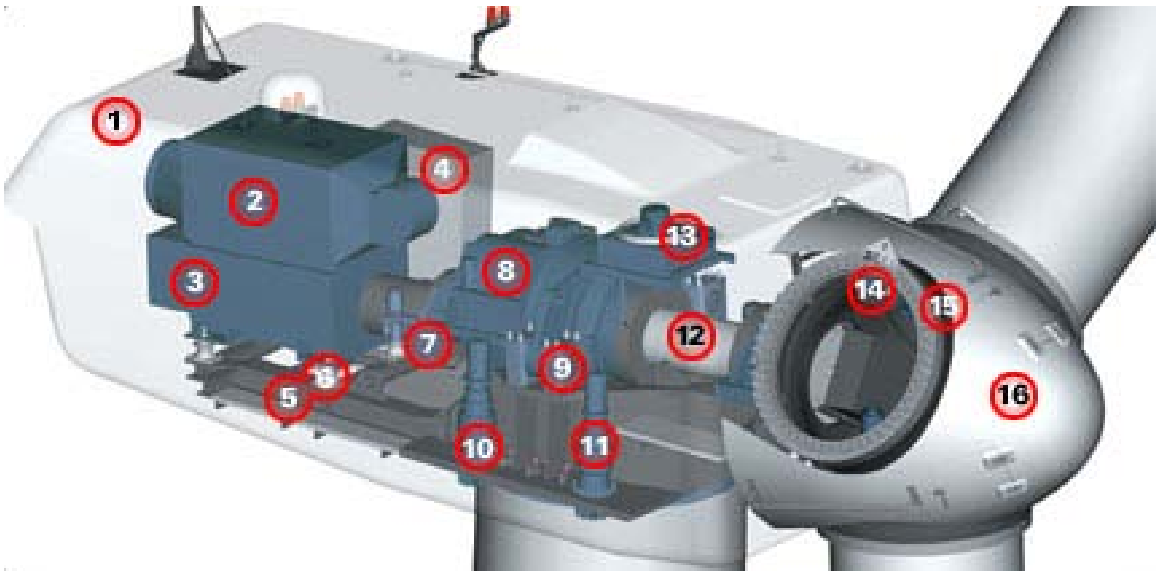


Fig. 4: Wind speed, pitch angle, generator speed and power output of V90 3.0 MW wind generator. As the wind speed varies, the variation in the pitch angle and the

speed of the rotor and generator maintain a constant power output. Source: Vestas.

The V90 3.0 MW allows the rotor speed to vary within a range of approximately 60 percent in relation to nominal rpm. Thus the rotor speed can vary by as much as 30 percent above and below synchronous speed. This minimizes both unwanted fluctuations in the output to the grid supply and the loads on the vital parts of the construction.

GENERAL ELECTRIC, GE WIND TURBINES



Nacelle (1), Heat Exchanger (2), Generator (3), Control Panel (4), Main Frame (5), Impact Noise Reduction (6), Hydraulic Parking Brake (7), Gearbox (8), Impact Noise Reduction (9), Yaw Drive (10 and 11), Main Shaft (12), Oil Cooler (13), Pitch Drive (14), Rotor Hub (15) and Nose Cone (16).

Fig. 5: The General Electric GE 1.5 MW Wind turbine Nacelle. Source: GE.

The GE Company had a $4 billion wind energy revenue in 2007, increasing to $6 in 2008. In 2008 it had a $1 billion contract with Invenergy Wind LLC from Chicago, Illinois for 750 MW of wind power to be installed by 2010. This followed another $1 billion contract for European wind farms to be built by 2009. At 3.75 kW electrical usage per household, this would provide electricity to 750,000 /3.75 = 200,000 homes. The capital cost amounts to 10^9 / 750,000 = 1,333.3 $/kW of installed capacity.

The GE 1.5 MW wind turbines are active yaw and pitch regulated with power/torque control capability and an asynchronous generator. The yaw system is electro-mechanically driven with a wind direction sensor and automatic cable unwinding that could cause shorts and fires. Power is varied using active blade pitch control. The blade pitch angle is continually adjusted for optimum rotational speed and maximum lift-to-drag at each wind speed.

Variable speed operation as a design feature ensures the turbines work at high efficiency, compared with fixed speed wind turbines which only reach peak efficiency at a particular wind speed. While constant speed rotors must deflect high wind gust loads, the variable speed operation absorbs the loads from the wind gusts and converts them to electric power. Cut-in and cut-out wind speeds are 3 m/s and 25 m/s respectively. The three blades give a rotor diameter of 77 m with a swept area of 4,657 m^2. Rotor speed is variable between 10.1 rpm and 20.4 rpm.

OVERSPEED IN STRONG GUSTY WINDS

The generator torque in the turbines is controlled by the frequency converter. The turbine rotor can overspeed in strong, gusty winds to reduce the torque loads in the drive train. The GE's turbines store the energy in gusts by accelerating the rotor. The operating speed range is notably wider than the slip range used by other wind generators manufacturers, which produce heat rather than electric power when regulating power in strong, gusty winds.

The conversion system generates reactive power or current leading voltage to improve transmission efficiencies and voltage stability, particularly useful in weak grid applications. It automatically maintains defined grid voltage levels and power quality in fractions of a second.

FAIL-SAFE BRAKING AND LIGHTNING PROTECTION

The wind generator's fail-safe braking system has electromechanical pitch control for each blade with three self-contained systems and a hydraulic parking brake. Lightning receptors are installed on the blade tips, with surge protection for the electrical components.

The turbines can remain on-line and feed reactive power to the electric grid right through major system disturbances. A Low Voltage Ride Thru (LVRT) feature enables wind turbines to meet transmission reliability standards similar to those demanded of conventional power plants thermal generators.

Active damping of the entire wind turbine system gives less tower oscillation than constant speed wind turbines. Active damping also limits peak torque, providing greater drive train reliability, reduced maintenance cost and longer turbine life. The bedplate drive train design provides that all nacelle components are joined on a common structure for durability. A three-step planetary spur gear system is used, with both the generator and the gearbox supported by elastomeric elements to minimize noise emissions.

SUZLON WIND GENERATORS

A design feature in the Suzlon 1.25 MW wind turbine generator is the minimization of energy losses. A direct grid connected high speed generator, in combination with a multiple stage combined spur/planetary gearbox, offers greater robustness and reliability than a low-speed generator connected to the electrical grid via AC-DC-AC inverter systems. It delivers harmonics free and grid friendly power.

The salient features of such a design are:

1. Optimized efficiency and wind rotor power coefficient (Cp).
2. Well balanced weight distribution ensures minimum static stress and dynamic loads.

3. An advanced hydrodynamic fluid coupling system absorbs peak loads and vibrations assuring shock load free operation.
4. Intelligent control technologies inspired by operational experience maximizes the yield.
5. High speed asynchronous generator with a multi-stage intelligent switching compensation system delivers power factor up to 0.99 assuring a maximum power factor operation.
6. Hermetically sheltered, advanced over voltage and lightning climatic shield protection system.
7. Micro fine rotor pitch control with a 0.1 degree of rotation resolution to extract maximum power from the wind stream.
8. Grid friendly design generates harmonics-free pure sinusoidal power

Fig. 6: The Suzlon 1.25 MW wind turbine generator yaw mechanism. Source: Suzlon.

Fig.7: The Suzlon 1.25 MW electrical generator. Source: Suzlon.

STRESS AND LOAD REDUCTION

The wind turbine is subjected to combination of static, dynamic and peak load induced stresses. The static stresses are taken care of by a well-balanced weight distribution design. Wind induced dynamic radial loads are picked up by the separate main shaft bearing, which is integrated into the gearbox housing.

Peak loads are compensated by a torque adjustable fluid coupling which also acts as an excellent vibration separation and shock-dampening device.

AMBIENT CONDITIONS PROTECTION

In addition to mechanical stresses, a wind turbine is also subjected to thermal stresses, moisture, salinity, dust, snow, lightning strikes and extreme wind conditions. The components are hermetically sheltered. An over-voltage and lightning protection system is in compliance with international standards.

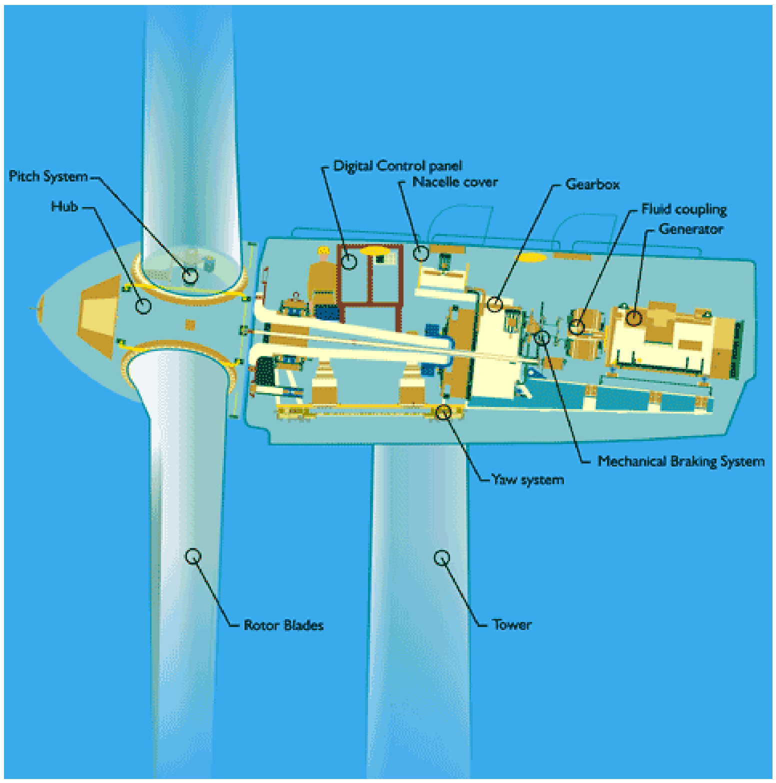


Fig. 8: The Suzlon 1.25 MW wind generator. Source: Suzlon.

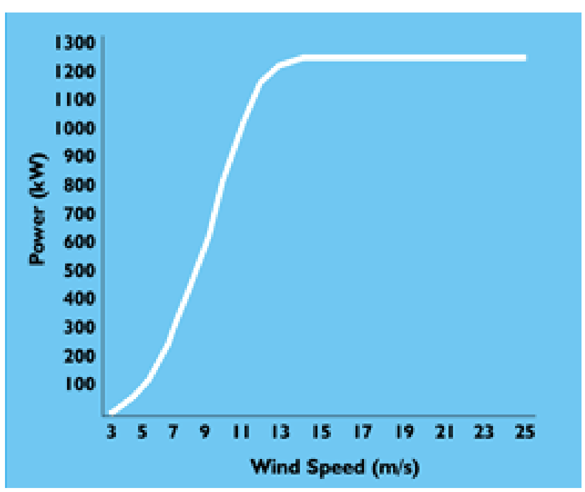


Fig. 9: The Suzlon 1.25 MW wind turbine power curve. Source: Suzlon.

TECHNICAL SPECIFICATIONS

Operating Data	S.64/1250 (50 Hz)	S.64/1250 (60 Hz)	S.66/1250 (50 Hz)	S.66/1250 (60 Hz)
Rotor diameter	64 m	64 m	66 m	66 m
Hub height	65 m (variable as per requirement)			
Installed electrical output	1,250 kW			
Cut-in wind speed	3 m/s			
Rated wind speed	12 m/s	12 m/s	12 m/s	12 m/s
Cut-out wind speed	25 m/s			
Survival wind speed	67 m/s			

Rotor	S.64/1250 (50 Hz)	S.64/1250 (60 Hz)	S.66/1250 (50 Hz)	S.66/1250 (60 Hz)
Blade	3 bladed horizontal axis			
Swept area	3217 m^2	3217 m^2	3421 m^2	3421 m^2
Rotational speed	13.9 / 20.8 rpm			
Regulation	Pitch regulation			

Generator	S.64/1250 (50 Hz)	S.64/1250 (60 Hz)	S.66/1250 (50 Hz)	S.66/1250 (60 Hz)
Type	Asynchronous 4/6 poles			
Rated output	250 / 1250 kW			
Rotational speed	1006/1506 rpm	1208/1807 rpm	1006/1506 rpm	1208/1807 rpm
Frequency	50 Hz	60 Hz	50 Hz	60 Hz

Gearbox	S.64/1250 (50 Hz)	S.64/1250 (60 Hz)	S.66/1250 (50 Hz)	S.66/1250 (60 Hz)
Type	Integrated (1 planetary and 2 helical)			
Ratio	74.917 : 1	89.229 : 1	74.917 : 1	89.229 : 1

Yaw System	S.64/1250 (50 Hz)	S.64/1250 (60 Hz)	S.66/1250 (50 Hz)	S.66/1250 (60 Hz)
Drive	4 electrically driven planetary gearbox			
Bearings	Polyamide slide bearings			

Braking System	S.64/1250 (50 Hz)	S.64/1250 (60 Hz)	S.66/1250 (50 Hz)	S.66/1250 (60 Hz)
Aerodynamic brake	3 independent systems with blade pitching			
Mechanical brake	Hydraulic fail-safe disc brake system			

Control Unit	S.64/1250 (50 Hz)	S.64/1250 (60 Hz)	S.66/1250 (50 Hz)	S.66/1250 (60 Hz)
Type	Programmable microprocessor-based; high speed data communication, active multilevel security, sophisticated operating software, advance data collection remote monitoring and control option, UPS back up, real time operation indication			

ROTOR BLADES

The rotor blades are aerodynamically optimized to provide high lifting forces and low air resistance values. They are manufactured using Resin Infusion Molding (RIM) technology, which makes them lightweight, and at the same time possess high stiffness and mechanical strength. Their low weight to diameter ratio results in lower stresses enhancing the life and efficiency of the turbine.

The rotor blades are the starting point of the train for power transmission. Even a small increase in blade efficiency is magnified across the power train to give higher efficiencies for the entire machine.

MICRO PITCH SYSTEM

The rotor blades are connected to the hub via pitch ball bearings and can swivel fully perpendicular to the direction of rotation. The motors of the pitching system have an in-built intelligent system, with frequency control drives controlled by their own microprocessor. These intelligent frequency drives communicate with the control system in real time, with a response time of 30 ms. The control system updates the motors after gauging the available wind regime, and the motors constantly update the control system on the instant blade angle.

A precision electromechanical micro pitch mechanism achieves 0.1 degree pitching resolution, resulting in extreme fine tuning of the aerodynamic profile.

ELECTRICAL GENERATOR MACRO SLIP MECHANISM

The flexible, adjustable slip system in the electrical generator offers a maximum slip of as high as 16 percent, thereby increasing the efficiency of energy conversion by ensuring extremely low loss of power from wind due to gusts and frequent changes in wind speeds.

The robust and compact mechanism ensures that the overall machine reliability is maximized. The system is simple, easy to use and cost effective to service. The main advantage of the system is that it allows the use of standard, conventional generators with proven reliability. The macro slip mechanism is finely synchronized with the micro pitching mechanism to give optimum performance. The entire related power electronics is static and does not rotate at high speeds, increasing their reliability and overall life.

GEARBOX

A multi stage planetary and spur wheel gearbox ensures the highest possible mechanical efficiency and power. The first planetary gear stage takes up the slow rotor movement and distributes the high torque input to the subsequent planetary gears.

Reduced torque values and increased rotational speeds are optimally converted to the high-speed operation of the generator.

A permanent, mechanically driven oil-pump supplies the gearbox and main shaft bearings with pressure lubrication, in addition to the splash lubrication.

A micro filtering system retains the quality of the oil and assures an extended service interval. An oil cooling device provides temperature optimization under full load operation.

ASYNCHRONOUS GENERATOR

A 4 pole, single winding, asynchronous slip ring type generator with a highly adaptable and flexible macro slip mechanism leads to high efficiency values.

The high slippage is achieved by varying the resistance on the rotor windings dynamically. The resistors are connected to the rotor windings via a slip ring mechanism making them static and mountable outside the generator cage. Externally mounted resistors provide excellent heat dissipation and the resistors do not rotate at the high speed of the rotor, which results in a longer service life.

These generators are robust and have a proven track record of decades in operation. The moisture repellant insulation in a high class F configuration combined with a forced surface air cooling system provides total protection from moisture and dust.

A welded squirrel cage, vibration resistant windings and a regreasing device with a grease collection chamber result in increased service life and longer maintenance intervals.

DIGITAL CONTROL SYSTEM

The control system is scalable in nature with standard interface options including RS232/422/485, Ethernet, Fiber optic link, CAN Bus, and networking. An option for web-enabled communication is also available. The entire control system is modular and offers a high degree of customization.

The grid connection module is designed for soft connection to the grid. With COS PHI circuitry, it ensures effective current control at all times, before, during and after the synchronous point. The pitch module has its own microprocessor to perform the pitch calculations. Various safety modules for rotor revolution and vibration ensure safe and reliable running of the turbines. The control systems have a condition monitoring feature to help monitor the health of the turbine for any predictive and preventive maintenance.

A graphical display unit shows information about the performance and the state of various parameters. The remote monitoring and control options have various combinations which can be customized.

The system is designed to perform in tough environmental conditions, and can withstand shock, vibration and temperatures ranging from arctic cold to hot and humid tropical.

YAW SYSTEM

A braking torque adjustable polyamide slide bearing transmits the loads from the nacelle to the tower through an expansive surface.

The yawing movement is activated and controlled by 3 electrically braked gear motors. Precise wind direction measurement and an advanced statistics software ensure an exact alignment of the rotor to the wind, thereby reducing energy losses and additional loads caused by oblique incident flows.

A cable twist sensor in the yaw system monitors over twisting of cables due to constant wind direction changes and alerts the controller to untwist the cables.

MECHANICAL BRAKING SYSTEM

In addition to the aerodynamic braking system, the turbines are equipped with mechanical braking to stop the wind turbine in case of an emergency.

The disc brake is configured to be fail-safe. It is activated by spring forces and released hydraulically.

This combination of aerodynamic and mechanical systems, allows for complete load control during braking processes and maximum load reduction in any operational case, ensuring safety to the wind turbine even in case of an emergency.

HYDRAULIC SYSTEM

A hydraulic system, similar to the one found in jet planes, supports the mechanical braking devices. A motor and pump assembly draws oil from a reservoir and pushes it via high efficiency filters through the system to ensure that the hydraulic oil remains clean during an extended service interval.

STRUCTURAL TOWER

An option of tubular or lattice tower can be chosen. Stiffness of both these designs eliminates the critical natural frequencies of the tower. This reduces the dynamic stressing of the tower and the entire wind turbine to a minimum.

A high corrosion protection system comprising several layers of either epoxy coat, in case of tubular towers, or hot dip galvanization, in case of lattice towers, protects the structure and increases its service life.

Nondestructive testing, including ultrasonic and x-ray tests are part of the quality management system. The climbing guard system meets the requirements of international safety supervisory authorities.

NACELLE COVER

The nacelle cover is made of fiber reinforced plastic and designed in such away that the internal components are fully protected against various ambient conditions. It also ensures adequate noise dampening.

SIEMENS WIND TURBINES

DESIGN CHARACTERISTICS

The salient characteristics of the Siemens wind turbines designs are:

1. Simple generator systems without slip rings.
2. A fail-safe double safety systems approach.
3. A rugged, conservative structural design.
4. Use of well proven lightning protection methods of the rotor blades, the nacelle and the controller.
5. Automatic lubrication systems with ample suppliers.
6. Climate control of the internal environment for turbines of 2.3 MW rated power and higher.

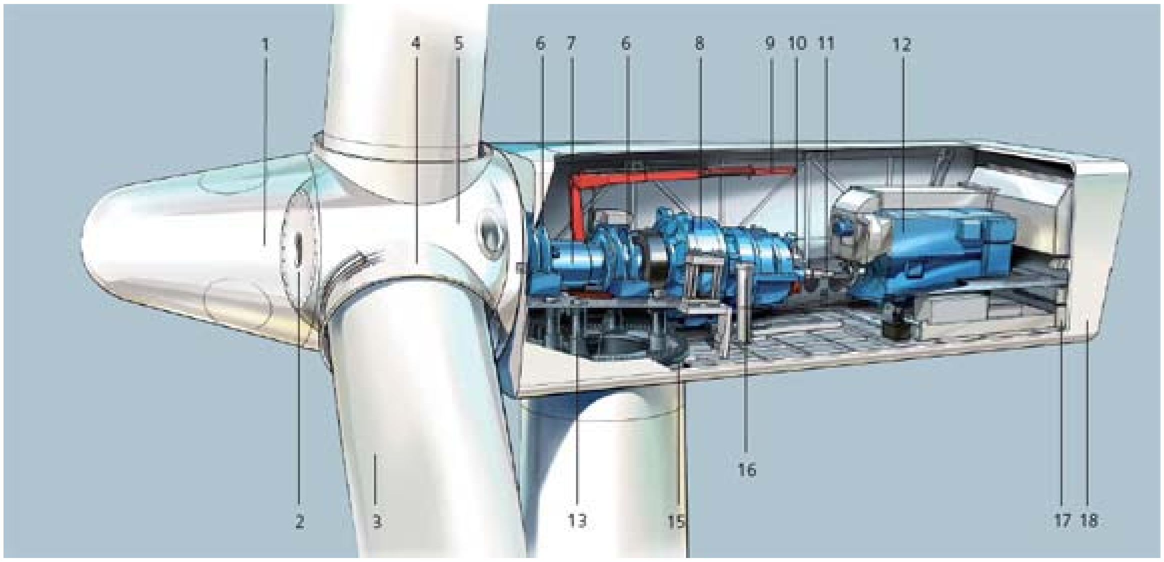
TURBINE DESIGN VARIANTS

The SWT-2.3-93, 2.3 MW wind turbine is a large rotor variant of the SWT-2.3-82 VS. It provides optimum project economy for low and medium wind sites.

The SWT-2.3-82 VS, 2.3 MW turbine is a variable speed turbine with pitch power control referred to as the proprietary CombiPitch variant of the 2.3 MW turbine. It fits a noise restricted segment of the SWT-2.3 spectrum.

The SWT-1.3-62, 1.3 MW wind turbine is a widely-proven work horse for small and moderate size projects and for projects with noise or structural tower height restrictions.

The SWT-2.3-82, 2.3 MW wind turbine is a recommended option for utilities and other large developers and is particularly suited for high wind sites.



1 Spinner	**10** Brake disc
2 Spinner bracket	**11** Coupling
3 Blade	**12** Electrical generator
4 Pitch bearing	**13** Yaw gear
5 Rotor hub	**14** Tower
6 Main bearing	**15** Yaw ring
7 Main shaft	**16** Oil filter
8 Gearbox	**17** Generator cooling fan
9 Service crane	**18** Canopy

Fig. 10: Nacelle components of the SWT-2.3-93, 2.3 MW Siemens wind turbine. Source: Siemens.

Fig. 11: Interior view of a Siemens wind turbine nacelle. Source: Siemens.

CHARACTERICTICS OF THE SWT-3.6-107, 3.6 MW WIND TURBINE

The SWT-3.6-107 wind turbine is meant for both offshore and for onshore wind farms.

Rotor

The rotor of the SWT-3.6-107 turbine is of a three blade cantilevered configuration, mounted upwind of the tower. The power output is controlled by pitch regulation. The rotor speed is variable in order to maximize the aerodynamic efficiency and the speed compliance during power regulation. This also minimizes the dynamic loads on the transmission system.

Rotor blades

The rotor blades are manufactured of Fiber Glass Reinforced Epoxy (GRE) and are manufactured by Siemens in a single operation. No glue joints exist between the spars and the shells, with no weak points and no easy access for water or lightning strikes.

The aerodynamic design of the rotor blades has been tested at a test site under both static and dynamic loadings. They are mounted on pitch bearings and can be feathered 80 degrees for shutdown purposes. Each blade has its own independent fail safe pitching mechanism capable of feathering the blade under any operating condition, and allowing fine tuning to maximize the power output.

Gearbox and brakes

The gearbox is a custom built 3 stage planetary helical design that is mounted on the nacelle with flexible rubber bushings, thereby providing a compact high performance construction and the lowest possible noise level. The gearbox is fitted with fail safe mechanical brakes at the high speed electrical generator shaft.

Electrical generator

The electrical generator rotor construction and stator windings are designed for high efficiency at partial loads. It is fitted with a separate thermostat controlled ventilation system. With efficient cooling, the electrical generator can be operated at temperatures well below the normal level of the standard insulation class, thereby providing the best possible lifetime of the winding insulation.

Structural tower

The structural tower is of a tapered tubular steel configuration. The tower has internal ascent and direct access to the yaw system and nacelle.

Turbine controller

The turbine controller is a microprocessor based industrial controller. It is self contained with switch gear and protection devices. It is self diagnosing and has a keyboard and display for easy readout of status and for adjustment of the settings.

Operation

The wind turbine operates automatically and is self starting when the wind reaches an average speed of about 3–5 m/s. The output increases linearly with the wind speed until the wind reaches 13–14 m/s. At that point the power is regulated at the turbine's rated power output. If the average wind speed exceeds the maximum operational limit of 25 m/s, the turbine is shut down by feathering of the blades using the pitch mechanism. When the wind drops back below the restart speed the safety systems reset automatically.

Safety system

The turbine has several redundant levels in the safety system, including an independent pitch system for each of the rotor blades, and as a result the turbine can shut down safely from any operational condition.

Remote control

The turbine is equipped with the WebWPS Surveillance, Control and Data

Acquisition (SCADA) system. The system offers long distance control and a variety of status views and useful reports from a standard internet web browser.

Grid compliance

The turbine is fitted with a NetConverter system that is compliant with demanding grid codes. It has a ride through capability for all normal faults.

TECHNICAL SPECIFICATIONS, SWT-3.6-107

Rotor

Type	3- bladed, horizontal axis
Position	Upwind
Diameter	107 m
Swept area	9,000 m^2
Rotor speed	5-13 rpm
Power regulation	Pitch regulation with variable speed
Rotor tilt	6 degrees

Blades

Type	B52
Blade length	52 m
Tip chord	1.0 m
Root chord	4.20 m
Aerodynamic profile	NACA 63.xxx, FFAxxx
Material	Fiber Glass Reinforced Epoxy (GRE)
Surface gloss	Semi-matt, <30 / ISO2813
Surface color	Light gray, RAL 7035
Blade manufacturer	Siemens Wind Power A/S

Aerodynamic brake

Type	Full span pitching
Activation	Activate, fail safe

Load supporting parts

Hub	Nodular cast iron
Main bearings	Spherical roller bearing
Transmission shaft	Alloy steel
Nacelle bedplate	Steel

Transmission system

Coupling hub - shaft	Flange
Coupling shaft - gearbox	Shrink disc
Gearbox type	3-stage planetary-helical
Gearbox ratio	1 : 119
Gearbox lubrication	Forced lubrication
Oil volume	About 750 liters
Gearbox cooling	Separate oil cooler
Gearbox designation	PZAB 3540
Gearbox manufacturer	Winergy AG

Coupling gear - generator	Double flexible coupling
Mechanical brake	
Type	Fail safe disc brake
Position	High speed shaft
Number of calipers	2
Generator	
Type	Asynchronous
Nominal power	3,600 kWe
Synchronous speed	1,500 rpm
Voltage	690 V
Frequency	Variable
Protection	IP 54
Cooling	Integrated heat exchanger
Insulation class	F
Generator designation	AMB 506L4A
Canopy	
Type	Totally enclosed
Material	Steel / Aluminum
Yaw system	
Type	Active
Yaw bearing	Internally geared slew ring
Yaw drive	Six electric gear motors
Yaw brake	Active friction brake and six brake motors
Controller	
Type	Microprocessor
SCADA system	WebWPS
Controller designation	KK WTC 3
Structural tower	
Type	Tapered tubular
Hub heights	80 m or site specific
Corrosion protection	Painted
Surface gloss	Semi-matt 30-40 ISO2813
Surface color	Light gray, RAL 7035
Operational data	
Cut-in wind speed	3-5 m/s
Nominal power speed	12-14 m/s
Cut-out wind speed	25 m/s
Maximum 2 s wind gust	55 m/s (standard version) 60-80 m/s (special version)
Weights	
Rotor	95 t
Nacelle	125 t
Tower	Site specific

OFFSHORE APPLICATIONS

Fig. 12: Installation of the rotor blades on an offshore wind turbine. Source: Siemens.

Fig. 13: Blades ready for offshore installation. Source: Siemens.

Fig. 14: Offshore 3.6 MW Siemens wind turbines at the Burbo offshore wind site operated by Dong Energy. Source: Siemens.

Siemens pioneered the offshore installation of wind turbines with the world's first offshore wind farm at Vindeby, Denmark, installed in 1991.

Later notable projects include the Middelgrunden offshore wind farm outside Copenhagen and the world's largest offshore wind farm at Nysted in the Baltic Sea.

Siemens offshore turbines have the following features:

Corrosion protection: The external turbine components are painted with offshore-grade painting systems that minimize any corrosion caused by salty air and water. The nacelle and tower are fully enclosed with climate control including dehumidifiers constantly maintaining the internal humidity below the 60 percent corrosion threshold.

Cooling systems: Cooling is carried out with air-to-air heat exchangers. Ambient air is not circulated through the nacelle or tower but is limited to flow through the external side of the heat exchangers. As a result, the internal nacelle climate can be controlled.

Engineered safety features: The lightning protection system minimizes the risk of damage from lightning strikes that occur frequently in some locations offshore. The turbines are normally fitted with navigational lights and aerial warning lights meeting the relevant safety standards. Rescue equipment is provided at the foundation level.

ROTOR BLADES

The blades used for the SWT-1.3-62, SWT-2.3-82, SWT-2.3-82 VS, SWT-2.3-93 and SWT-3.6-107 turbines are fitted with Siemens blades manufactured with its proprietary IntegralBlade technology. It manufactures the wind turbine blades in one piece using a closed process. The glass fiber reinforcement is laid out to dry using a special molding arrangement with a closed outer mold and an expanding inner mold. After completion of the lamination of the fiber glass, the epoxy resin is injected under vacuum. Following this injection, the blade is hardened at a high temperature while still enclosed in the mold. Once the blade is hardened, it is removed from the outer mold, and the inner mold is collapsed with a vacuum and pulled from the blade. The result is a complete, seamless blade finished in one process.

The blades are made of fiber Glass Reinforced Epoxy (GRE) and their external design represents state of the art wind turbine aerodynamics.

Compared with the traditional processes used by other blade manufacturers, the process has several advantages. It is efficient in man power requirements and space, requiring only one mold set for the manufacturing cycle. There are no issues relating to tolerances between shells and spars. The resulting blade is an integral structure with no glued joints that act as weak points potentially exposing the structure to cracking, water ingress and lightning.

The blade factory offers a clean and attractive work environment. The resins applied to the blade do not release Volatile Organic Compounds (VOCs) pollutants to the atmosphere and the risk of exposure of the workers to allergenic compounds is minimal.

LIGHTNING PROTECTION

The lightning protection aims to protect from the effects of both direct and nearby strikes. Even though protection from lightning cannot be wholly assured, the lightning protection system has shown very good performance in wind turbine applications all over the world.

The overall design basis adheres to the international standard IEC 1024-1 and the Danish Standard DS 453.

The components of the wind turbines are protected in various ways:

Blades: The blades are protected with a dedicated protection system that has been laboratory tested to currents of 200 kA without showing any signs of damage other than superficial weld marks from the strike itself. Each blade has a lightning rod fitted close to the tip. The rod projects slightly above the blade surface on both sides. A flexible steel wire located inside the blade provides the conduction path from the rod to the rotor hub which in turn is used as a conductor to the main shaft. The electrical and hydraulic equipment located inside the hub is completely protected by the Faraday cage effect of the hub itself.

Nacelle: The canopy is fabricated from a 5-mm steel plate, acting as a Faraday cage for the nacelle. The meteorological instruments at the rear of the canopy are protected by a separate lightning rod projecting well above the instruments. All main components are efficiently grounded, and metal oxide arrestors in the controller provide transient protection from the electromagnetic pulse effects of nearby strikes.

Turbine controller: Metal oxide lightning arrestors protect the turbine controller. The arrestors are installed with mechanical overload protection to prevent explosion in case of a direct lightning strike. The controller is fitted with three arrestors, one for each phase, all connected to the local grounding system. All metal parts, such as DIN-rails, cabinet doors, and components are efficiently grounded.

Structural tower: The steel tower acts as a conductor from the nacelle and controller to the ground. The ground connection is provided through several copper leads. Grounding is achieved to a resistance of less than 10 ohms, using two depth electrodes and a grounding ring surrounding the foundation.

ELECTRICAL GRID CONVERTER

The NetConverter power conversion system allows generator operation at variable speed, frequency and voltage while supplying power at constant frequency and voltage to the MV transformer.

This system provides maximum flexibility in the turbine response to voltage and frequency requirements and fault conditions and can be adapted to meet the requirements of relevant grid codes.

The power conversion system uses a number of modular water cooled converter units in parallel mounting for easy maintenance.

POWER REGULATION

Limitation of the power output in high winds is necessary on all wind turbines; otherwise the turbine would become overloaded. A runaway turbine would be subjected to such high forces that it would disintegrate.

Two types of power limitation are used: stall regulation and pitch regulation. Both methods are based on the continuous adjustment of the pitch setting of the blades relative to the hub. Each blade has its own hydraulic actuator unit with position feedback, ensuring continuous stable operation.

CombiStall: Stall regulation is used on *constant* speed turbines such as the SWT-1.3-62 and SWT-2.3-82. In low and medium wind speeds the blade pitch setting is slowly adjusted to provide maximum power output at any given wind speed. When the rated wind speed is reached, the blades are adjusted to a more negative pitch setting, tripping aerodynamic stall and thereby spilling the excess power. At higher wind speeds, the pitch angle is adjusted continuously to maintain the maximum power specified. The advantage of stall regulation is that it is very simple and efficient, working well with constant speed operation. The disadvantages are that the noise level and blade deflection in high wind are somewhat higher than with pitch regulation. These disadvantages are of little importance for smaller turbines, but for very large turbines they tend to outweigh the benefits of the robust constant speed operation.

CombiPitch: Pitch regulation is used on *variable* speed turbines such as the SWT-2.3-82 VS, SWT-2.3-93 and SWT-3.6-107 turbines. In low and medium wind speeds the blade pitch setting is slowly adjusted to provide maximum power output at any given wind speed. When the rated wind speed is reached, the blades are adjusted to a more positive pitch setting, thereby reducing the aerodynamic forces and maintaining the power level programmed into the turbine controller. At higher wind speeds, the pitch angle is adjusted continuously to maintain the maximum power specified. The advantage of pitch regulation is that it provides low aerodynamic noise and moderate blade deflections. Furthermore, even lower noise can be obtained by special operation. The disadvantage is that variable speed operation is required to provide the necessary flexibility in regulation. However, this disadvantage is of little importance for large turbines, where the benefits of pitch regulation clearly outweigh the added complexity of variable speed operation.

MONITORING SYSTEM

The WebWPS SCADA system is based on standard World Wide Web (www) technologies, including XML, XSL style sheets, Microsoft Internet Information Server (IIS) and ASP. With its flexible architecture the system is fairly easy to adapt to project-specific requirements, customized data and report formats. The web server on site generates reports and stores historical data and remote terminals can be connected via modem, routers or an ethernet network.

Communication network: On site, the SCADA and the wind turbines are linked with an internal communication network using optical fiber cables preferably on a single-mode basis. Depending on the site layout the network is split into loops each consisting of 8 to 10 turbines.

WebWPS software: The main component of the WebWPS software is installed on the site server. It has three distinct parts:

1. The communication driver controls the site network. It is fully configurable and can be set up to handle any project-specific combination of turbines, net masts, and grid monitoring stations.
2. The database management system that also generates the reports is based on Microsoft ActiveX Data Objects (ADO). The report generation engine offers customized reports as well as a number of predefined reports with setup based on typical wind farm operator requirements.
3. The web server delivers information such as reports and real time data mostly based on XML and XSL style sheets. It can be expanded easily to provide project-specific pages.

Status displays: A detailed view of a specific turbine will typically present the following data:

1. Wind turbine data: Wind speed, active and reactive power, yaw angle, etc. and command, operational and fault status.

2. Electrical and mechanical data: 3 phases and current voltage, power factor, frequency, rotational speeds of generator and rotor, temperatures of gear oil, generator and nacelle.
3. Statistical data: Total and subtotal turbine statistics such as availability, external errors hours, and calendar hours.
4. Meteorological data: Wind speed and direction, air pressure, temperature, mean wind speed and any other project-specific data.
5. Grid data: Three phases and current voltage, active and reactive power and any project-specific data.

Reports: The WebWPS SCADA system provides both standardized and customized reports. All of them can be easily exported to an Excel work sheet allowing quick analysis of these reports within customer organization. Some of the standards include:
1. Browsing and filtering of date, station, alarm codes, and historical data.
2. Daily, weekly and monthly reports on turbine performance, meteorological and grid data.
3. Project-specific reports.

SIEMENS SWT-2.3-82 VS VARIABLE SPEED TURBINE

The SWT-2.3-82 VS variable speed wind turbine with 2,3 MW of rated power and 82 m diameter rotor, is a variable speed version of the standard SWT-2.3-82 turbine, a preferred choice for utilities and other large developers. The VS version is suited for locations with noise restrictions.

ROTOR

The rotor of the SWT-2.3-82 VS turbine is a three blade cantilevered construction, mounted upwind of the tower. The power limitation is regulated by pitch regulation.

ROTOR BLADES

The blades are made of fiber Glass Reinforced Epoxy (GRE) and are manufactured using a single integral operation. No glued joints are generated between the spars and shells avoiding weak points and eliminating water ingress as well as discouraging lightning strikes paths.

The aerodynamic design of the blades has been tested under both static and dynamic loadings. The blades are mounted on pitch bearings and can be feathered 90 degrees for shutdown purposes. Each blade has its own independent fail safe pitching mechanism capable of feathering the blade under any operating condition, and allowing fine-tuning to maximize power output.

GEARBOX AND BRAKE

The gearbox is a custom built 3 stage planetary helical design, mounted on the nacelle with flexible rubber bushings, thereby providing a compact high performance construction and the lowest possible noise level. The gearbox is fitted with a fail-safe mechanical brake at the high speed shaft.

GENERATOR

The generator rotor construction and stator windings are specifically designed for high efficiency at partial loads. The generator is fitted with a separate thermostat-controlled ventilation arrangement, and by ensuring a very efficient cooling the generator can be operated at temperatures well below the normal level of the standard insulation class, thereby providing the best possible lifetime of the winding insulation.

TOWER

The SWT-2.3-82 VS turbine is mounted on a tapered tubular steel tower. The tower has internal ascent and direct access to the yaw system and nacelle.

CONTROLLER

The turbine controller is a microprocessor based industrial controller. The controller is complete with switch gear and protection devices. It is self diagnosing and has a keyboard and display for an easy readout of status and for adjustment of settings.

OPERATION

The turbine operates automatically under all wind conditions. When the wind speed increases from a calm condition, the turbine will self start at about 4 m/s average wind speed. The small generator winding remains connected to the grid up to approximately 7 m/s wind speed. At higher wind speeds, the generator switches to the main winding. The wind turbine output increases roughly linearly with the wind speed until the wind reaches 13-14 m/s. At that point the power is limited at the rated power.

SAFETY FEATURES

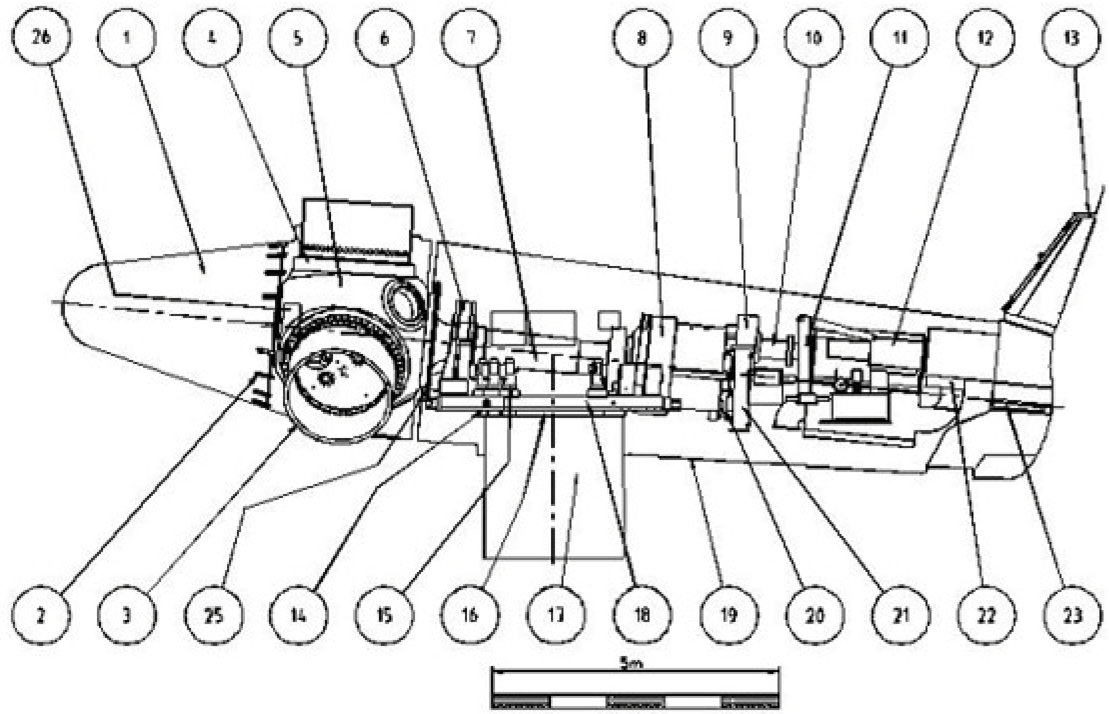
The turbine has several redundant levels in the safety system, including an independent pitch system for each of the blades, and as a result the turbine can shut down safely from any operational condition.

REMOTE CONTROL

The turbine is equipped with the WebWPS SCADA system. The system offers long distance control and a variety of status views and useful reports from a standard internet web browser.

GRID CONNECTIVITY

The SWT-2.3-82 VS turbine is fitted with the NetConverter system that is compliant with demanding grid codes. It has a ride through capability for all normal faults.



1: Spinner, 2: Spinner bracket, 3: Blade, 4: Pitch bearing, 5: Rotor hub, 6: Main bearing, 7: Main shaft, 8: Gearbox, 9: Brake disc, 10: Coupling, 11: Service crane, 12: Generator, 13: Meteorological sensors, 14: Yaw bearing, 15: Yaw gear, 16: Yaw ring, 17: Tower, 18: Nacelle bedplate, 19: Canopy, 20: Oil filter, 21: Oil filter, 22:Generator fan, 23: Oil cooler, 25: Rotor lock, 26: Hub controller box.

Fig. 15: Nacelle components of the Siemens SWT-2.3-82 VS variable speed wind turbine. Source: Siemens.

TECHNICAL SPECIFICATIONS

Operational data	
Cut in wind speed	3 – 5 m/s
Nominal power at about	13 - 14 m/sec
Cut out wind speed	25 m/s
Maximum wind gust	55 m/s (standard version) 60-80 m/s (special version)

Rotor	
Type	3 bladed horizontal axis
Position	Upwind
Diameter	82.4 m
Swept area	5,300 m^2
Synchronous rotor speed	6-18 rpm
Regulation	Pitch regulation
Rotor tilt	6 degrees

Rotor Blade	
Type	Self supporting
Blade length	40 m
Tip chord	0.80 m
Root chord	3.1 m
Aerodynamic profile	NACA 63.xxx, FFAxxx
Material	Glass Reinforced Epoxy (GRE)
Surface gloss	Semi matt, <30 / ISO2813
Surface color	Light gray, RAL 7035

Aerodynamic Brake	
Type	Full span pitching
Activation	Active, fail safe

Load supporting parts	
Hub	Nodular cast iron
Main bearings	Spherical roller bearing
Main shaft	Alloy steel
Nacelle bedplate	Steel

Transmission system	
Coupling hub shaft	Flange
Coupling shaft gearbox	Shrink disc

Gearbox type	3 stage planetary helical
Gearbox ratio	1:91
Gearbox lubrication	Splash / forced lubrication
Oil volume	About 400 liters
Gearbox cooling	Separate oil cooler
Gearbox designation	PEA 4456
Gearbox manufacturer	Winergy AG
Coupling gear generator	Double flexible coupling
Mechanical Brake	
Type	Fail safe disc brake
Position	High speed shaft
Number of calipers	2
Electrical Generator	
Type	Asynchronous
Miminal power	2,300 kWe
Protection	IP 54
Cooling	Integrated heat exchanger
Insulation class	F
Generator designation	AMA 500L4 BAYH
Canopy	
Type	Totally enclosed
Material	Steel
Yaw System	
Type	Active
Yaw bearing	Externally geared slew ring
Yaw drive	Eight electric gear motors
Yaw brake	Passive friction brake
Controller	
Type	Microprocessor
SCADA system	WPS via modem
Controller	WTC 3.0

designation	
Tower	
Type	Cylindrical and/or tapered tubular
Hub height	80 m or site specific
Corrosion protection	Painted
Surface gloss	Silk matt, 30-34/ ISO 2813
Surface color	Light gray, RAL 7035
Masses	
Rotor	54 t
Nacelle excluding rotor	82 t
Tower (89 m)	158 t

ENERCON WIND TURBINES

The Enercon E-70 wind turbine is suitable for sites with high wind speeds, with 2.3 MW of rated power output. With numerous steel and precast concrete tower versions it is designed to ensure maximum yield in the upper power range. It is characterized by a gearless or direct drive system eliminating the weak link of the gearbox in modern wind machines.

The rotor hub is not manufactured of cast steel which has been replaced by modern spheroidal graphite cast iron.

DIRECT DRIVE SYSTEM

The drive system has fewer rotating components compared with other systems, reducing mechanical stress and increasing the technical service life of the equipment. The maintenance and service costs for the wind turbine are lower because of the fewer wearing parts and the absence of need for gear oil change, resulting in reduced operational costs.

The rotor hub and annular generator are directly connected to each other as a fixed unit without gears. The rotor unit is mounted on a fixed axle or axle pin. Compared with conventional geared systems that have a large number of bearing points in a moving drive train, such drive system has only two slow moving roller bearings, a configuration made possible by the low speed of the direct drive.

The rotor hub is not made of cast steel anymore and has been replaced by modern spheroidal graphite cast iron. It is also used in the manufacturing of other major components such as the blade adaptors, the axle pins and the main carriers.

The cast components are drawn at the foundries on a three dimensional Computer Aided Design (CAD) system and calculated using the finite element method to test the strain increases at the critical points. During the entire prototype phase, the designer tests and optimizes performance. In order to guarantee the identification and traceability of each cast component, each part is given a specific barcode, from which the serial number can be obtained in the event of quality issues. Cast components are not released for further steps in the manufacturing process until comprehensive quality testing has taken place, thus guaranteeing high quality standards in the cast component supply sector.

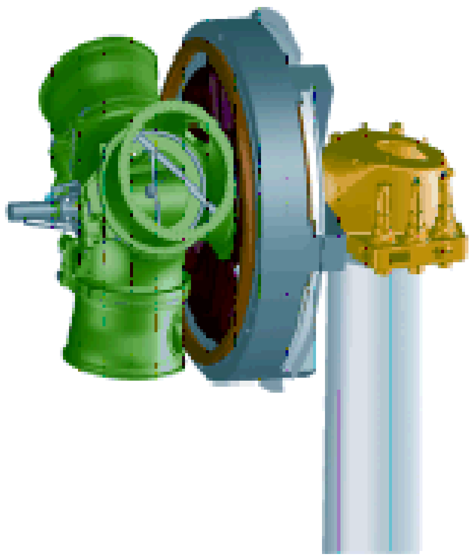


Fig. 16: The Enercon direct drive system has few rotating components, eliminating the gearbox and increasing its design lifespan. Source: Enercon.

Fig. 17: Enercon E-112 wind turbine.

The Enercon E-112 turbine was upgraded, so that instead of generating 4.5 megawatts, it now produces 6 megawatts, enough to supply power to 4,000 homes in Germany. It is named the E-112 because it has a rotor diameter of 112 meters or about 367 feet. The gearless drive system does not require any oil to operate. The tips of the turbine's blades are tilted to reduce noise emissions.

Fig. 18: Enercon E-126, 7 MW wind turbine. These turbines are equipped with a number of new features: an optimized blade design with a spoiler extending down to the hub, and a precast concrete base.

The Enercon E-126 has a rated capacity 6 MW and 20 million kW.hr/year. That is enough to power about 5,000 households of 4 in Europe. For the USA, 938 kW.hr is needed per home per month, yielding 11,256 kW.hr per year per house, suggesting that 1,776 American homes could be powered by one wind turbine.

The rotor blade length is 126 meters or 413 feet. These turbines are equipped with new features: an optimized blade design with a spoiler extending down to the hub, and a pre cast concrete base.

In the Enercon design, no gearbox is used and the generator is housed just at the widest part of the nose cone. It takes up the entire width of the nacelle to generate power more efficiently, and provide longer service life with less wear.

Like small wind turbines, these have inverters instead of synchronous generators, that is to say, a separate controller that converts the AC electrical power generated into something the grid can be fed with. This means that the rotor can rotate at more optimal and varied speeds.

Also, like small turbines, the E-126 does not shut right off at a predetermined speed due to gusts or just very high wind speeds. It simply throttles down by turning the blades slightly away from the wind so as to continue to generate power though at a lower production rate. Then the instant the wind is more favorable, it starts back up again. Many smaller wind turbines do something similar except that they have no blade pitch control, and they use the technique of side furling where the whole machine, excepting the tail, turns sideways to catch less wind but continue operating.

Due to the elevated hub height and the new blade profile, the performance of the E-126 is expected to by far surpass that of the E-112.

Fig. 19: Enercon E-70 2.3 MW wind turbine. The bottom of the turbine is painted in green to blend with the green surroundings. Source: Enercon.

Fig. 20: Nacelle of the Enercon E-70 wind turbine is shaped as an artistic liquid drop. Source: Enercon.

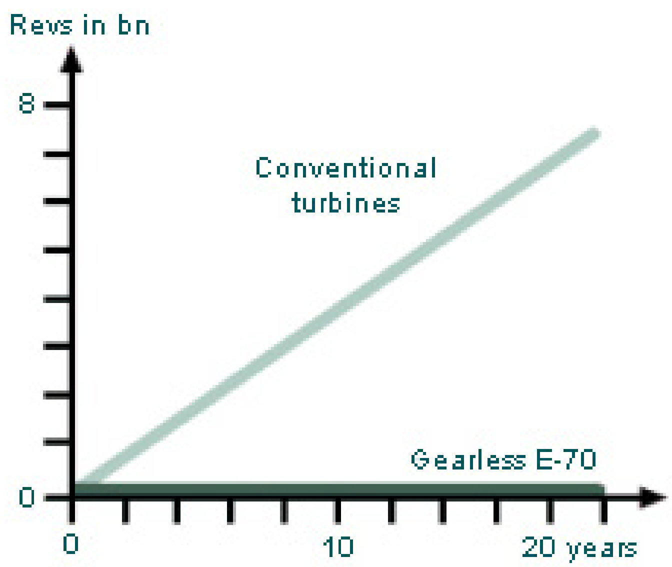


Fig. 21: Number of rotations in E-70 turbine with direct drive compared with conventional turbines. The generator of an E-70 undergoes the same number of rotations in 20 years as the generators in conventional wind turbines in three months. Source: Enercon.

ANNULAR GENERATOR

The annular generator is of primary importance in the gearless system design of the E-70 wind turbine. It offers the advantages of totally avoiding the gearbox components, a lower wear caused by a slow machine rotation, low stress due to the high level of speed variability, the incorporation of yield optimized control and the high level of grid compatibility.

Combined with the rotor hub, it provides an almost frictionless flow of energy, while the gentle running of fewer moving components guarantees minimal material wear. Unlike conventional asynchronous generators, the annular generator is subjected to minimal mechanical wear, which makes it ideal for particularly heavy demands and a long service life.

The annular generator is a low speed synchronous generator with no direct grid coupling. The output voltage and frequency vary with the speed and are converted for output to the grid by a DC link and inverter. This achieves a high degree of speed variability.

Fig. 22: Annular generators assembly line. Source: Enercon.

STATOR AND ROTOR

To enhance the service life time, the copper winding in the stator, the stationary part of the annular generator, known as closed, single layer basket winding is produced in the insulation class F to 155 °C. It consists of individual round wires that are gathered in bundles and varnish insulated. The copper winding is done manually. In spite of increasing automation in other manufacturing areas, preference has been given to manual labor in this case since it ensures that the materials used are fully tested. A special processing method allows continuous windings to be produced. Each wire strand is continuous from start to finish.

The advantages of continuous winding are:

1. Prevents processing faults in the production of electrical connections.
2. Maintains the high quality copper wire insulating system.
3. Eliminates the contact resistance.
4. Eliminates weak points that are susceptible to corrosion or material fatigue.

The magnetic field of the stator winding is excited via pole shoes. These are located on the disk rotor, the mobile part of the annular generator. Since the shape and position of the pole shoes have a decisive influence on the noise emission of the annular generator, Research and Development (RD) has dedicated particular attention to this aspect. The result is an improved adaptation of the pole shoes to the slow rotation of the annular generator with no significant noise being generated.

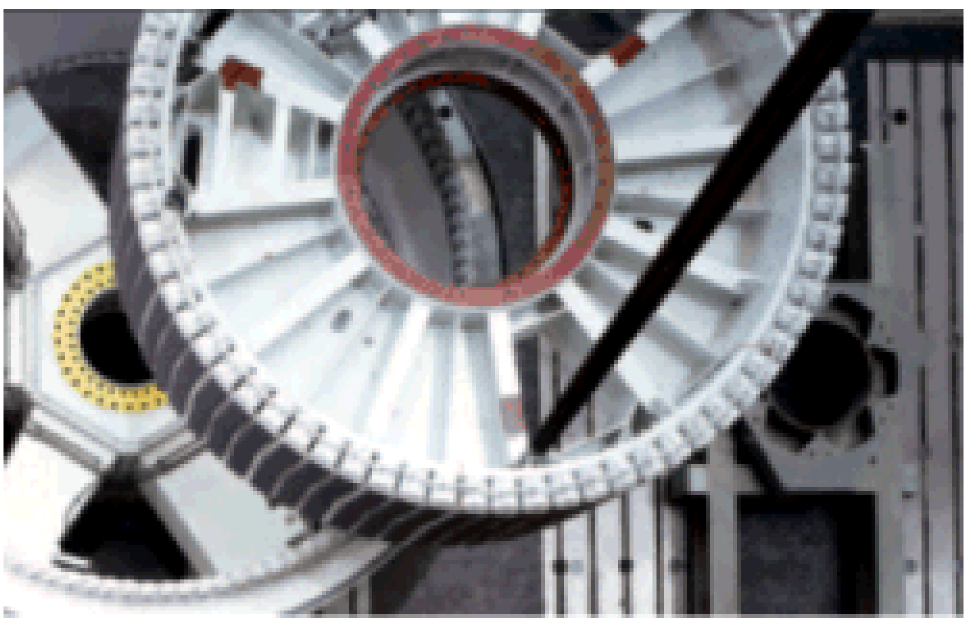


Fig. 23: Stator and rotor of E-70 wind turbine. Source: Enercon.

TEMPERATURE RESPONSE

The annular generator features optimized temperature control. The hottest areas in the annular generator are constantly monitored by a large number of temperature sensors. The sensors activation temperature is well below the constant temperature resistance of the insulating materials used in the generator. This prevents temperature overload. The maximum operating temperature in an annular generator is considerably below the limit values of the processed materials.

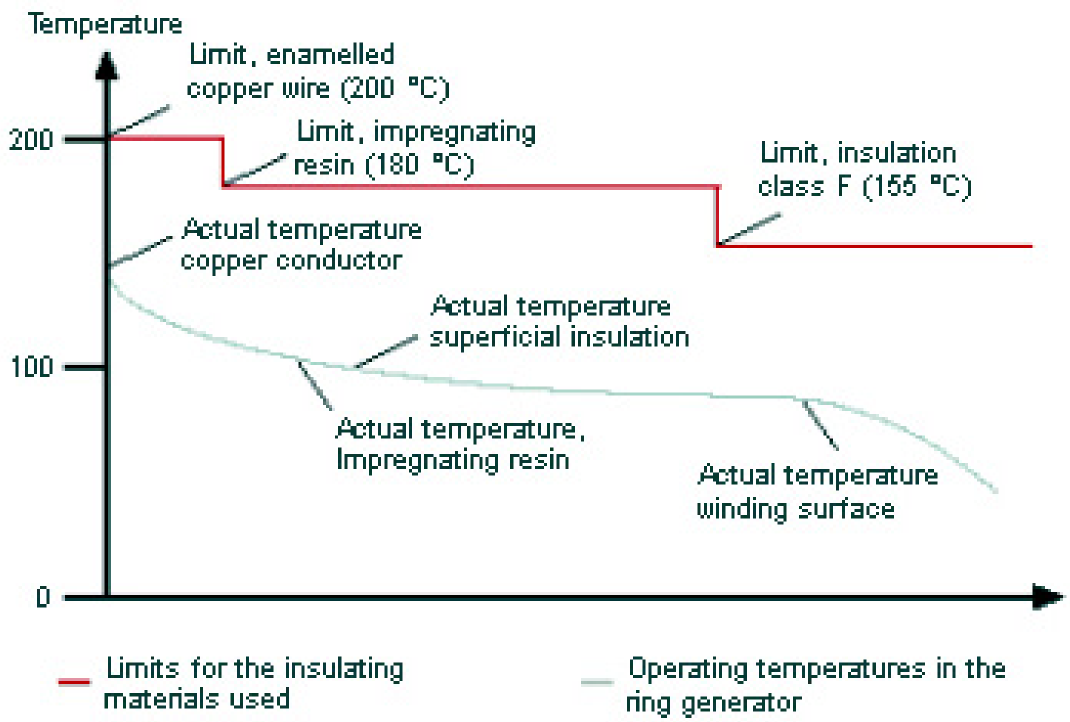


Fig. 24: Temperature response in the annular ring generator. Source: Enercon.

QUALITY ASSURANCE

Annular generators are manufactured with close collaboration with the supplier companies. The enameled copper wires are subjected to more testing than is specified in the industrial standard and samples are archived, while surge voltage tests are performed on the pole shoes and then documented in the computer system.

ROTOR BLADES DESIGN

The goals of the rotor blade concept are to maximize yield, reduce noise emission, and minimize the induced stresses. The blades use the inner part of the rotor area and considerably increase the energy yield. The rotor blades are less susceptible to turbulence and provide an even flow along the entire length of the blade profile.

The blade tips have been optimized with regard to noise emission and energy yield. Turbulence that occurs at the blade tips due to over pressure and under pressure is effectively removed from the rotor plane. The entire length of the blade is utilized without any loss of energy caused by turbulence.

Fig. 25: Blade tip design eliminating noise emission. Source: Enercon.

The rotor blades offer higher efficiency due to the modified design, generate less noise and have a longer life span due to their optimized tips, and offer easier transport due to their streamlined geometry.

The rotor blades are manufactured with a vacuum infusion process using the sandwich method. Glass fiber mats placed in the mold are vacuum impregnated with resin via a pump and a hose system. This method eliminates the formation of air pockets in the laminate.

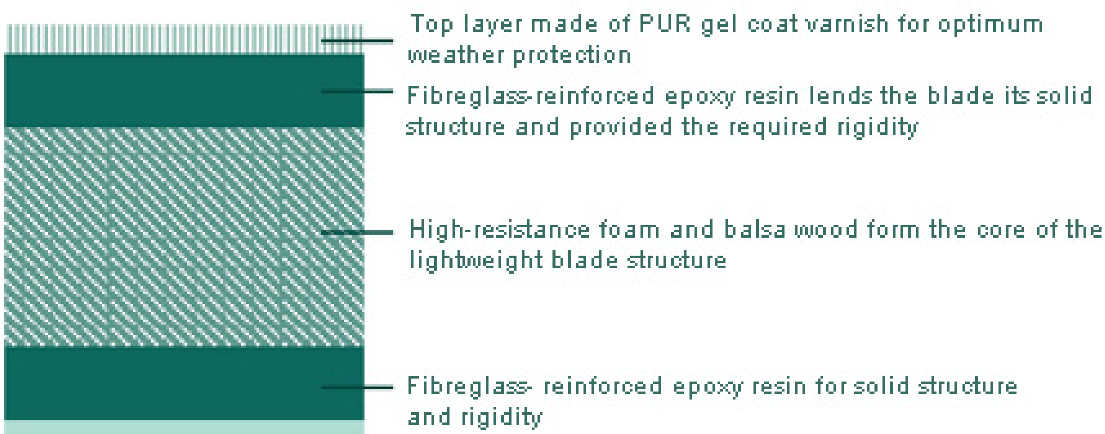


Fig. 26: Layered composite construction of E-70 rotor blade. Source: Enercon.

To efficiently protect the rotor blade surface against the elements such as wind and water, ultra violet (UV) radiation, as well as erosion and bending loads, the rotor blade finish protection system includes gel coat, filler, edge protection and a top coating. Solvent free two component polyurethane compounds are used in the entire system.

To effectively withstand wind stress over the entire usage period, the rotor blades have an extremely large blade flange diameter. A double-row bolt connection specially developed for large wind turbines provides additional strength by creating an even load distribution. This is an important at sites with extreme winds and large stress fluctuations.

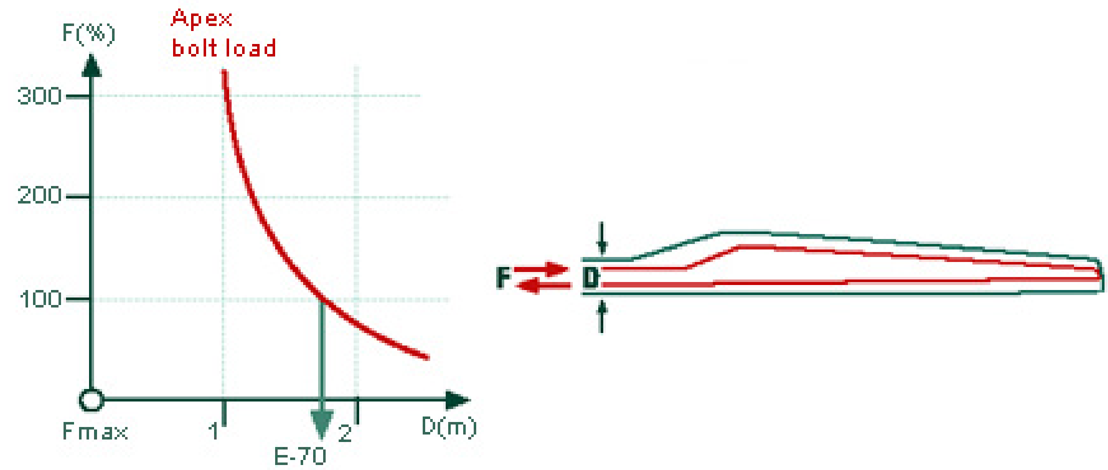


Fig. 27: Load diagram on rotor blades. The load diagram indicates that the load F is reduced by using a larger blade diameter D, suggesting an enhanced loading capability. Source: Enercon.

SYSTEM MONITORING AND CONTROL

Fig. 28: System controls are located inside the structural tower protecting them from the environmental conditions and from possible intrusion and vandalism.

Source: Enercon.

State of the art microelectronics is used for the control of wind turbines. The Main Processing Unit (MPU), the central element of the control system, constantly registers information from the peripheral control elements, such as the yaw control and active pitch control systems. Its function is to adjust the individual system parameters to ensure that the wind turbines achieve maximum output under all weather conditions. The functions of the control system include:

1. The constant evaluation of measurement data from wind sensor for adaptive nacelle yaw control.
2. Variable speed for maximum wind turbine efficiency at all wind speeds, and elimination of undesirable output peaks and high operating load.
3. Active pitch control system to obtain ideal angle of flow on the rotor blades ensures maximum output and stress reduction on the entire wind turbine.
4. Monitor the brake system for maximum turbine reliability by means of three independently operating pitch mechanisms with a standby power supply in the form of batteries in case of supply failure
5. Tower and generator monitoring by means of vibration and acceleration sensors to check tower oscillations.
6. Monitor the temperature and air gap sensors between rotor and stator ensure dependable annular generator operation

GRID CONNECTION MONITORING

Ensuring proper power feed from the wind turbines into the grid requires grid connection monitoring. Grid parameters such as voltage, current and frequency are measured on the low voltage side between an inverter and the system transformer. The measured values are continuously transmitted to the control system, enabling the turbine to react immediately to changes in the grid voltage or frequency. If the defined limit values of the system protection are exceeded, the wind turbine is reliably shut down and service is informed.

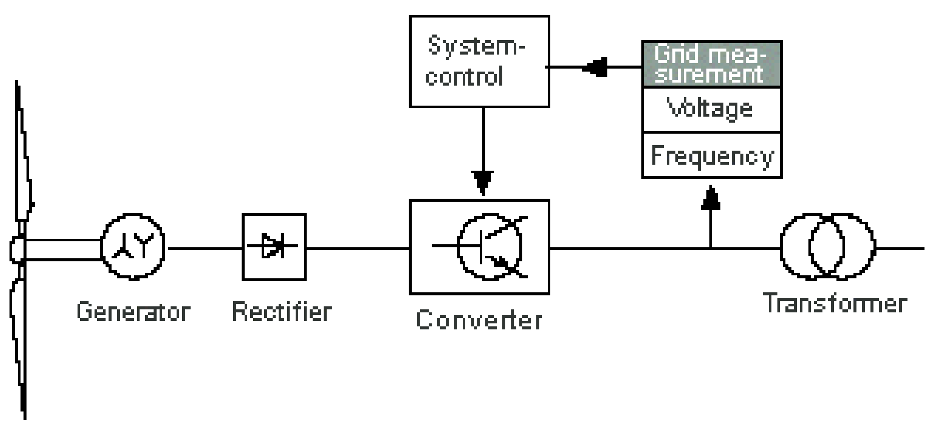


Fig. 29: Grid connection monitoring system. Source: Enercon.

As soon as the voltage and frequency return to within the permissible tolerances, the wind turbine is automatically started up again avoiding prolonged downtimes.

MONITORING AND CONTROL SYSTEM

The Surveillance, Control and Data Acquisition (SCADA) monitoring and control system has been a proven system for remote wind farm control and monitoring for many years. Introduced in 1998, this system is now used in more than 6,500 wind turbines worldwide. It offers a number of optional functions and interfaces to connect wind farms to the grid while meeting demanding grid connection regulations.

Due to its modular design, expansion is simple and flexible and can be adapted to electrical utilities specific applications.

POWER REGULATION AND ENERGY MANAGEMENT

If the cumulative nominal output of a wind farm is greater than the grid connection capacity at the point of common coupling, the wind farm power regulation system ensures that the capacity is used to the fullest at all times. If a wind turbine in the wind farm generates less power, the other turbines are appropriately adjusted to run at a higher capacity and take the slack. This is an optional energy management feature that can be added to the monitoring and control system

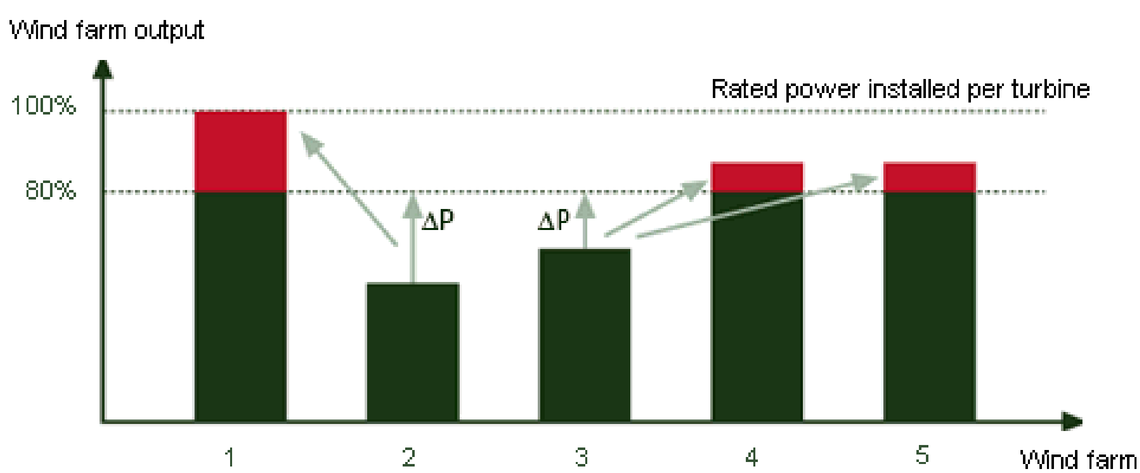


Fig. 30: Energy management and power regulation. Without energy management, the available grid capacity could not be fully exploited. The grid capacity is 80 percent of the cumulative rated power installed. Therefore this becomes the feed-in limit without energy management. Source: Enercon.

VOLTAGE CONTROL

As an option, the monitoring and control system can be expanded to provide wind farms with a voltage control feature. This feature, which is a mandatory requirement by utilities in some countries, enables large wind farms to be integrated into relatively weak grids. The reactive power range of the wind turbines is in this case is usually used to control the voltage at the point of common coupling. Voltage can be controlled by the grid operator according to some predefined conditions or via additional interfaces.

There are various requirements concerning wind farm voltage control. If a wind farm is connected to a substation, automatic voltage regulators can be integrated into the control concept. In large wind farms with respective cable lengths, a control system can be used to improve reactive power demand for the contractually agreed point of common coupling with centralized compensation equipment and decentralized wind turbines.

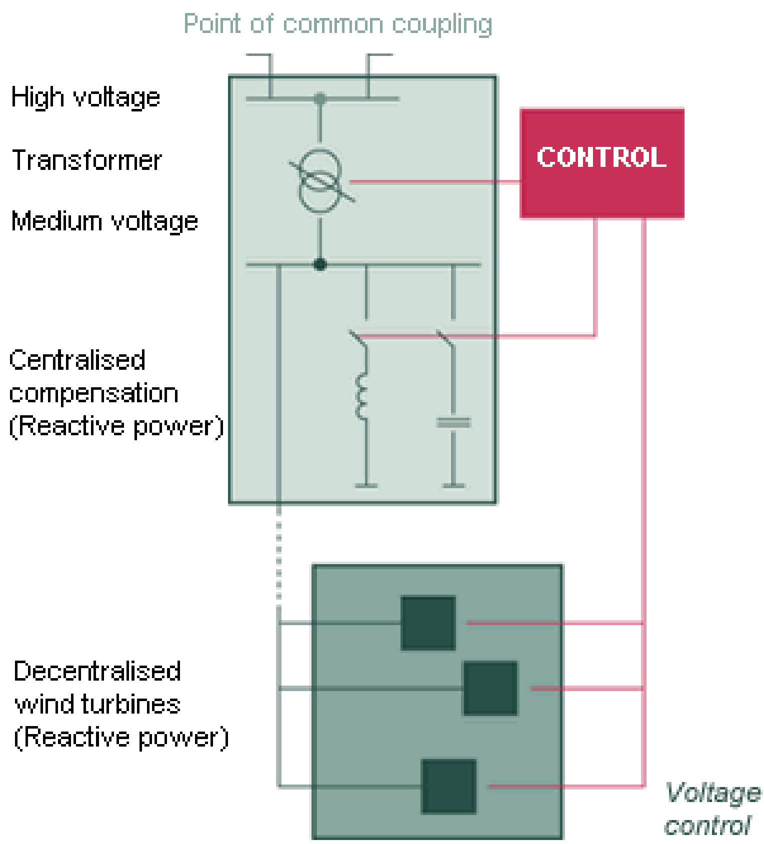


Fig. 31: Voltage control for a wind farm. Source: Enercon.

SYSTEM INTERFACES

In most countries, the integration of wind farms into the grid control systems and connection to grid control stations are today standard requirements for wind farms. Different optional modules that are added to the control system can act as interfaces between the various systems. This enables the control system to communicate via analog or digital interfaces depending on the requirements. Certain wind farm target values can be preset and status messages or wind farm measurement values transmitted to the grid operator. If desired the wind masts in a wind farm can be integrated into the permanent data transfer system.

BOTTLENECK MANAGEMENT, FEEDING INTO WEAK GRIDS

Not all regions have sufficient transmission capacity available to manage each low load and strong wind situation. A bottleneck management system offers the possibility of connecting wind farms to this type of grid. Constant data exchange between the wind farm and the grid operator ensures that transmission capacity is well adapted to the highest permissible wind farm output.

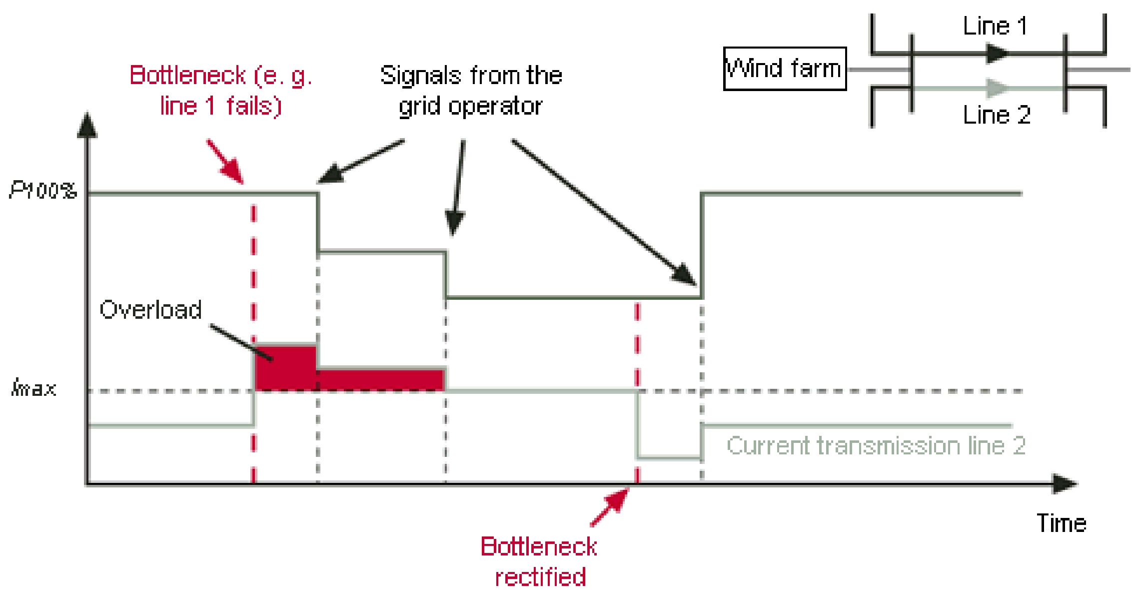


Fig. 32: System interfaces and bottleneck management. The wind farm output can be infinitely adjusted during bottlenecks at the grid operator's request. Source: Enercon.

SUBSTATIONS FOR WIND FARMS

Wind farms are increasingly feeding power into the grid via substations especially constructed for this purpose. Remote monitoring and control of these substations are often required in order to receive continuous information on switchgear assemblies and, as the case may be, carry out switching operations.

The control system can incorporate special optional modules for remote monitoring and control of switchgear units and entire substations.

MAIN CONTROL UNIT (MCU)

Individual wind farms functioning similar to conventional power plants have successfully been in operation and integrated into existing grid structures for many years. It is common to find several wind farms connected to a central point of common coupling to form wind power plants. Since installed power output is high, these plants usually feed power into high performance transmission grids. The MCU assumes centralized open-loop and closed loop control of a wind power plant. It takes over typical communication and data transfer tasks to grid control systems and load dispatching centers fulfilling complex technical grid connection regulations for wind power plants.

The MCU comes a as module. Each application is customized with features best suited to the project. Depending on requirements, the MCU has different interfaces to connect to the grid control systems. Bottleneck management for wind power plants is yet another feature part in addition to reactive power management, or the integration of switchgear assemblies or entire substations into the wind power plant.

The typical requirements for wind power plants connection to the power grid are:

1. The wind turbines should be able to remain connected to the grid without power reduction even if considerable voltage and frequency deviations occur.
2. If voltage dips occur due to grid problems, the wind turbines should remain connected to the grid for a defined period.
3. Short circuit current feeding may be demanded during a grid failure.
4. After a fault has been remedied, a wind farm should resume power feed as quickly as possible within a specified maximum time range.
5. Wind farms should be able to be operated with reduced power output without any time restrictions.
6. For coordinated load distribution in the grid, the increase in power output (power gradient), for example when the wind farm is started up, should be able to be restricted in accordance with the grid operator's specifications.
7. Wind farms should be able to contribute reserve energy within the grid. If the grid frequency increases, the power output of a wind farm should be reduced.
8. If necessary, wind farms should be able to contribute to maintaining voltage stability in the grid by supplying or accepting reactive power.
9. Wind farms should be able to be integrated in the grid control system for remote monitoring and control of all wind turbines in the grid.

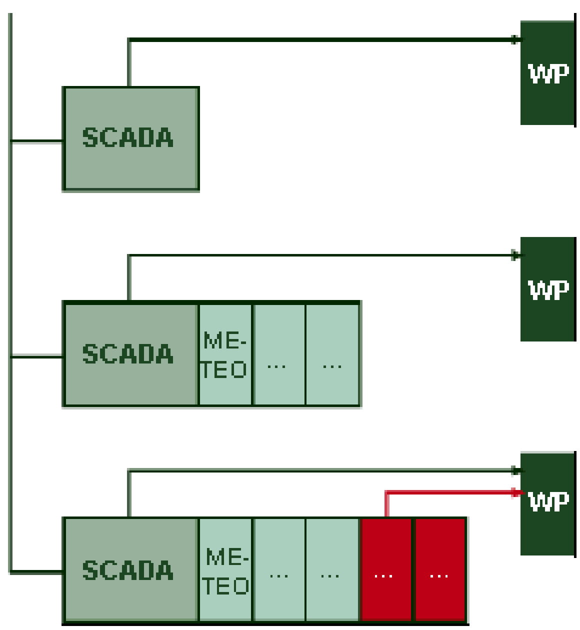


Fig. 33: The Main Control Unit (MCU) controls the grid connection of several wind power plants.

STORM CONTROL

Some wind turbine designs are equipped with a special storm control system, which enables reduced turbine operation in the event of extremely high wind speeds. This prevents the otherwise frequent shutdowns and the resulting yield losses.

The diagram of a power curve of a wind turbine without storm control shows that the wind turbine stops at a defined shutdown maximum wind speed V_3.

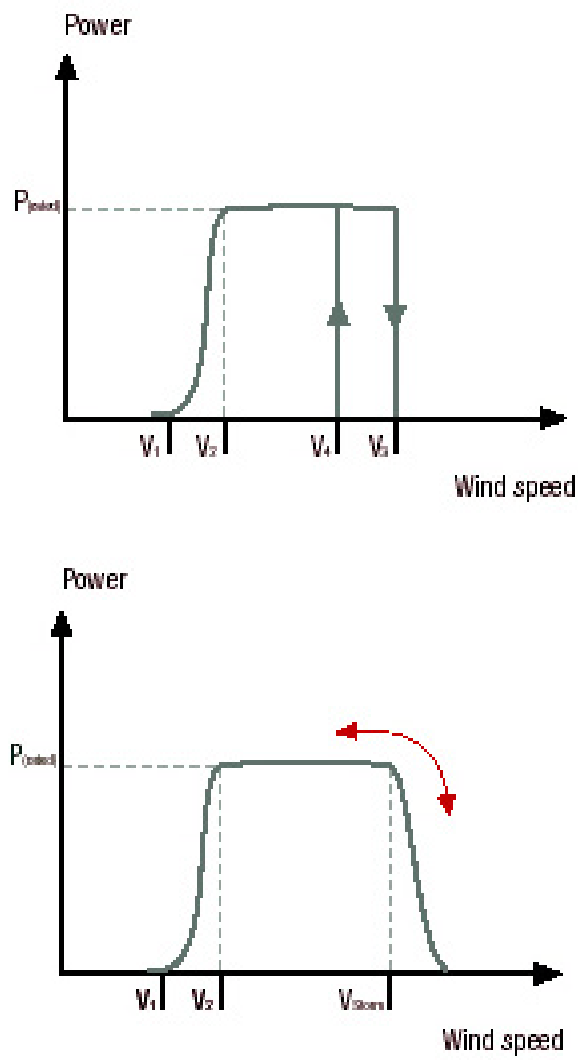


Fig. 34: Power curve with (bottom) and without (top) storm control showing the strong wind hysteresis effect. Source: Enercon.

In the case of a wind turbine without storm control this occurs at a wind speed of about 25 m/s with 20 seconds mean time duration. The wind turbine only starts up again when the average wind speed drops below the shutdown speed or possibly even lower restart speed at V_4 in the diagram. This is known as the strong wind hysteresis effect. In gusty wind conditions, this may take a while, which means that considerable yield losses are incurred.

TOWER CONSTRUCTION

The load dynamic design of materials and structure used in wind turbine towers provide the best conditions for transport, installation and use. They must conform to the international standards and codes such as ASA, DIN and Eurocode which assure quality and safety norms.

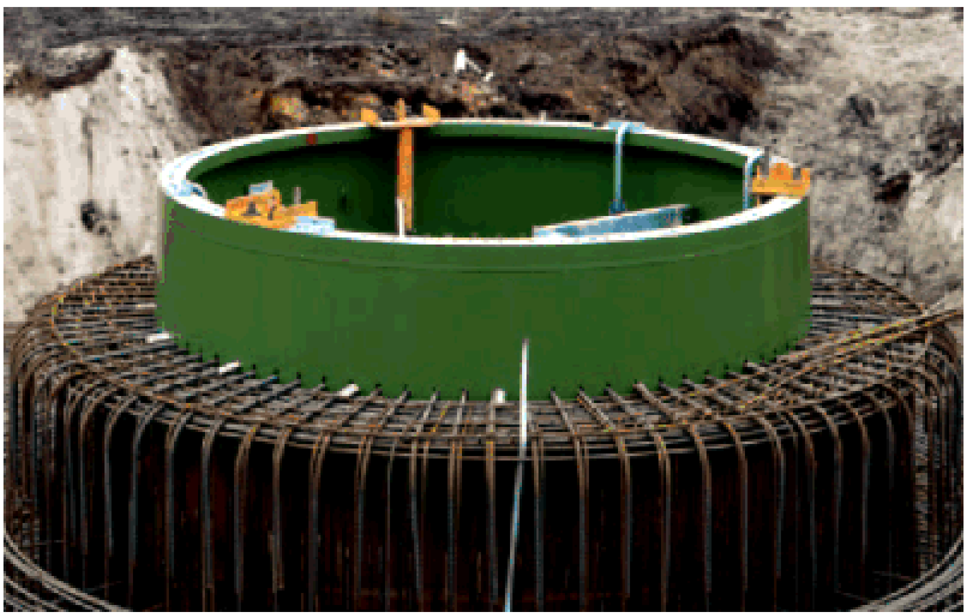


Fig. 36: Steel tower foundation. Source: Enercon

Virtual 3D models of the tower designs are produced during the development phase using the Finite Element Method (FEM). All possible stress on the wind turbine is then simulated on the model. Accurate predictions concerning tower stability and service life are not left to chance before building a prototype. Measurements on existing turbines provide verification of the calculated data. The calculations are supported by results produced by specially commissioned certification bodies, research institutes and engineering firms.

The aesthetic aspect is also a decisive factor during tower development, which is obvious in the finished product. The streamlined gradually tapered design offers a visibly sophisticated aesthetic concept.

TUBULAR STEEL TOWERS

Tubular steel towers are manufactured in several individual tower sections

connected using stress reducing L flanges. Unlike the conventional flange connections used in steel chimney construction, the welding seam of the L-flange is outside the stress zone. The L flange approach presents several advantages:
1. It dispenses with complicated and costly welding work on site.
2. It offers quick, reliable assembly with the highest quality standard.
3. It allows full corrosion protection, applied under the best production engineering conditions

Fig. 37: Tubular steel sections. Source: Enercon.

Due to their relatively small circumference, shorter tubular steel towers are mounted on the foundations using a foundation basket, which consists of a double rowed circular array of threaded steel bolts. A retainer ring, fitted to the tower flange dimensions, is used to hold the individual bolts in position. When the foundation is completed, the lower tower section is placed on the bolts protruding out of the concrete surface and then bolted with nuts and washers.

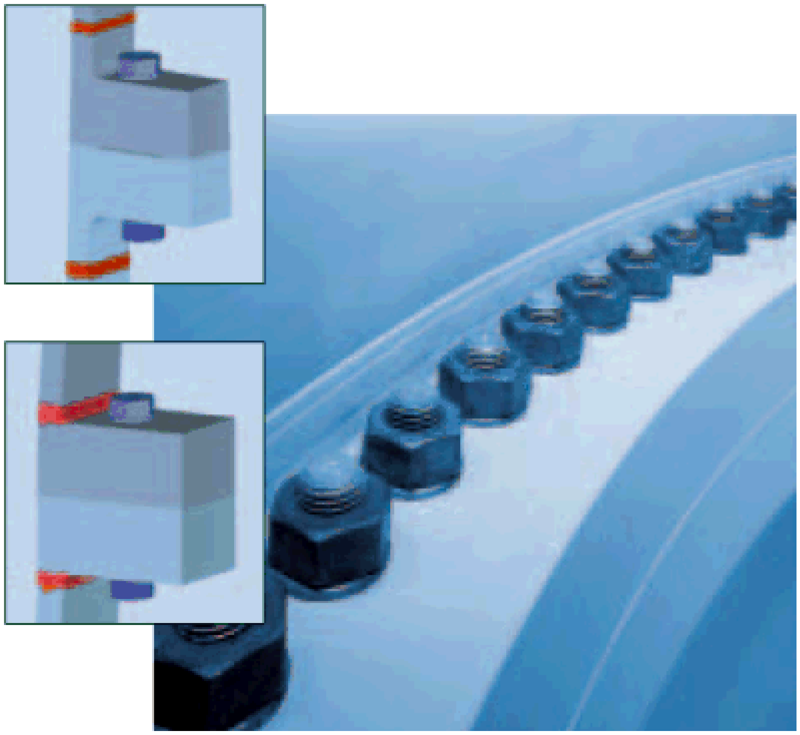


Fig. 38: Tubular steel sections connections. Source: Enercon.

A specially developed foundation connection system is used for taller steel towers. A cylindrical structural element is set on the blinding layer and precisely aligned with adjusting bolts. Once the foundation is completed, the tower is flanged together with the foundation section

Tubular steel towers are subject to strict quality standards. Quality assurance begins already in the design development stages to ensure that the prototype meets all requirements before going into series production.

PRE CAST CONCRETE TOWER

Fig. 39: Precast concrete tower sections.

Precast concrete structural towers are made using specially developed prestressed steel reinforcement. The individual tower sections and foundation are fastened together to form an inseparable unit with stay cables running through jacket tubes in the core of the concrete tower wall. The tower sections themselves are manufactured entirely in the precasting plant. Specially constructed steel molds assure manufacturing precision for each individual concrete section. This manufacturing process minimizes dimensional tolerances which assures a high degree of fitting accuracy.

Quality Assurance carries strict inspections and detailed procedural and work instructions are available for each manufacturing sector ensuring that each individual manufacturing stage as well as the materials used can be completely retraced

FOUNDATION CONSTRUCTION

The foundation transmits the wind turbine's dead load and wind load into the ground. Circular foundations are favored. The advantages of rounded foundations can be identified as:

1. The forces are equal in all wind directions, whereas asymmetrical foundation pressure is possible with square bases or cross shaped foundations.

2. The circular design has proven to reduce the amount of reinforcement and concrete required. The circular design reduces the size of the formwork area.

3. Backfilling the foundation with soil from the excavation pit is included in the structural analysis as a load. This means that less reinforced concrete is needed for foundation stability.

Fig. 40: Pouring of reinforced concrete into a round foundation. Source: Enercon.

Depending on the site, the ground can only absorb a certain amount of compressive strain so the foundation surfaces are adapted accordingly. Circular foundations are designed based on this elementary realization and as a rule are installed as shallow foundations. If necessary in soft soil a special deep foundation distributes the load down to deeper load bearing soil strata. The piles, symmetrically arranged, are slightly inclined so that the imagined extended pile center lines meet at a point above the center of the foundation. This provides maximum force/load distribution over the entire surface.

TECHNICAL SPECIFICATIONS

Rated power	2,300 kW
Rotor diameter:	71 m
Hub height:	58 - 113 m
Wind class (IEC)	IEC/NVN I
Turbine concept	Gearless, variable speed, variable pitch control
Rotor	
Type	Upwind rotor with active pitch control

Direction of rotation	Clockwise
Number of blades	3
Swept area	3,959 m^2
Blade material	Fiberglass reinforced with epoxy resin, integrated lightning protection
Rotational speed:	Variable, 6 - 21.5 rpm
Pitch control:	Blade pitch system, one independent pitching system per rotor blade with allocated emergency supply
Drive train with generator	
Hub	Rigid
Main bearings	Dual-row tapered/single-row cylindrical roller bearings
Generator:	Direct-drive synchronous annular generator
Grid feeding	ENERCON converter
Braking systems	Three independent blade pitch systems with emergency supply Rotor brake Rotor lock
Yaw control	Active via adjustment gears, load-dependent damping
Cut-out wind speed	28 - 34 m/s with storm control
Remote monitoring:	SCADA

NORDEX WIND TURBINES

A rotor diameter of 80 m and an installed capacity of 2.5 MW characterize the Nordex N80 as a choice for strong wind sites.

Using pitch control, the GL-1-certified machine is able to optimize the energy yield at all wind speeds.

Fig. 41: Erection of a Nordex N80/2500 wind turbine. Source: Nordex.

The machine offers low maintenance due to having no rotating hydraulics in the hub, maintenance-free blade adjustment drives and easily accessible control cabinets.

It offers user friendly construction and access to the control system both from the bottom of the tower and from the nacelle. It possesses a wide range of remote query possibilities for the control system and converter.

CONTROL SYSTEM

The N80/2500 wind turbine is controlled by Nordex Control 2 (NC2), a software/hardware system for managing the central wind power system components right up to wind farms or the power station networks of non-centralized energy producers. The software system continuously evaluates all operating and weather data measured and ensures yield-optimized operation of the system. The system programs each system with turbine and location-based parameters. The wind turbines are fitted with two anemometers to record the wind data. The first one is used to manage the system and the second one monitors the first device. If one device fails, the other takes over.

Each system is linked to a remote monitoring system for controlling the hardware and software component. All data and signals are transmitted by ISDN and can be viewed using an Internet browser. This ensures data monitoring as well as active remote management at start-up, deactivation and wind tracking, for each turbine from the Nordex service center in Rostock. The remote monitoring office works around the clock and is automatically alerted in the event of any deviation in operating data from standard parameters. The system is backed by an emergency power supply. Together with the batteries fitted to the pitch system, the system is deactivated securely in the event of any loss of power.

The turbine can be fitted with a condition monitoring system to ensure proactive maintenance. This early warning system alerts the operator when a component needs to be replaced in the foreseeable future. It is thus possible to avoid an unscheduled shutdown.

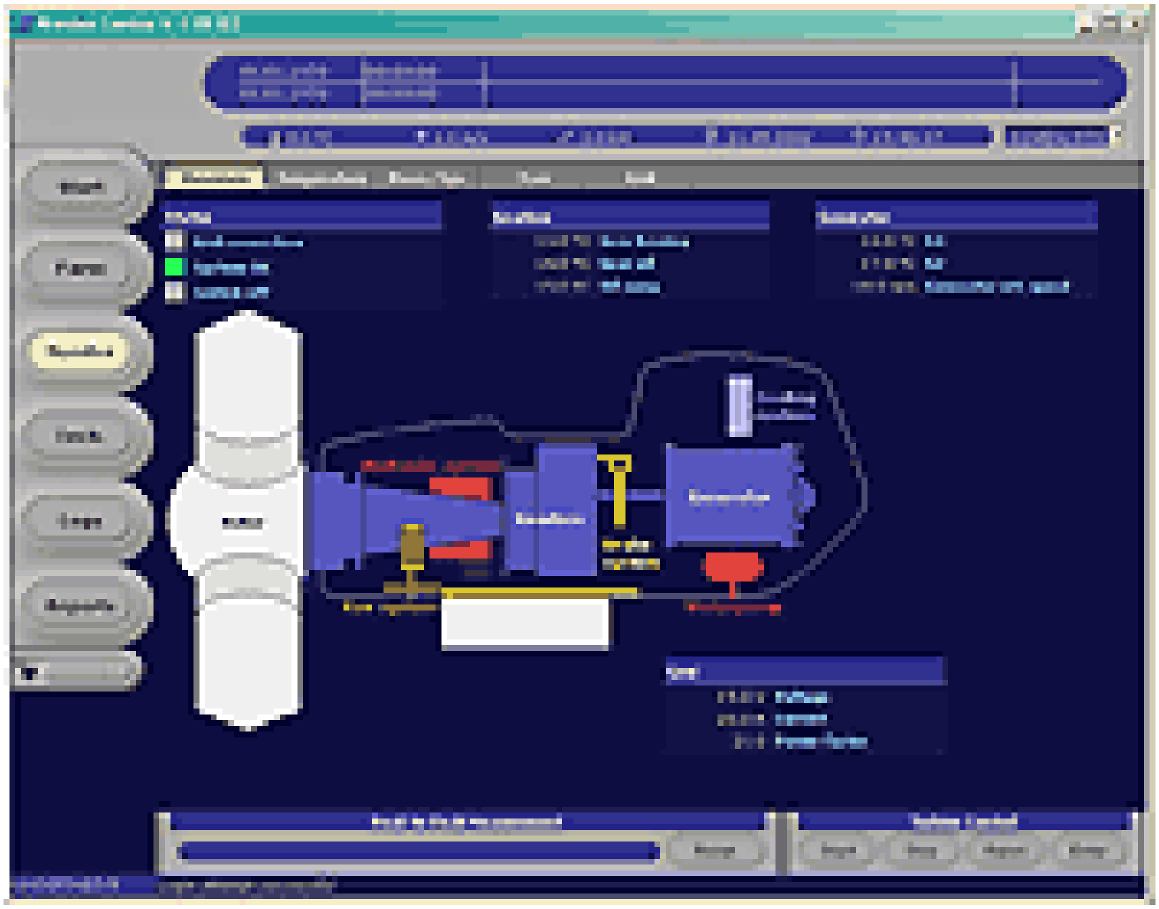


Fig. 42: Control system display. Source: Nordex.

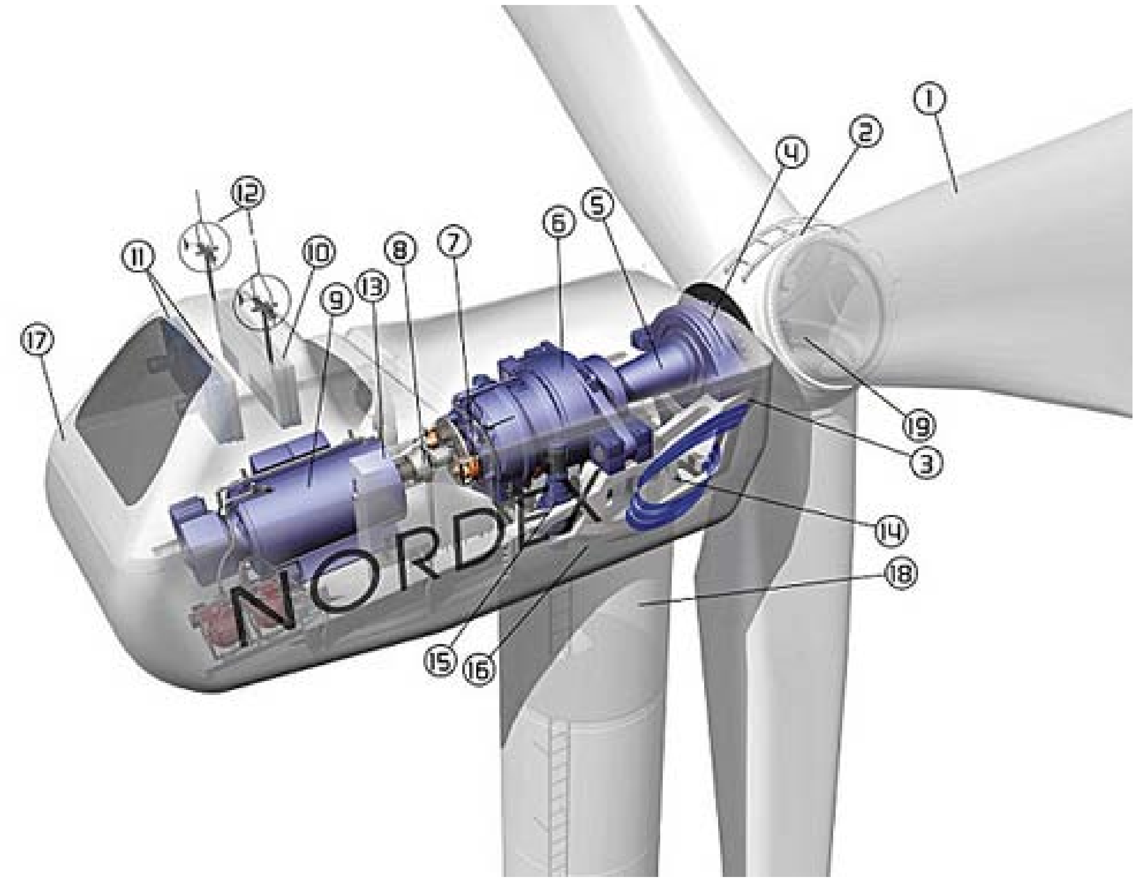


Fig. 43: Nordex N80 2.5 MW Wind turbine. Source: Nordex.

TURBINE DESCRIPTION

1. The rotor blades are made of glass fiber reinforced plastic composite. The rotor is pitch regulated.
2. The hub is made of cast iron.
3. The turbine frame is made of ductile cast iron. A superior material with regards to strength, vibration and noise reduction features.
4. The rotor bearing is a solid double spherical roller bearing with a ductile cast iron casing.
5. The rotor shaft is made of ductile cast iron.
6. The gearbox is a custom designed two stage planetary gears.
7. The disk brake is equipped with two brake calipers and located on the high speed shaft of the gearbox.
8. The generator coupling is a flexible coupling.
9. The generator is a 2500 kW of rated power liquid cooled double fed asynchronous generator.
10. The cooling radiator is a part of the gearbox cooling system.
11. The fan coolers for the generator cooling.
12. The wind measuring system consists of a redundant anemometer and wind vane, which measures the wind conditions and gives signal to the turbine control system.

13. The control system monitors and controls the operation of the wind turbine.
14. The hydraulic system maintains and controls the hydraulic pressure to the disc brakes and the yaw brake system.
15. The yaw drive consists of 2 planetary yaw gears, driven by frequency controlled electrical motors.
16. The yaw bearing is a 4 point ball bearing with outer teething. In addition the turbine is equipped with an active yaw disc brake system.
17. The nacelle cover is made of glass fiber reinforced plastic on a steel frame.
18. The tower is a tubular steel structure which can be delivered in various heights.
19. The pitch system consists of 3 independent pitch gears, driven by electrical motors.

Fig. 44: Nordex N80 2.5 MW wind turbine nacelle. Source: Nordex.

REPOWER WING TURBINES

The REpower 5M is variable speed wind turbine has a rated power of 5 MW and a rotor diameter of 126 m. The 5M is one of the largest and most powerful wind turbines in the world targeting offshore installations.

Wind farms with turbines of this capacity achieve outputs similar to conventional power plants. This in turn places high demands on the control and regulation system since optimized integration into the power grid becomes essential.

With a modular structure and logistical flexibility, it is is suitable for onshore and offshore installation. The offshore version is specifically designed to withstand the conditions of the high seas, including redundancy of key components to guarantee maximum availability, effective protection against corrosion and permanent monitoring.

Fig. 45: The REpower 5M variable speed wind turbine. Source: REpower.

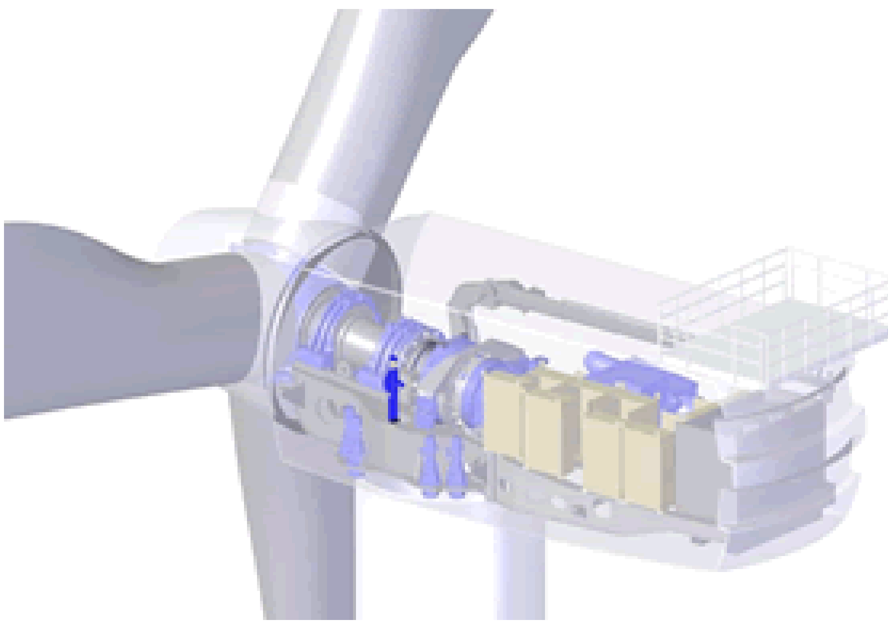


Fig. 46: REpower 5 MW wind turbine cutout showing a standard person inside the nacelle. Source: Repower.

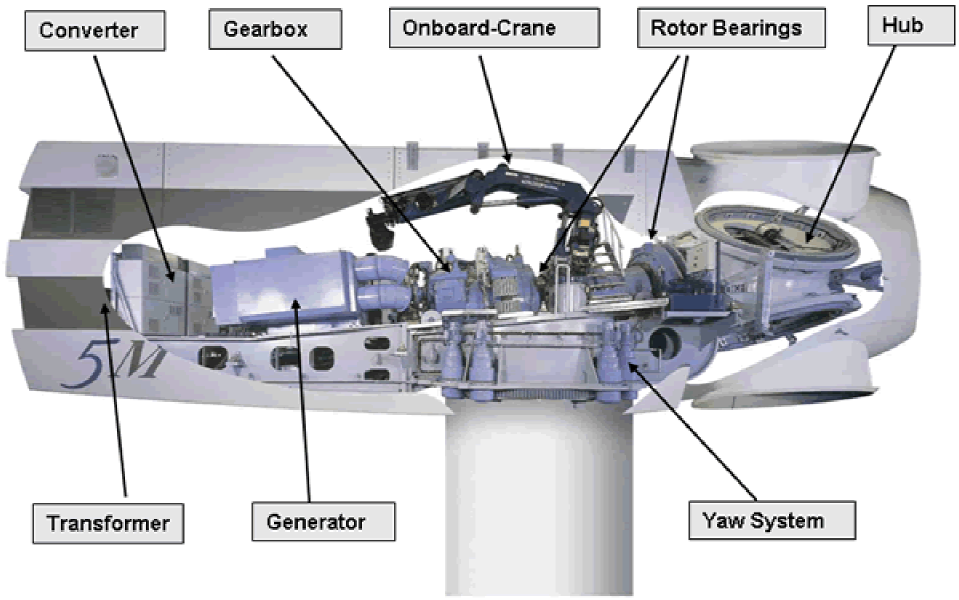


Fig. 47: Components of REpower 5M wind turbine. Source: Repower.

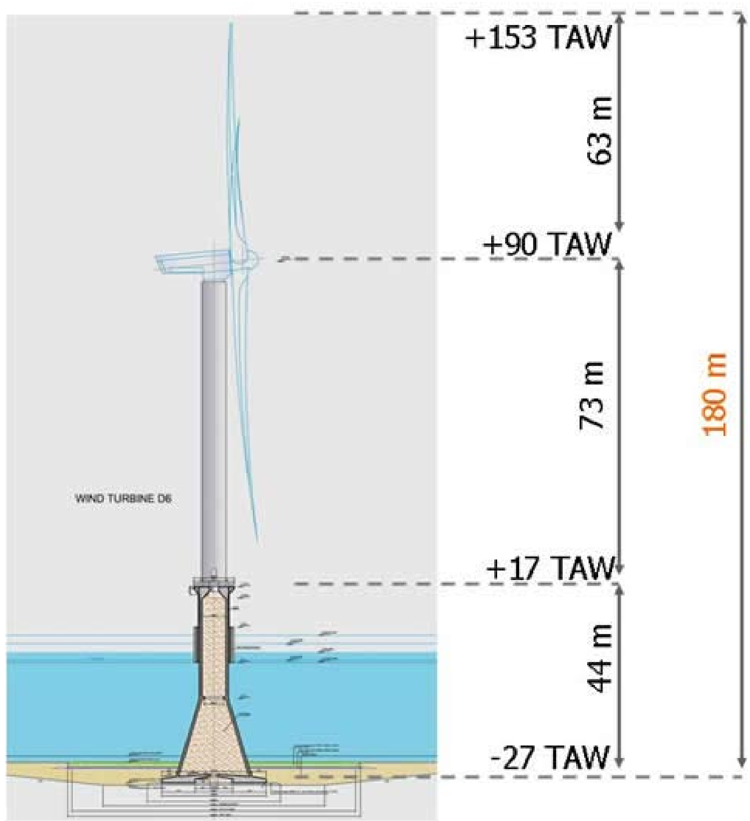


Fig. 48: Offshore foundation installation of the REpower 5M wind turbine showing the underwater foundation. Source: REpower.

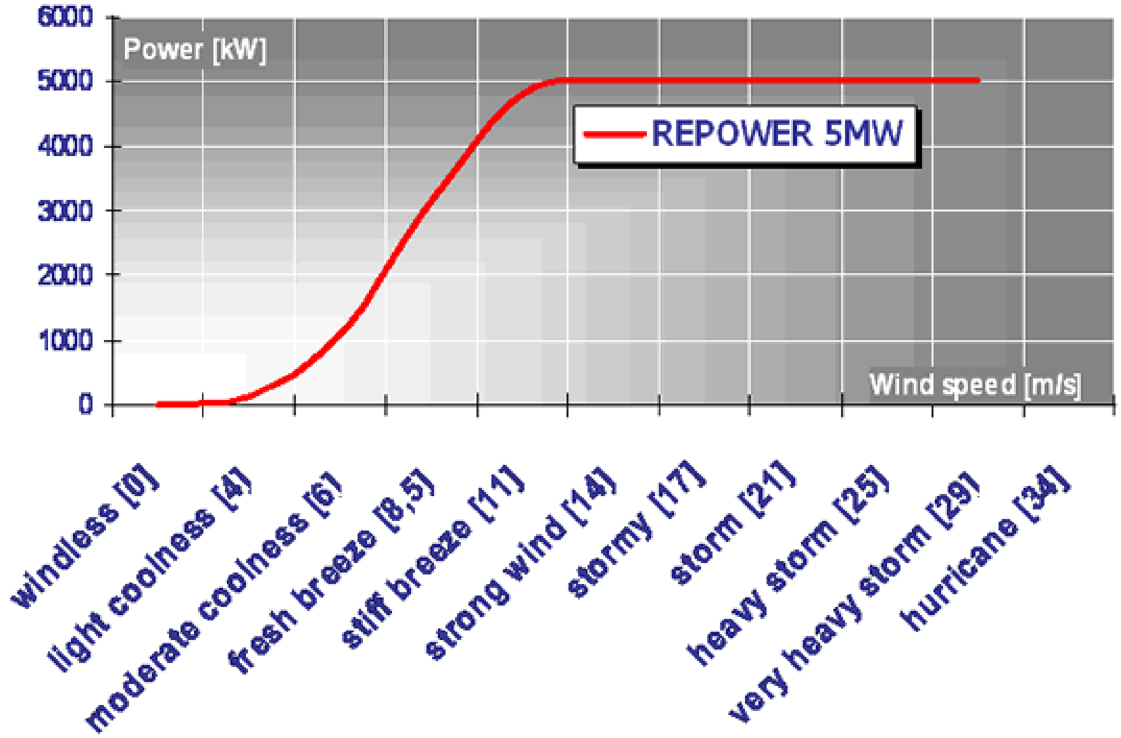


Fig. 49: REpower 5 MW wind turbine power curve. Source: Repower.

TECHNICAL SPECIFICATIONS

Rotor	
Number of blades	3
Vane length	61.5 m
Rotor diameter	126 m
Rotor speed	6.9-12.1 T/min (+/- 15.0 percent)
Rotor area	12, 469 m^2
Cut in wind speed	3 m/s
Rated capacity	5MW at 13 m/s
Cut out wind speed	31 m/s
Power control	Active blade stalling

OFFSHORE TRANSFORMER

On the offshore transformer platform step up voltage takes place to transform the power that has been collected to a higher voltage of 150 kV. This is necessary to limit losses when transporting power over long distances.

Fig. 50: Offshore transformer barge installation. Source: Repower.

GRID CONNECTION

Connection of the land cables to the public 150 kV electricity grid takes place at a high voltage switching station.

Fig. 51: Onshore switching station for connection to the power grid. Source:

Repower.

MULTIBRID OFFSHORE WIND TURBINES

DESCRIPTION

The Multibrid company specializes in large power wind turbines in the 5 MW power range such as the M5000 turbine for offshore power applications. The company develops and produces offshore turbines at Bremerhaven, a harbor site in Germany. The M5000 is the first wind energy converter that has been exclusively designed for large offshore wind farms. As a result of the continuous development process new solutions were found that set new standards and are best adapted to fit the requirements of offshore operation.

Since its foundation in 2000, the Multibrid company has been working on the development and manufacture of the offshore wind energy converter Multibrid M5000. It is affiliated with the Prokon Nord Group with a long experience in wind farm technology. The maritime environment in Bremerhaven supports the consequential orientation of the turbine's technology towards offshore deployment with knowledge about transportation and installation on the high seas.

PRODUCTION AND INSTALLATION

The Multibrid M5000 is produced directly at the Bremerhaven's harbor. In this way, ideal preconditions exist for the transport to the offshore wind farms. An in house team of technicians installs all components of the nacelle and the hub, including the sensitive components of the drive train. The turbine design is conceptualized in such a way that for the installation at the offshore site only the smallest number of installation steps is required. Besides the erection of the tower, just the nacelle and rotor have to be mounted. The converter system, transformer and switchgear are already installed on the tower ready for operation in order to reduce the installation risk at the offshore location to a minimum.

SERVICE AND MAINTENANCE

To account for the weather related reduced accessibility of the offshore location, particular attention has been paid to long service intervals. The use of maintenance complex components has been avoided wherever possible. Where regular inspections are required, as for the filter units, the maintenance cycles were considerably increased by the sizing of these parts and the inclusion of redundancies. The plant's condition can be checked at all times by the monitoring of all turbine parts that are indispensable for operation. This way, repairs on the high seas may be planned on a long term basis for most operations.

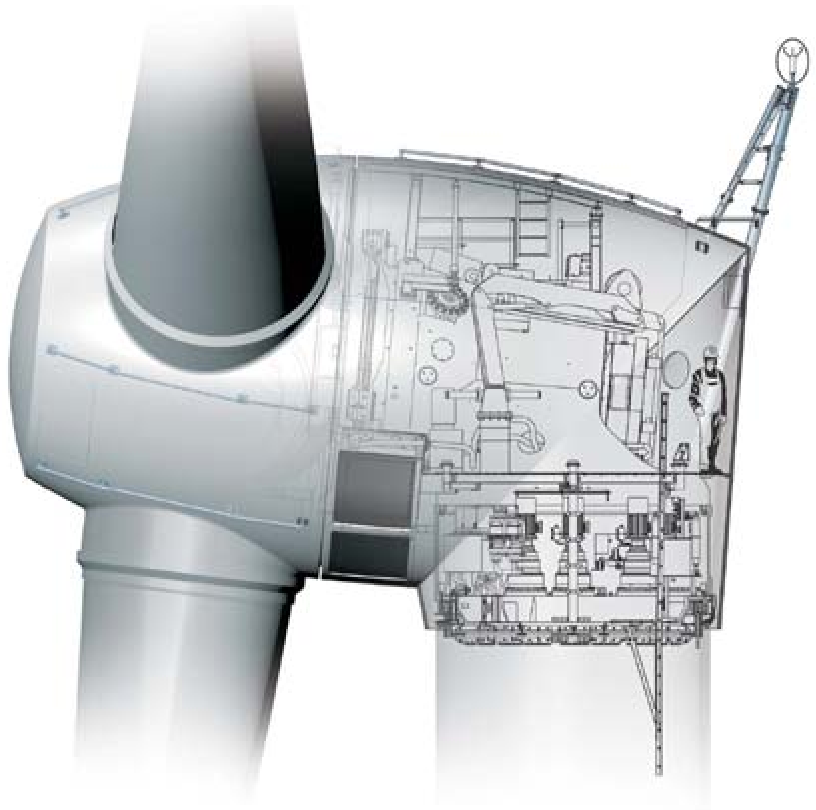


Fig. 52: Multibrid M5000 5 MW offshore wind turbine. Source: Multibrid.

TECHNICAL SPECIFICATIONS

General	
Rated power	5 MW
Cut-in wind speed	4 m/s
Rated wind speed	12 m/s
Cut-out wind speed	25 m/s
Design life time	20 years
Type class	IEC 1a/GL-TK 1 offshore

Gearbox	
Type	step-planetary gear, helical
Rated power	5,540 kW
Rated torque	3,575 kNm
Ratio	1:9.92

Rotor	
Rotor diameter	116 m
Number of blades	3
Rotor area	10,568 m^2
Rated speed	14.8 min^{-1}

Tilt angle	5º
Cone angle	-2º

Generator and converter	
Generator type	synchronous, permanent magnet
Rated generator power	5,315 kWe
Speed range	5.9 - 14.8 min^{-1} ± 10 %
Cooling	Water cooled
Protection class	IP 54
Converter type	4-quadrant-converter
Power factor of grid	0.9 inductive 0.9 capacitive

Tower	
Type	Tubular steel tower

Pitch system	
Principle	Electrical single pitch
Power control	Blade angle and rotor speed control

Masses	
Blade	16,500 kg
Hub	60,100 kg
Nacelle	199,300 kg

WEIGHT

In the development of the turbine the greatest importance was attached to the low weight of nacelle and rotor. This simplifies the transport considerably and allows a safe and fast installation, since the nacelle can be lifted as one complete unit on top of the structural tower. The low nacelle weight ensures the use of highly cost effective foundation structures.

RELIABILITY

Reliability is a decisive factor for the operation of offshore wind energy converters, is an integral element of the concept. The low rotational speed level and the small number of rotating parts and roller bearings reduce the risk of damage in the drive train to a minimum. Additionally, all auxiliary aggregates and sensors that are indispensable for the operation are installed in duplicate in order to avoid that a failure of these parts will lead to a failure of the overall system.

SEALING

The permanent protection of the converter’s technology from the corrosive sea atmosphere is the basic precondition for a long life time. Therefore nacelle and hub of are hermetically sealed against the ambient air. An air treatment system filters the air throughout all weather and operational conditions and provides that the plant's interior is not affected by corrosion through salt and humidity.

COMPACTNESS

The drive train evolved from the combination of the advantages of conventional turbine concepts. The integration of the rotor bearing, gear system and generator allows an extraordinary compact design and a very effective utilization of the main components. This leads to short load paths from the rotor to the tower head. The compactness is not an end in itself, but the result of a consequential implementation of the requirements on offshore wind energy converters.

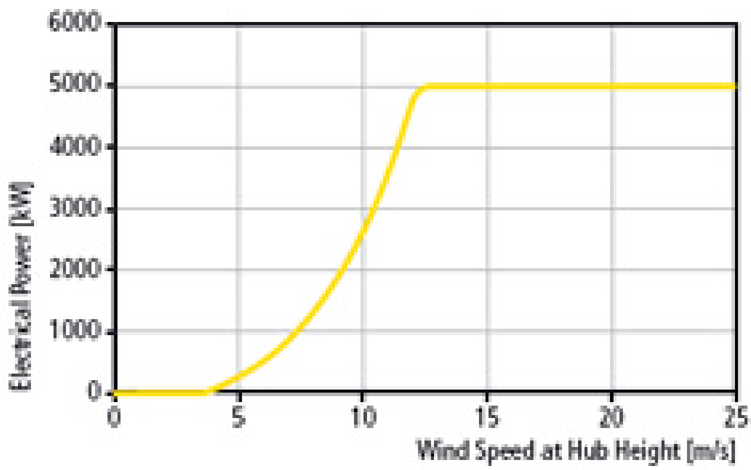


Fig. 53: Calculated power curve for the Multibrid M5000 wind turbine. Source: Multibrid.

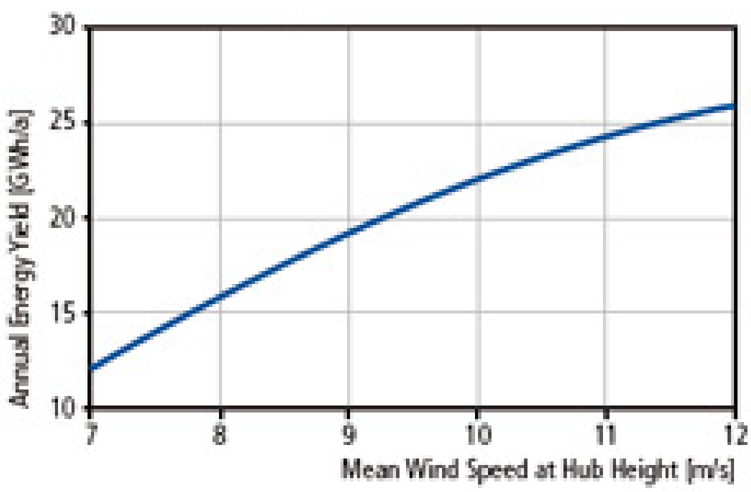


Fig. 54: Calculated energy yield curve for the Multibrid M5000. Source: Multibrid.

ROTOR

The rotor blades are characterized by exceptionally high stiffness and low weight due to the employment of carbon fiber girders. The aerodynamics of the rotor blades were designed towards yield performance and provide low noise emission. Three independent electrical blade pitch systems guarantee a highly dynamic blade angle adjustment and maximum safety in case of failure. The blade pitch system is completely located inside the closed rotor hub and thus protected against weather conditions.

Fig. 55: Rotor blade end of M5000 wind turbine. Source: Multibrid.

ROTOR BEARING, GEARBOX

A double tapered roller bearing in the TDO configuration transfers the rotor loads from the hub into the machine housing. The bearing and the gearbox are arranged in such a way that the dynamic rotor loads cannot have a harmful impact on the tooth engagements. The planetary gear is driven by the hollow wheel and the planetary shafts are fixed in a stationary cage. The shafts running on friction bearings as well as the gear meshing can be easily lubricated.

Fig. 56: Rotor bearing and gearbox M5000 wind turbine. Source: Multibrid.

GENERATOR AND CONVERTER

The stator of the permanent magnet synchronous generator is directly installed into the main frame. The rotor is mounted on the output shaft of the gearbox and therefore needs no further bearings. By using a permanent magnet technology, high efficiency is achieved at nominal loads as well as at partial load operation. The generator is connected to the grid via a 4Q converter, which allows maximum speed variability and full compliance with grid connection codes.

Fig. 57: Rotor bearings, gearbox and generator assembly of M5000 wind turbine. Source: Multibrid.

AIR VENTILATION

For offshore applications there is a need to include an air treatment system which is located at the tower bottom. It takes in ambient air and separates water and salt particles. An overpressure in the tower and nacelle is built up with the treated air and secures a controlled volume flow through the turbine. With a pressure difference monitoring system it is possible to eliminate any intrusion of untreated air. In addition, the temperature in the nacelle is adjusted by variation of the air flow.

GAMESA WIND TURBINES

DESCRIPTION

A feature of this design is that the drive train and the main shaft are supported with two spherical bearings transmitting the side loads to the frame through the bearing housing. This approach prevents the gearbox from receiving additional loads reducing faults and providing an adequate servicing capability.

The primary braking system uses aerodynamic full feathering. The secondary braking system is a hydraulically activated disc brake mounted on the gearbox speed shaft.

A total lightning protection system following the IEC 61024-1 standard conducts any lightning discharge from both sides of the rotor blade tip down to the root joint and across the nacelle and tower structure to a grounding system located in the foundation, protecting the blade and sensitive electrical components from damage.

Fig. 58: Gamesa G52-850 kW wind turbine farm. Source: Gamesa.

CONTROL SYSTEM

The generator used is a doubly fed machine whose speed and power are controlled using IGBT converters and Pulse Width Modulation (PWM) electronic control. Such a system offers both active and reactive power control, low harmonic content and minimal losses, increased efficiency and a long lifetime for the turbine.

The control system allows real time operation and remote control of the wind turbines, meteorological mast and the electrical substation by way of a satellite and terrestrial network using the TCP/IP protocol with a world wide web (www) interface. A modular design is adopted with control tools for active and reactive energy, noise, shadows and wake effects.

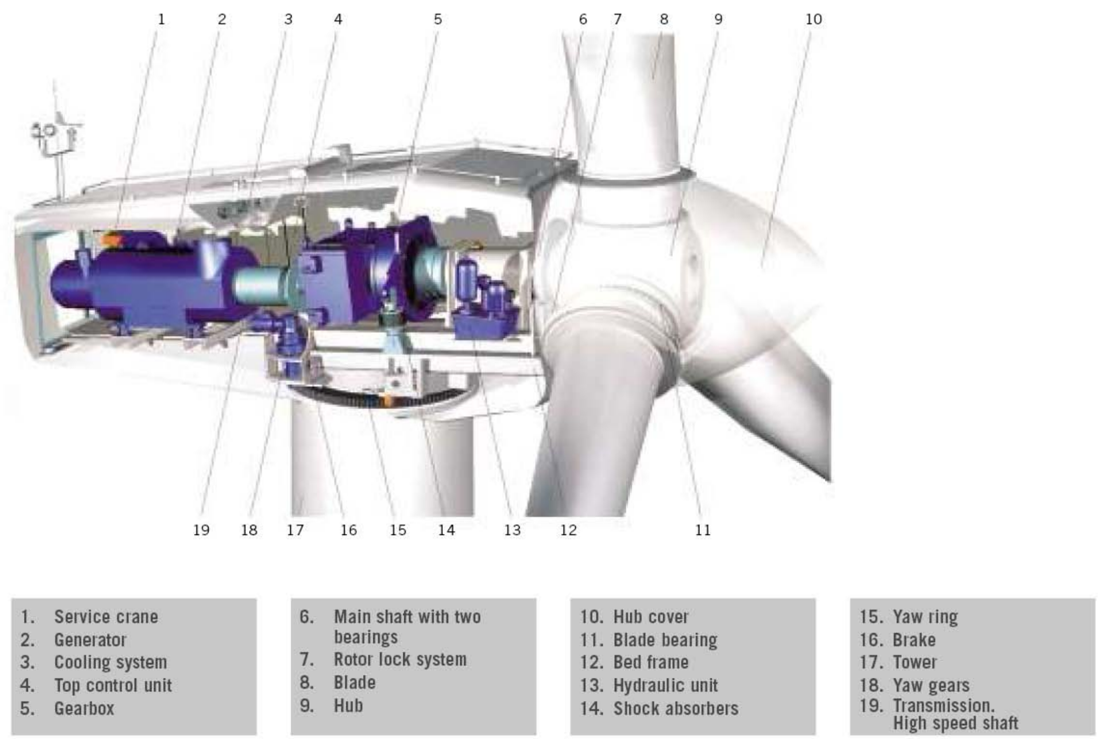


Fig. 59: Gamesa G52 850 kW wind turbine. Source: Gamesa.

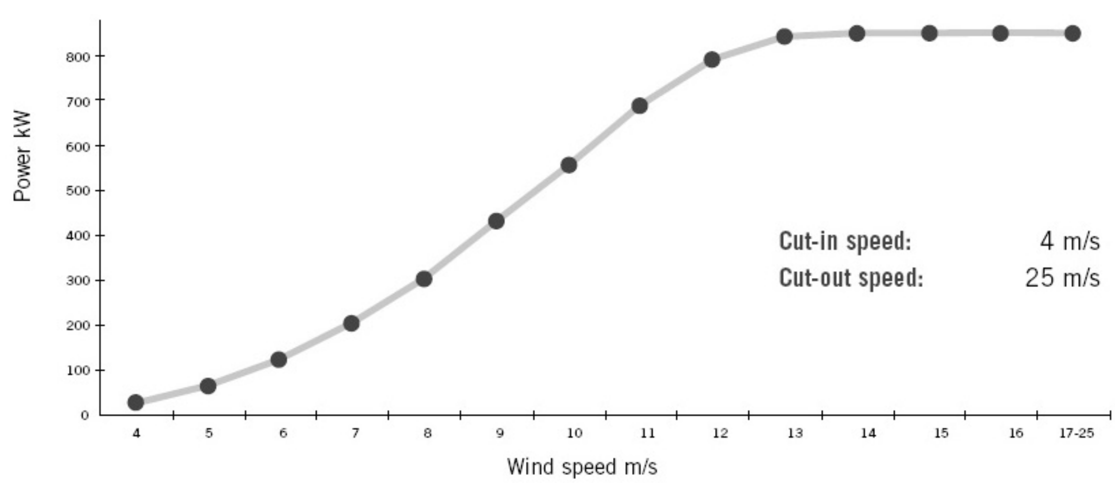


Fig. 60: Power curve of the Gamesa G52 850 kW wind turbine. Source: Gamesa.

Table 2: Power curve data for the Gamesa G52-850 kW wind turbine.

Power [kW]	Wind speed [m/s]
27.9	4
65.2	5
123.1	6
203.0	7
307.0	8
435.3	9
564.5	10
684.6	11
779.9	12
840.6	13
848.0	14
849.0	15
850.0	16
850.0	17-25

POWER CURVE

The power curve for the Gamesa G52 850 kW wind turbine is generated based on the NACA 63.xxx and FFA-W3 air foil profiles for an air density of 1.225 kg/m^3.

The rotor blade is tip angle pitch regulated supplying a grid at 50 Hz frequency, at 10 percent turbulence intensity and a variable rotor rotational speed over the range 14.6-30.8 rpm.

The grid connection uses doubly fed wind turbines and active crowbar and over sized converter technologies. Low voltage ride through and dynamic regulation of the active and reactive power are added capabilities.

TECHNICAL SPECIFICATIONS

Rotor	
Rotor diameter	52 m
Number of blades	3
Length of blade	25.3 m
Airfoil type	NACA 63.xxx and FFA-W3
Composition	Glass fiber reinforced epoxy
Rotor area	2,124 m²
Rotational speed	Variable: 14.6-30.8 rpm, 55m and 65 m towers Variable: 16.2-30.8 rpm, 44 m tower
Rotation	Clockwise from front view

Rotor blade weight	1.9 t
Weight including hub	10 t
Top head mass	33 t
Gearbox	
Type	1 planetary stage / 2 helical stages
Gear ratio	1:61.74, 50 Hz 1:74.5, 60 Hz
Cooling	Oil pump with oil cooler
Oil heater	1.5 kW
Electrical Generator	
Rated power	850 kWe
Number of poles	4
Rotational speed	900:1,900 rpm rated: 1620 rpm
Type	Doubly fed machine
Voltage	690 Volts, AC
Rated stator current	67 Ampères at 690 Volts
Frequency	50/60 Hz
Protection class	IP 54
Power factor, At generator output terminals, at low voltage side before transformer input terminals.	Standard:0.95 CAP – 0.95 IND at partial loads and 1 at nominal power. Optional: 0.95 CAP – 0.95 IND throughout power range

PREDICTIVE MAINTENANCE

A predictive maintenance system is used for the early detection of sources of malfunction and early deterioration in the turbine's main components, is integrated with the control system. This reduces the occurrence of major corrective measures, increases the machine availability and working life, and allows for obtaining preferential terms in insurance premiums.

NOISE CONTROL

The aerodynamic blade tip and mechanical components design minimizes noise emissions. The noise emission is controlled according to chosen or regulatory criteria as concerns date, time or wind direction.

ECOTÈCNIA WIND TURBINES

INTRODUCTION

Ecotècnia, is a Spanish manufacturer and operator of wind turbines and solar energy products. It developed its first wind turbine in 1981, and designs, manufactures and operates its own wind turbines and builds turnkey wind farms.

MAIN FEATURES

The Ecotècnia 80 wind turbine of 2 MW nominal power has been designed following the Class II specifications of standard IEC-61400-1, suitable for sites with a mean annual wind speed of up to 8.5 m/s and an extreme gust speed with a 50 year repetition frequency of 60 m/s. An efficient control system incorporating control mechanisms associated with the structure has made it possible to attain a diameter of 80.5 m with a 2 MW wind turbine. It has a power flux or areal power of:

$$A_p = \frac{P}{\pi D^2/4} = \frac{4x2,000}{\pi x 80.5^2} = 392.96[\frac{W}{m^2}]$$

and has been designed for optimal exploitation of Class III sites by incorporating active damping mechanisms.

It has a characteristic mechanical design based on supporting the rotor directly on the frame, separating the tasks of supporting it from those of torque transmission. The drive train has a carefully studied design that includes controlled flexibility and torque control in any situation. Combined with variable speed operation, this permits a reduction of the number of cycles and extreme loads to which the drive train is subjected.

Fig. 61: Wind farm using ecotècnia wind turbines. Source: ecotècnia.

MECHANICAL DESIGN

This mechanical design concept, has been demonstrated its efficiency in commercial wind turbines of lower power of 0.64, 0.75, 1.3 and 1.67 MW, of which over 1,000 units have been installed. The concept is based on the following features:

1. The rotor supported directly by the frame.
2. A flexible drive train and floating shaft are used.
3. The transmission of loads is directly to the structure.
4. The yaw system uses gliding pads.

The design includes some important features:

1. A modular conception of the wind turbine.
2. An independent pitch control system in each blade.
3. A decentralized control system.
4. Use of built in predictive maintenance.
5. Use of active damping systems.

The optimization of the design process aims at greater cost effectiveness, reliability, integration into the electrical grid, and environmental compatibility.

The gearbox, better protected, is subjected to much lower loads than in conventional configurations, thus lengthening its working life.

The rotor, resting directly on the frame, is not supported by the gearbox, which suggests that this component is not subjected to the great asymmetry of loads generated on the rotor by the wind. The rotor being fixed; means that the gravity loads are deflected to the tower and only the useful wind rotational loads are transmitted to the drive train.

The length of the shaft gives the drive train considerable elasticity, thus preventing load peaks on the gearbox. The positioning of the gearbox, separate from the support structure, prevents it from being subjected to loads deriving from the behavior of the latter, such as deformations or displacements of large masses.

In extreme situations, these loads can generate overloads not foreseen in the load simulation and calculation stage.

Fig. 62: Ecotècnia wind turbines. Source: Ecotècnia.

MODULAR DESIGN

The wind turbine is conceived in a modular form. The nacelle is made up of three modules comprising the following components:
Module 1: Rotor, bearings and shaft.
Module 2: Mainframe, yaw system and housing support.
Module 3: Drive train.

These modules include both the mechanical components and the control systems, thus allowing independent verification of their integrity and operation. Their manufacturing process is also independent, and they are interchangeable.

These modules have reduced weight and reduced the external dimensions, thus facilitating the transport operations. In addition, the modules can be assembled at the top of the structural tower, thus reducing the requirements for assembly cranes and auxiliary elements.

The modularity of the wind turbine offers several advantages:

1. Less need for a civil engineering infrastructure: access to the site with the nacelle is made easier by having to transport only components weighing less than 30 tonnes.
2. Ease of transport: the modules have weights and dimensions which enable them to adapt to standard transport procedures and containerization.
3. Lower requirement of cranes: due to the reduced weight of the modules, the wind turbine can be hoisted with cranes of the same capacity as those currently used for machines of less than 1 MW power. This also means lower infrastructure requirements at the site.
4. A better exploitation of complex terrains due to ease of installation.

TECHNICAL SPECIFICATIONS

General characteristics	
Type	Wind turbine class II as per IEC-61400-1 Ecotèchnia 80 2.0
Nominal power	2 MW
Standard hub height	70 m
Power control system	Variable speed with independent pitch control in each blade
Range of operating temperatures	-10 to -40 ^{o}C
Mean annual wind speed for suitability	8.5 m/s
Maximum wind speed (mean 10’)	42.5 m/s
Extreme gust speed (IEC)	59.5 m/s
Instant stoppage speed	32 m/s
Turbulence intensity	A
Rotor	
Yaw	Windward
Speed range	9.44-17.9 rpm

Number of blades	3
Rotor diameter	80.5 m
Cut in and cut out speed	3 m/s and 25 m/s
Swept area	5,090 m^2
Rotor rotational speed	9.44-17.90 rpm at nominal power
Blade tip speed	80 m/s
Rotor weight including hub	53 t
Nacelle weight without hub	105 t
Blades manufacturer	LM Glassfiber
Type of blades	LM 37.3 II + 2.21 m lengthener
Nacelle	
Yaw	By means of guide shoes, with 4 motor reducers
Hub, shaft and bearings	
Hub material	Nodular cast iron EN-GJS400-18U-LT
Type of main bearings	2 conical roller bearings at front and rear, housed inside hub
Bearings manufacturer	FAG or SKF
Transmission shaft material	F.1252 UNE 36-012-75
Length of cylindrical shaft	4.17 m
Hub to shaft coupling system	Contraction ring and elastic coupling
Gearbox	
Type	Planetary with parallel shafts
Manufacturer	Winergy or equivalent
Gearing ratio	1:100.6
Mechanical power	2.225 MW
Nominal torque	1,190 kNm
Cooling system	Active cooling by means of radiator with forced ventilation
Lubrication system	Oil using active lubrication
Gearbox generator coupling	Contraction rings and elastic coupling
Weight	35 t
Operational temperature	65 ^oC with ambient temperature 40 ^oC
Grid connection	Asynchronous generator controlled by the rotor
Voltage drops	Capacity to maintain operation during voltage drops
Generator	
Type	Induction with wound rotor. Rotor generator winding with converter, based on IGBT technology, connected at the rotor
Manufacturer	ABB, Siemens, or equivalent
Quantity	1
Nominal power	2,050 kWe
Rotational speed	1000 / 1800 rpm
Nominal voltage	690 V +/- 10 %
Grid connection	Variable-speed
Power wave inverter	Two directional, IGBT technology

Cos φ range at nominal power	0.95 inductive/capacitive
Cooling system	Air/air
Structural Tower	
Type	Tronco-conical steel tube
Bottom diameter	3.95 m for 70 m tower
Top diameter	2.13 m
Rust protection	Class 4 as per standards ISO 9332, ISO 9224 and EN 10025
Height	70 m
Color	RAL 7053
Control System	
Type	Control of torque and pass angle
Torque control	Digital Signal Processor (DSP) and power electronics
Control of blade pass angle or pitch control	Three independent microprocessor controlled systems, one for each blade using electrical pitch control
Power control	Vectorial control by the generator
Interconnection and communication protocols	Bus device Net and TCP/IP
Monitoring	ARGOS system
Speed control	Pitch control
Main brake	Independent pitch control
Auxiliary brake	Independent emergency system
Yaw system	
Yaw speed	0.47 ^{o}/s
Type	Active, with mechanical brake
Yaw motion	3 polymer gliding pads
Yaw motor	4 electrical motors and planetary type gears
Activation	At variable frequency and torque control
Manufacturer	Bonfiglioli or similar
Yaw brake	2 guide shoes acting as clamps by means of hydraulic safety system
Brakes system	
Main brake	Aerodynamic by means of pitch rotation of the blades
Stop or parking brake	Disc brake located on the high speed shaft
Weights	
Nacelle including hub	64 t
Structural tower, 70 m height	126 t
Blade unit without lengheners	6.035 t

INDEPENDENT ROTOR PITCH CONTROL

The incorporation of independent pitch control into each rotor blade represents an advance over the traditional wind turbine in terms of safety and regulation. The principle is based on having three independent electrical pitch control systems, one for each blade.

The functions of the pitch control are to carry out the commands of the central control system, with which it is communicated by means of a digital bus. The redundancy due to the existence of independent systems in the three blades ensures greater safety, since one single blade in a downwind position is capable of maintaining the rotor in a safe condition.

The advantages of incorporating the pitch control system are:

1. Control of the rotor speed within the regulation margin, maintaining the power constant in the grid connection.
2. Reduction of extreme loads in the structure, enabling operation in strong winds with the blades in closed position without the risk of gusts of wind causing extreme values of operational loads. In the machine-stopped situation or storms, the loads in the support structure and foundations are lower.
3. Elimination of the mechanical brake without loss of safety. The independent activation ensures the braking of the wind turbine under any circumstance. A fault in one of the pitch control systems is not critical for the structural safety of the wind turbine.
4. Start-up in low winds, by providing significant torque values at low turning speeds.
5. Better use of blades when dirty, by allowing the position of optimal aerodynamic performance to be sought.
6. Active damping of the structure in the direction parallel to the rotor shaft. The use of acceleration signals of the nacelle and their inclusion in the pitch control loop allows the oscillations of the nacelle and tower structure to be actively damped, thus reducing fatigue loads.

Fig. 63: The Ecotècnia rotor is directly supported by the structural tower. Source:

Ecotècnia.

DECENTRALIZED CONTROL SYSTEM

The control system consists of a decentralized system formed by interconnected elements which perform specialized functions:

1. Management control system which carries out the supervision of the systems of the wind turbine and operation of activating elements and sensors.
2. Torque control system involving the vectorial control of the generator and its synchronization with the grid.
3. Blade angle of attack control system.
4. Status monitoring system including the measurement of vibrations.

The effective control of the drive train is based on the capacity of injecting electrical energy into the grid in a controlled manner within a wide range of rotational speeds. This is based on a fast control system based on a Digital Signal Processor (DSP) and power electronics capable of modeling the electromagnetic processes (vectorial control of the electrical machine) of the interior of the generator in real time. This makes it possible to feed constant power into the grid free of influence of speed variations in the drive train.

The following advantages are achieved by means of the torque control system:

1. Increase in energy produced throughout the wind speed range: at low speeds, by improving the aerodynamic performance of the rotor, and at high speeds by permitting efficient control of the power, preventing the external influences of dirt on the blades and changes in density and temperature.
2. Improved operational conditions.
3. Reduction of peaks and oscillations in the production of energy and reduction of extreme loads in the drive train with transient-free interconnection.
4. Possibilities of control of the power delivered to the grid.
5. Dynamic control of the reactive power, allowing a contribution to regulation to the grid. This implies improved characteristics for weak grids.
6. Lower environmental impact due to reduction of turning speed at low wind speeds.
7. Less risk of bird collision thanks to reduced frequency of blade tip passage, due to reduced turning speed at low wind speeds.

Speed [m/s]	Power [kW]
3,5	32
4,5	97
5,5	197
6,5	346
7,5	549
8,5	815
9,5	1124
10,5	1463
11,5	1798
12,5	1961
13,5	2000
14,5	2000
15,5	2000
16,5	2000
17,5	2000
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19,5	2000
20,5	2000
21,5	2000
22,5	2000
23,5	2000
24,5	2000

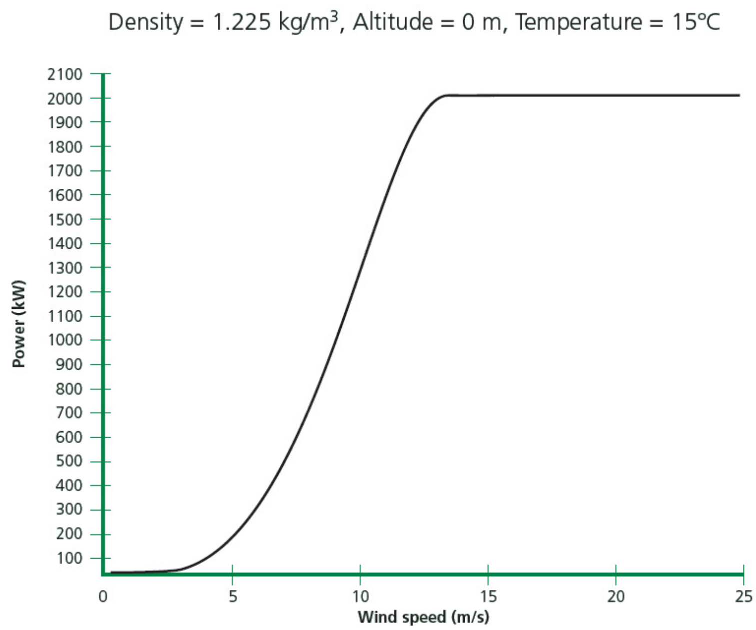

Fig. 64: Power curve of the Ecotècnia A80, 2 MW wind turbine. Source: Ecotècnia.

PREDICTIVE MAINTENANCE

The integration into the wind farm control and monitoring systems of status monitoring enables predictive maintenance to be carried out in an automated or in a remote mode.

This predictive maintenance is based on monitoring the status and condition of the machinery throughout the lifetime of the units. In general it is based on the measurement of vibrations, allowing the monitoring of their operation on time scales of the order of the lifetime of the complete system.

The integration into the control systems of fast vibration measurements and their direct frequency processing permits the periodical collection of data to establish the evolution of the status and to establish alarms or stoppages requiring an inspection of the wind turbine.

The data analysis is separated into two frequency ranges:

1. Low-frequency range of up to 10 Hz, in which the behavior of the structure of the wind turbine is analyzed. In this range the analysis is based on the modes of the wind turbine itself, the aim being a permanent diagnosis of the correct status of the structure of the wind turbine. This range includes also the low-speed rotary elements.
2. High-frequency range of 10-4,000 Hz, in which the rotary elements of the drive train are analyzed. In this range the analysis is based on monitoring the multiple frequencies of the turning speed, and in a variable-speed machine it requires special frequency processing.

MITSUBISHI WIND TURBINES

Mitsubishi wind turbines have a range of available ratings: 200 kW, 300 kW, 500 kW, 600 kW and 1 MW and a 2 MW design under development.

The characteristics of Mitsubishi wind turbine include:

1. Lightweight blades with full span pitch control and optimum blade profile for maximum power performance.
2. Noise reduction technology in the rotor blade and the gearbox.

Fig. 65: The Mitsubishi MWT 1000, 1 MW wind turbine. Source: Mitsubishi.

TECHNICAL SPECIFICATIONS

Turbine	
Type	Blade pitch controlled upwind type
Rated output	1 MW
Rotor diameter	57.0 m (Class 1) 61.4 m (Class 2)
Rotational speed	21.0 rpm 19.8 rpm
Number of blades	3 (GFRP)
Blade length	26.8 m 29.5 m

Generator	
Type	Induction
Rated output	1 MWe
Voltage, phase and frequency	690 V / 600 V 3 phase 50 Hz / 60 Hz
Tower	
Type	Monopo;e
Hub height	45 / 60 / 69 m
Control systems	
Power regulation	Pitch control
Yaw orientation	Active yaw control
Safety Systems	
Overspeed	
Low governor oil pressure	
Excessive nacelle vibration	
Yaw disorder control	
Generator over current	
Controller disorder	

JAPAN STEEL WORKS (JSW) GEARLESS WIND TURBINE

INTRODUCTION

Japan Steel Works (JSW) became involved in Wind Power Systems using its long experience in industrial machinery and energy technology. Initially, it delivered 30 sets of General Electric (GE) 1.5s wind turbines in Japan. Using the acquired operational experience, JSW adopted the technology of permanent magnet gearless synchronous generator wind turbines from Enercon in Germany and manufactures its own wind turbine including the rotor blades and the tower.

Fig. 66: Japan Steel Works (JSW) J82 permanent magnet synchronous generator gearless wind turbine. The nacelle contains the transformer and the converter instead of having them placed on the ground. Source: JSW.

JSW uses the SCADA remote monitoring and control system. It produces 34 and 40 meters length blades. Its production capacity is about 60 wind turbines sets per year and delivers turnkey projects.

The CO_2 reduction is estimated in comparison with an oil-fired power system as 0.704 kg-CO_2/kWh.

Table 3: Estimated Annual Performance of the J82 Wind Turbine.

	Average wind speed [m/s]	
	6	7
Power generation	4,465 MWh	6,069 MWh
CO_2 reduction	3,140 tons	4,270 tons

FEATURES OF JSW TURBINES

1. Efficiency: The direct gearless drive eliminates gear loss and the synchronous generator with permanent magnet offers high efficiency compared with conventional designs.
2. Reliability: The avoidance of the gearbox and the oil cooler eliminates a major cause of down time. Compared with an asynchronous slip ring anchor generator, no abrasion parts such as brushes are required, eliminating the need for frequent maintenance and replacement.
3. Reduced noise level: The gearbox, which is the major source of noise claim, is omitted.
4. Low maintenance cost: In addition to the high reliability, because there are no equipment requiring oil lubrication, such as the gearbox, the main shaft and the brushes, a reduction in maintenance cost is achieved.
5. Less influence on grid: The full conversion of the power using a converter and transformer in the nacelle leads to several advantages for the power quality supplied to the grid and the flexibility offered to the grid operator.

TECHNICAL SPECIFICATIONS

		J82-2.0 / III	**J82-2.0 / II**
Main specifications	Rated power	2 MW	2 MW
	Cut-in wind speed	3.0 m/s	3.5 m/s
	Rated wind speed	12 m/s	13 m/s
	Cut-out wind speed	20 m/s	25 m/s
	IEC class	S	S
	Extreme wind speed according to IEC61400 class I	70 m/s	70 m/s
	Average wind speed	7.5 m/s	8.5 m/s
	Turbulence intensity	0.18	0.18
Rotor	Material	GFRE	GFRE
	Length of rotor blade	40 m	40 m
	Diameter	82.6 m	82.6 m
	Rated rotational speed	19 rpm	19 rpm
	Rotational speed	Variable	Variable
Tower	Hub height	65/80 m	
Electrical specifications	Generator type	Direct drive gearless permanent magnet synchronous generator	
	Nominal voltage	660 V	
	Transformer output voltage	6.6 or 22 kV	
	Voltage frequencies	50/60 Hz	
Control	Pitch system	Variable speed control	
	Yaw system	Active	
Weight	Rotor	42 tons	42 tons

	Nacelle	17 tons	18 tons
	Subframe	15 tons	15 tons
	Generator	48 tons	48tons
	Tower	110 tons (Hub height 65 m) 160 tons (Hub height 80 m)	

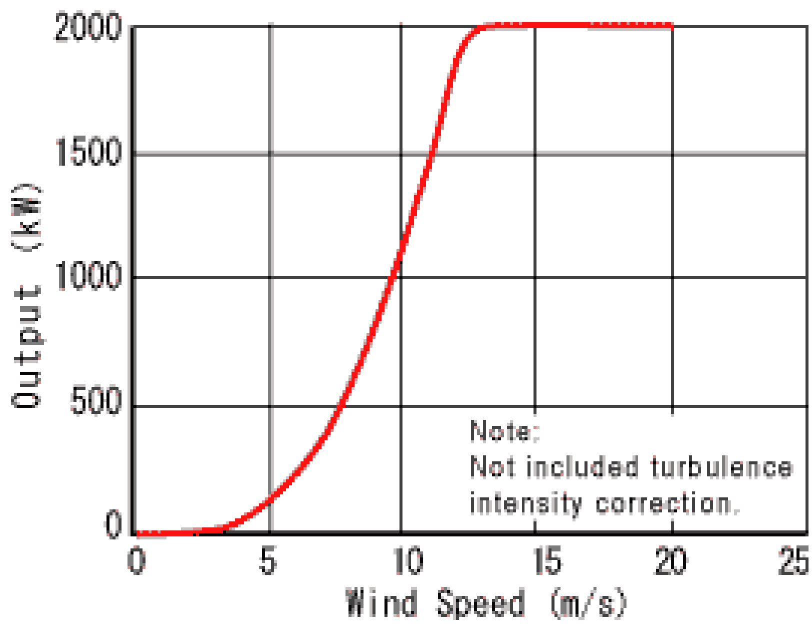

Fig. 67: J82 gearless turbine power curve. The estimated power generation is based on the average annual wind speed at the hub height. Source: JSW.

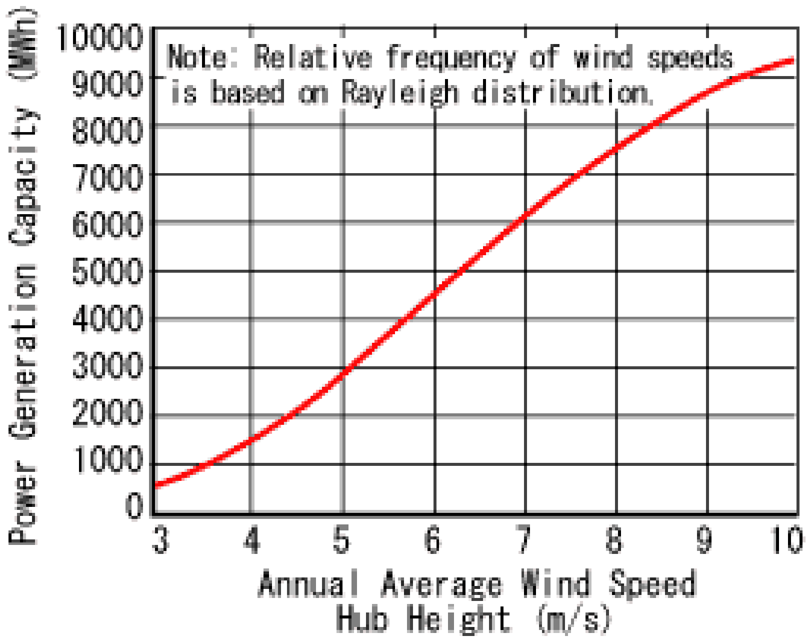

Fig. 68: Annual power generation capacity for the J82 gearless turbine. Source: JSW.

TECHNOLOGY CHOICE CONSIDERATIONS

Numerous workable technology options exist in windmill designs. Some manufacturers advocate a direct drive approach. These direct drive turbines have no gearbox, which reduces the number of moving components and teeth problems as well as the oil cooling system posing a fire hazard and an environmental spillage problems. The generator is much larger than the gearbox models and if it failed, it would be costly to repair or replace.

There are passive stall regulated models, compared with active pitch models. Passive stall turbines automatically stall because of the blade aerodynamics, when the wind speed exceeds about 14 m/s, slowing down the rotor, ensuring that the generator output does not exceed the rated capacity of the turbine, causing it to overheat. Active stall control and active pitch turbines have motors that adjust the blade pitch, and let the wind pass through when the wind speed is high accomplishing the same purpose.

The manufacturers make claims about how their technology is simpler or superior than each other. Direct drive manufacturers claim that eliminating the gearbox reduces the maintenance cost. Passive stall manufacturers suggest that the simplicity of passive stall, with no need to pitch the blades, reduces the probability of failure. The active pitch manufacturers advocate that their technology eases some of the strain on the tower and blades.

Experience shows that the different technologies work. What actually matters is the availability of service in a given local area. Servicing wind turbines is a specialized field, and factory training and updates are essential.

Parts of a wind turbine design are proprietary, particularly the controller and its associated software. This includes the pitch algorithms, and the protection and control system which ensure the safety of the turbine. Temperature sensors exist at many turbine locations, shutting down the turbine if it overheats. The protection and monitoring software measures voltages, and shuts down if the voltage drops too much, or if the current is unbalanced which could damage the generator. An optical rotor speed sensor is used to shut the turbine down if it spins too fast and gets into a runaway condition. A flash detector in the transformer detects arcing or fire. The control system measures wind direction, and the yaw motors adjust the nacelle to face the wind in the optimal direction. Wind speed is measured to adjust the blade pitch to let some of the wind pass by if it is too strong, and shut down the turbine in very high winds, to protect the structure. The software manages automatic restarts if conditions improve. It logs events and even places calls to the technical staff when problems are detected.

Parts availability in winds turbines operation is essential. Summoning parts from distant locations can result in significant turbine downtime. Stocking an inventory of spare parts requires a critical mass of installed wind turbines before it becomes economically feasible. A critical mass of installed turbines is essential for allowing the service technicians to be trained at diagnosing faults and making repairs. Third party service organizations for wind turbines are needed in the future, but presently factory trained engineers and technicians are in vogue.

According to these considerations, when a turbine design is chosen it is advisable that it should include a 5-10 years warranty, with availability guarantees from the supplier.