WINDTEC 1200kW-Low-Cost/Light-Weight Wind Turbine

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WINDTEC Anlagenerrichtungs- und Consulting GmbH

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1. Partnership

Company name	**Project role**	**Address**	**Contact person**
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2. Objectives of the project

Tasks Of Joule Work Programme	State of the Art/ WEGA II	Project Objectives/ Advances	Project Goals
Reduced Costs specific energy costs:1)	**0,27-0,40 ECU/kWh/y**	investment costs: 1,250,000 ECU, gross energy: 5,208 MWh/y **0,24 ECU/kWh/y**	- new blade - new drive train - new variable speed electrics - modular system/ slip-form concrete tower
electricity generating costs: 2)	**0,044-0,065 ECU/kWh**	**0,038 ECU/kWh**	- low specific energy costs - high reliability - on-board erectable crane system
Mass Reduction specific tower head mass	**15-20 kg/MWh/y**	**13 kg/MWh/y**	- light-weight rotor blades - new drive train - torque control
Development of machine-oriented components		new components as: rotor blade, drive train, power electrics, slip-form concrete tower, modular system	
Low Wind Speed Regime	swept area/kW: **1,7-2,4 m^2/ kW** in most cases fixed speed	**- 2,4 m^2/kW** - high-efficiency variable speed electric's	- 67 m diameter rotor - DFIG
Reliability (incl. power quality)	complex and expensive systems in case of high power quality; poor power quality in case of simple systems	**-** small, cost-effective and reliable power electronics - improved power quality	- doubly-fed induction generator (DFIG) - cosφ-control - low harmonics distortion level

1) turn-key installation incl. transformer; no O&M; one year of operation with 8,0 m/s average wind speed at hub height, 100% availability
2) assumptions as under 1) plus 15% compensating grid-connection costs, availability and array losses; incl.O&M (2,5% Of investment costs per year); 15years/8% interests financing

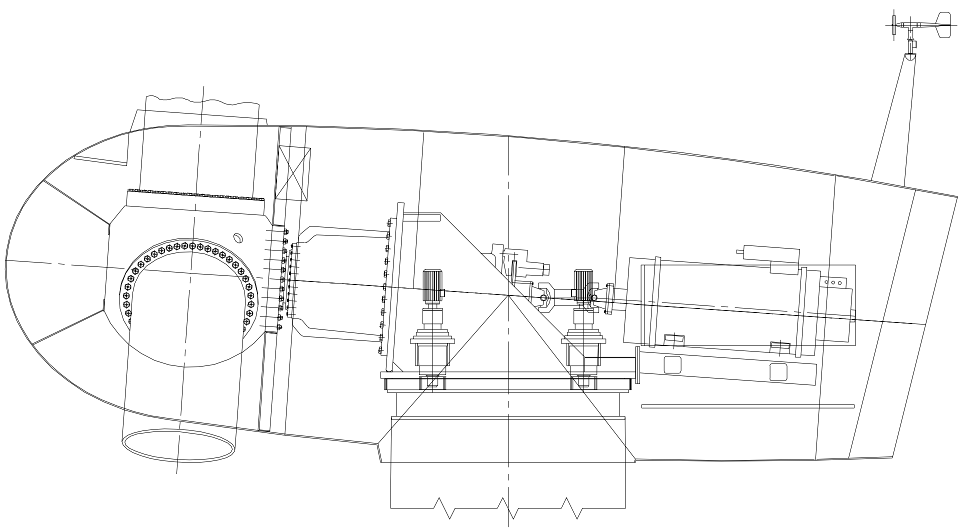
3. Technical description

The following section will describe activities and results for each work package:

3.1. Basic Engineering:

3.1.1. Objectives:
- detailed feasibility and parametric study
- conceptual layout
- development of safety system
- load calculations
- test of pitch system and controller
- site evaluations

3.1.2. Works performed and Results:
In the feasibility study rotor diameter and rated power output were varied to find the most economic combination of the turbine parameters. These works were done in close cooperation with the expert project partners regarding rotor blade and power electrics.
The conceptual layout of the turbine was defined (refer to drawing below).



In parallel the safety concept was developed, coming along with the assessment on its impact on the loads and safety of the turbine. The safety concept was laid out according to Germanischer Lloyd Regulations and approved by Germanischer Lloyd.
Based on the conceptual layout, the blade geometry and the preliminary weight distribution the preliminary load calculations were finished.

3.2. Rotor Blade:

3.2.1. Objectives:

Calculation and design of the rotor blade including evaluation of different blade materials.

3.2.2. Aerodynamic design:

The geometric design of the rotor blade is a critical factor in the resulting cost efficiency of the turbine, as the energy output mainly depending on the aerodynamics of the rotor. Further the aerodynamics and the dynamic behaviour of the rotor blades introduce the main loads on the wind turbine, an optimization of the rotor is thus an important step in the overall costs and efficiency of the complete wind turbine.

The design of the rotor blade for the Windtec turbine has been based on a parametric study of 4 different designs in geometry. The study included the following parameters:

- chord distribution
- thickness distribution
- blade length

The chord distributions and blade lengths analysed were:

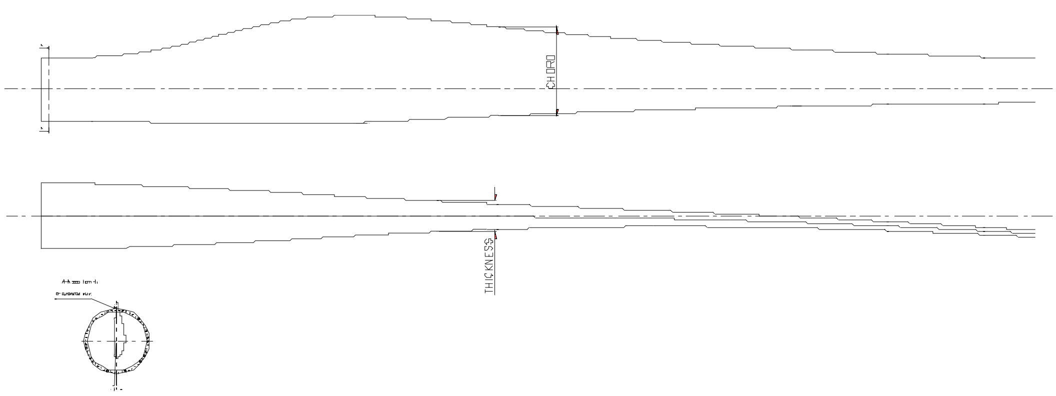
s1 designed for a limited maximal chord length, but optimized for the aerodynamic efficiency in the outer sections.

s2 optimized for the aerodynamic efficiency over the whole length

s3 reduced chord length in the outer sections, to obtain a smaller bending moment and a lighter structure.

s4 as s3, but increased blade length, for comparison of the cost efficiency.

A design close to s1 was chosen for the further study, where 2 different thickness distributions were analysed.

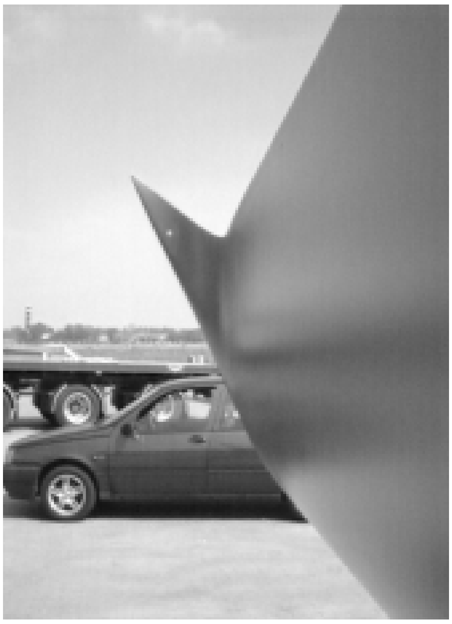


3.2.3 Profile selection

The aerodynamic profiles chosen for the rotor blade have been tested in a number of previous designs and show good performance. The profiles are Wortmann FX 77/79 laminar flow type profiles. The profiles have been selected from a group of well-known and tested profiles rather than new designs, as the scope of this project is to develop a cost-effective wind turbine, and minimizing the risk in the design. The characteristics of the Wortmann profiles are very low drag values, leading to very good aerodynamic performance of the rotor blades.

3.2.4. Noise and blade tip design

The noise emission from the rotor blades has several sources, where the profile selection, the trailing edge design and the blade tip design all contribute. The aerodynamic noise from a wind turbine increases in the fifth power with the blade tip speed and the experience and research at LM shows that the blade tip design has a very large share of the aerodynamic noise from the rotor blade. The basic design of the blade tip was to avoid noise caused by the tip vortex. The shape of the tip is an inverted winglet, following the theoretical vortex from the blade, developed on the basis of existing experience with this type of tip design. This design has also been tested on a large number of rotor blades produced by LM Aeroconstruct.



WWK 32.4 Blade tip design

3.2.5. Loads and dynamic behaviour

The loads in the rotor blades and the wind turbine were calculated with two different aeroelastic computer codes and a comparison of the results was subsequently carried out. The project thus caused a better understanding of the aeroelastic computer codes and the differences between them.

Furthermore the project emphasized the importance of a detailed description of the operational strategy of this type of wind turbine. Finally it turned out that correct information regarding the dynamics of the blades and the remaining part of the wind turbine was of major importance.

3.2.6. Lightning protection

The lightening protection system has been designed to withstand a lightning of 200.000 Amperes. The use of carbon fibers in the rotor blades contributes to the complexity of the system, as the carbon fibers are also a conductive material. This leads to a very special design of the lightening conductor cable inside the blade, which have to be designed to avoid flashing between the blade internal parts and the lightening conductor.

The Danish Institute of Technology has been consulted in the design work of the system.

The principle is based on a receptor with a sharp edge, that attracts the lightning, placed in the blade tip, and connected to the rotor blade root end and the hub.

3.2.7. Structural design

The WWK 32.4 rotor blade is designed as a self supporting shell, with the load carrying fibers integrated in the blade shells. The material used is carbon and glass fiber reinforced epoxy prepregs.

The use of carbon fibers are initiated by the demands for a high blade stiffness and a low blade mass. The high stiffness demand is a consequence of a compact wind turbine design, with a relative small clearance between the rotor blade tip and the wind turbine tower.

The different fibers, glass and carbon, are placed in the rotor blade in different orientations, in order to get the optimum use of the fiber properties

3.2.8. Materials selection

In order to place the fibers in the right position during manufacturing, the fibers can be either stitch or woven as dry cloth, or pre-impregnated with the resin (epoxy) before they are placed in the mould.

For the WWK 32.4 rotor blades the blade shells are made out of epoxy impregnated materials so called prepregs. The prepregs have to be stored in a max. temperature of -20°C. At this temperature the resin will cure very slow and the prepregs can be stored for a several months without curing. Before use the prepregs must be heated to room temperature where the open time before curing is app. 6 days.

The advantages with prepregs are:

- -Easy to handle in production.
- -Long working time (6 days)
- -The uniformity of resin content is high.
- -The uniformity in the lay up is high.

The disadvantages are:

- -relatively high material cost.
- -the prepregs have to be post-cured at 70°C, under vacuum.

Carbon fiber:

To achieve the right strength and stiffness in the WWK 32.4 rotor blade the load carrying fibers are carbon fiber. The characteristics of carbon fiber are:

- Very low specific weight: carbon = 1,900 kg/m^3
  E-glass = 2,540 kg/m^3
- Very high relative stiffness (E-modulus/density)

It is very important that the carbon fibers are positioned exactly parallel to the forces in the blade and no wrinkles or folds are seen, as this will reduce the stiffness and strength of the carbon fibers considerably.

Glass fiber:
Besides carbon fiber the blade contains different kind of glass fabrics, i.e. layers of glass positioned in different orientations.
The main surface of the blade is a sandwich structure of bi-directional glass fibers oriented in 45 degrees to the blade length, and balsa wood sandwich core.
The glass fabrics and sandwich structure gives the blade geometric stability, i.e. the aerodynamic profile is correct, and torsional stiffness.
Balsa wood is very suitable for sandwich constructions, because of the relative high stiffness compared to the low weight. Further the balsa wood is a natural material, containing no toxic additives.

3.2.9. Blade to hub connection.
The rotor blade is bolted to the pitch bearing, by internal bushings, embedded in the glass fiber/epoxy material. This design has been thoroughly tested in full scale fatigue experiments and used on a very large number of rotor blades. It incorporates an even load distribution in the rotor blade, and the bushing design allows for long mounting bolts thus increasing the dynamic strength of the bolt connection.

3.2.10. Investigation regarding an optional blade design:
Garrad Hassan have developed a wind turbine planform optimisation code which, given the wind turbine operational parameters, determines the twist and chord distribution which maximises energy yield. This code has been used to produce an aerodynamic design of the WT 1566 rotor blade.

The operational parameters used in the design of the rotor are summarised in Table 1 and the drive train effciency used is presented in Table 2.
The resulting electrical power curve is presented in Table 3.
The chord and twist distribution of the optimum rotor are presented in Table 4.

Rotor diameter	66 m
Rotational speed range	10 - 20 rpm
Aerofoil sections	NACA 63-421 - 63-212
Thickness distribution	12 - 21%
Tip speed ratio for variable speed operation	7.0
Rated electrical power	1500 kW
Cut -in wind speed	3.5 m/s
Cut-out wind speed	27.0 m/s
Annual mean wind speed at hub height	8.5 m/s

Table 1

Electrical Power [kW]	Drive Train Efficiency [%]
300	82.9
600	87.1
900	88.5
1200	89.2
1500	89.6

Table 2

Wind Speed [m/s]	Mechanical Power [MW]	Electrical Power [MW]
3.50	0.041	0.009
4.00	0.064	0.030
4.50	0.093	0.056
5.00	0.128	0.089
5.50	0.171	0.128
6.00	0.222	0.174
6.50	0.282	0.229
7.00	0.352	0.294
7.50	0.433	0.368
8.00	0.526	0.453
8.50	0.631	0.549
9.00	0.749	0.657
9.50	0.881	0.778
10.00	1.027	0.912
10.50	1.187	1.058
11.00	1.360	1.217
11.50	1.547	1.388
12.00	1.748	1.500

Table 3

radius	chord	twist

[m]	[m]	[deg]
3.00	5.49	32.85
6.00	5.25	20.28
9.00	4.51	13.78
12.00	3.90	9.77
15.00	3.44	7.34
18.00	3.07	5.61
21.00	2.80	4.41
24.00	2.53	3.33
27.00	2.29	2.42
30.00	1.93	1.70
32.00	1.60	1.00
33.00	1.50	0.90

Table 4

3.2.11 Concluding remarks:

It was understood by Garrad Hassan that LM Aero Construct will undertake the design of the WT 1566 rotor blade on the basis of Wortmann aerofoils. GH have therefore developed an alternative blade geometry design using NACA 63-xxx aerofoils. The two blade designs were compared in terms of performance, energy yield and steady loading.

Since the blade geometry design carried out by GH took no account of constraints associated with structural design, manufacturing, transportation or other requirements, it was decided to choose the LM-design, due to its comparable performance.

3.3. Double-Fed Induction Generator (DFIG):

3.3.1. Objectives:
Computer simulation and evaluation of efficiency, reliability and costs of the DFIG:
Tests on a small test stand during the design phase.

3.3.2. Overview of the generator system

The Windtec 1566 wind turbine has a double-fed induction generator (DFIG). The DFIG stator is directly connected to the three-phase system. The rotor is controlled by an IGBT converter with a voltage link (see Fig. 1).

The DFIG has control response similar to a synchronous motor. Two independent variables can be set on the rotor-side converter: torque and excitation. The excitation determines the reactive power produced at the stator.

In normal operation cosφ is kept constant. The torque is regulated depending on the speed. See Fig. 2 for the speed-torque curve. The generator operates with constant torque from 20,5 rpm upwards. This produces a constant mechanical load on the entire system. Gusts of wind are not therefore passed onto the grid. Motor acceleration above a defined limit is prevented by the rotor blade adjustment.

Double-fed induction generator (DFIG)

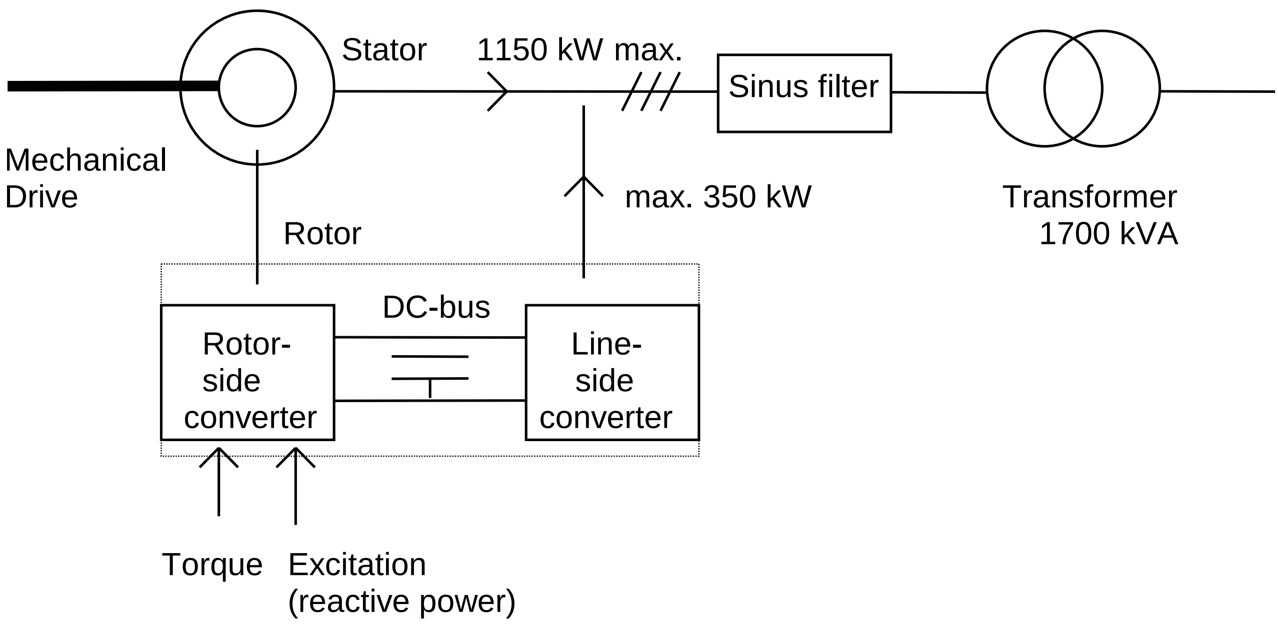


Fig. 1 power circuit overview

Speed-torque curve

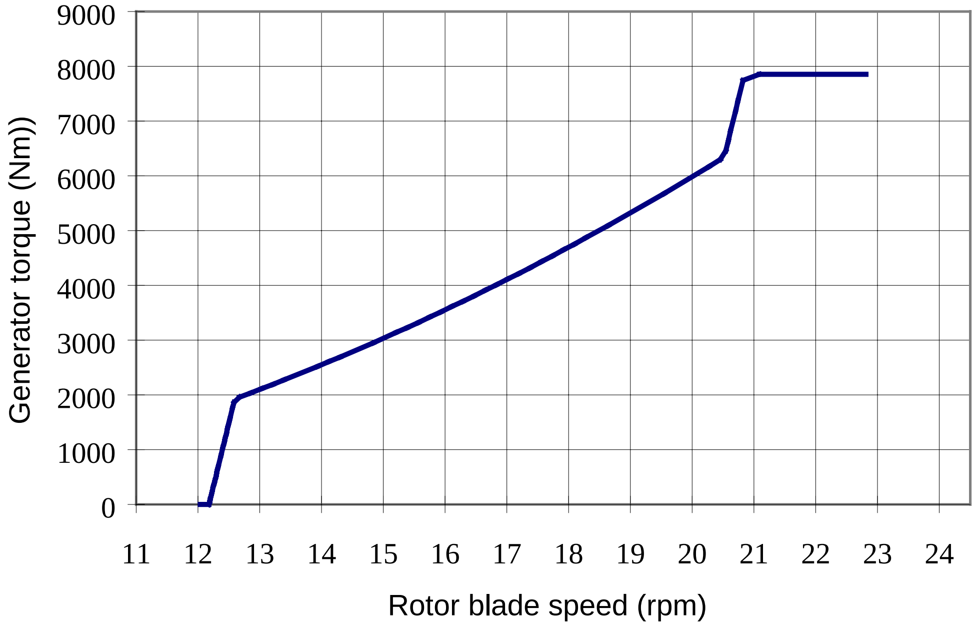


Fig. 2: Speed-Torque Curve

At maximum power, 1150 kW of the active power comes from the stator and 350 kW from the rotor. For this reason the DFIG produces fewer harmonics compared to a variable speed machine with a synchronous or asynchronous motor where the power is all fed through the converter.

Power factor λ (cosφ)
Basically the wind turbine has infinitely variable reactive power (VAr) control, i.e. at any power factor cosφ can be 1.
If required, the VAr can be increased capacitively to cosφ=0.95. It can also be reduced reactively to cosφ=0.90. The infinitely variable VAr control enables to regulate the voltage in the power system, if necessary.

Flicker
The Windtec 1566 wind turbine is regulated so that no abrupt load fluctuations can occur within a second. As a result the flicker that occurs is negligible according to the VEÖ report (Recommendation for evaluating system perturbation), 1st edition, 1995, VEÖ. Quotation page 4.4: “ramp-shaped voltage fluctuation curves with a rise or fall time of >1 s do not count“).

Harmonics
The IGBT converter has a constant operating frequency of 2000 Hz. As a result the 40th harmonic occurs in the spectrum. Because of the high operating frequency, little filtering is required and the harmonic percentage is minimal (THD = 1%).

Switching operations
A switching operation only takes place when the DC bus is charged. The DC bus capacitors are charged through a resistor. The current which occurs is 3% max. of the nominal current.

Power system connection
Synchronisation of the DFIG with the power system is surge-free. After synchronisation, the torque and therefore the power is slowly increased.

Short-circuit power
Transformer short-circuit power: 1700 kVA/uk 10% = 17 MVA
Power switch short-circuit power: 2000 A * 2 * √3 x 690 = 4,8 MVA

Electrical properties

System model:	Windtec 1500	Nominal capacity:	1500 kW
		Nominal voltage:	690 V
System manufacturer:	Windtec Anlagen-errichtungs und Consulting GmbH	Nominal current:	1670 A
		Hub height:	65 / 82 m
		Rotor diameter:	66, 70 m

Power factor λ	P/P at λ >0.9 always	¼ P_a 0.95 cap	½ P_a 0.95 cap	¾ P_a 0.95 cap	P_n 0.95 cap	P_{max} 0.95 cap

Power peak P/P_n	Instantaneous 1.1	1 min. 1.00	10 min. 1.00	Power curve max. 1.1

3.4. Control

3.4.1. Objectives:

- specification and tests of PLC hardware and i/o-performance
- development of task lists for control software
- creating interface between PLC and DFIG-system

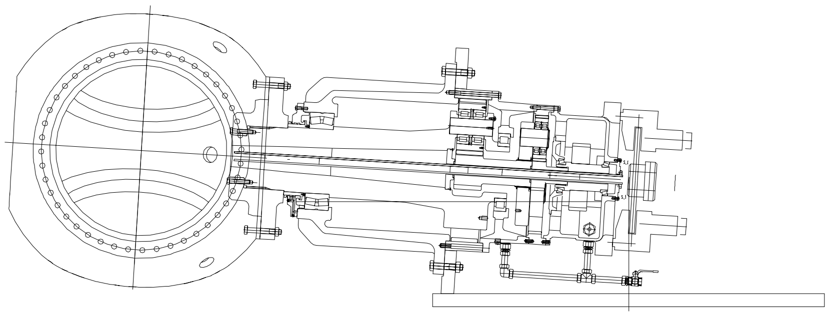
3.4.2. Works performed and Results:

Specification and tests of the free programmable controller hardware was completed. To reduce costs and complexity of the control system, tailor-made controller cards were developed. These controller cards substantially reduce the required number of i/o-modules.
Task list for software was completed.
Interface between PLC and DFIG was programmed and tested.

3.5 Drive Train

3.5.1. Objectives:
Design and calculations of an integrated drive train with the rotor shaft being an integral part of the pinion cage at the input section of the planetary gear box.
Evaluations of measures to be taken for noise reduction.

3.5.2. Works performed and Results:
A version of the gear box was designed (see figure below) and evaluated. Special emphasis was given to both, weight and cost reduction. The preliminary design loads were calculated based on a wind class II regime.
Regarding noise reduction the following measures are taken:
- Helical type high-speed stage of the gear box
- Cover which encloses the complete nacelle and hub, including a cooling air outlet with integrated noise damper
- Concrete tower to avoid structure borne noise propagation through the tower



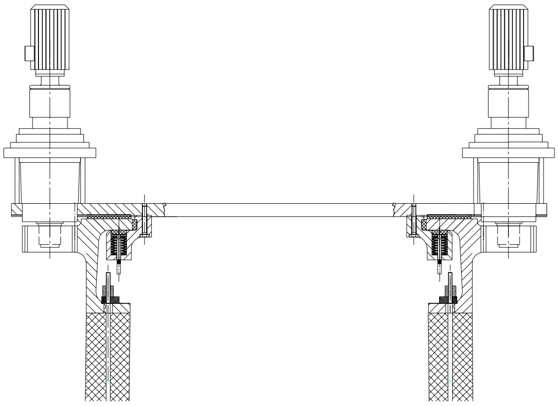
3.6 Mechanics

3.6.1. Objectives:
Layout, design and calculation of:
- Pitch system
- Yaw system
- Other mechanical parts

3.6.2. Works performed and Results:
Four options for the pitch system were evaluated. The best option incorporating three individual vector-controlled electrical drive units with one central DC supply including battery back-up was chosen for manufacturing. A test stand was designed and built. The tests were completed and the software for pitch control implemented.

The chassis sits on a sliding bearing made of sliding elements, simply to be readjusted. The yaw system is driven by four drive units based on the actual measurement of a yaw misalignment sensed by the wind-vane.

The following figure shows an overview drawing of the yaw system.



For technical details regarding mechanical components refer to section *3.17 Technical Description and Data*.

An on-board erectable crane is to be assembled on the ground and will be attached to the top of the tower by means of a small mobile crane then. Since a mobile crane is needed for manipulating the turbine components on the ground anyway, the effort to install the on-board erectable crane can be reduced in such way.

3.7 Electrics

3.7.1. Objectives:
General electrical layout and design.

3.7.2. Works performed and Results:
The general layout and the design were completed. For technical data refer to Section *3.17 Technical Description and Data*

3.8 Civil Engineering

3.8.1 Objectives:
Development of tower and foundation including:
- Concept development
- Structural calculations and design
- Costs optimization

3.8.2. General Layout:
The basic idea was to build the wind turbine for the 1.5 MW system on a reinforced concrete tower. The idea stemmed from the fact that a concrete tower has substantial advantages over the conventional alternative of a steel tower.

The three basic advantages are:

- Because a reinforced concrete tower has greater mass, it can be assumed that noise emissions during WEC operation will be lower
- Slip-form construction, where the concrete is continuously cast in upward moving formwork round the tower, means that no heavy-duty hoisting equipment is required during the building phase and the tower can therefore be erected in any terrain
- Optimum, value-for-money tower architecture thanks to the option of variable cross section design to suit the required load or natural frequency

The general layout and the design were completed. For technical data refer to Section *3.17 Technical Description and Data*

3.9 Grid Connection

3.9.1. Objectives:
Design of grid connection including transformer, switch gear and ground cable.

3.9.2. Works performed and Results:
A 20 kV cable was used for connection to the grid.
The transformer is located in a separate transformer station including medium voltage switch gear aside the wind turbine.

3.10 Design Certification

3.10.1. Objectives:
Preparation of :

- Safety and control system
- Design loads

for certification.

3.10.2. Works performed and Results:
Both, the description for control and safety concept and the definition of load cases were completed. The assumptions for the dynamic load calculations were checked by the Germanischer Lloyd. Since the loads are calculated by dynamic simulation, a specific procedure for the fatigue calculations was worked out with Germanischer Lloyd.
Safety and Control System as well as the Design Loads were certified by Germanischer Lloyd.

3.11 Software

3.11.1. Objectives:
Programming, testing and debugging of software code for turbine control.

3.11.2. Works performed and Results:
Software code was programmed. Testing and debugging of software code was performed.

3.12 Manufacturing of mould

3.12.1. Objectives:
Manufacturing of model and mould.

3.12.2. Works performed and Results:

The blades are made in 3 main parts.
- the blade shells
- the internal spars stiffeners
- the root section with embedded steel bushings

The blade shells are manufactured in two separate half, top and bottom, in two separate moulds. During manufacture of the shells, the pre-manufactured root section parts are laminated into the blade shells. After curing the two blade shells, the internal spars are bonded into one shell, as well as lightening conductors etc. is mounted. Finally the second shell is bonded on top of the first shell. This is done by closing the two shell moulds to one complete mould, thus securing the correct geometry of the blade when bonded.
After post-curing the adhesive at elevated temperature, the two shell moulds are separated, and the completed blade removed from the mould.

Mould of WWK 32.4

3.13 Manufacturing of components, assembly

3.13.1. Objectives:
Manufacturing of prototype wind turbine.

3.13.2. Works performed and Results:
A prototype machine with the technical data as under Section *"3.17 Technical Description and Data"* was manufactured.

3.14 Installation, Start-up

3.14.1. Objectives:
- Installation of prototype wind turbine
- Commissioning

3.14.2. Works performed and Results:
The wind turbine incl. grid connection was installed at the site in Zurndorf.
Commissioning tests were completed.

3.15 Measurements and Simulations

3.15.1. Objectives:
- Instrumentation of wind turbine with strain gauges
- Implementing wind data of anemometer tower
- simulation and measurements of different control strategies

3.15.2. Works performed and Results:
Instrumentation of strain gauges was completed.

3.15.3 Measurements
The following list gives an overview on the scope of the measurements campaign, started after the commissioning of the WEC:
- Start-up and optimization of parameters
- Power Curve
- Loads
  - Transient operating conditions (emergency stops, starts, normal stop, yaw misalignment)
  - Stationary operating conditions at different wind speeds for different components
  - Evaluation of Eigenfrequencies (drive train, blades and tower)

Further measurements will be done in accordance with the SMEP program.

3.15.4 Points of measurements

The following instrumentation was installed and commissioned:

- Rotor blades: edgewise and flapwise bending moments
- Hub
  - Pitch moments
  - Pitch angle
- Rotor shaft:
  - Bending moments
  - Torque
- High speed shaft: Torque
- Tower (concrete): Bending moments at top and bottom
- Rotor:
  - Rotational speed
  - Position
- Nacelle:
  - Yaw position
  - Yaw moment
  - Wind vane
  - Wind speed
- General:
  - Electrical power output
  - Wind speed and wind direction at anemometer tower

3.16 Verification

3.16.1. Objectives:

Improvement resp. optimisation of design

3.16.2. Works performed and Results:

Based on the experience gained during design, workstests, manufacturing, installation, commissioning and measurements, the machine was redesigned with the following main features:

- Rotor diameter of 70m
- New main frame implementing a noise de-coupling provision

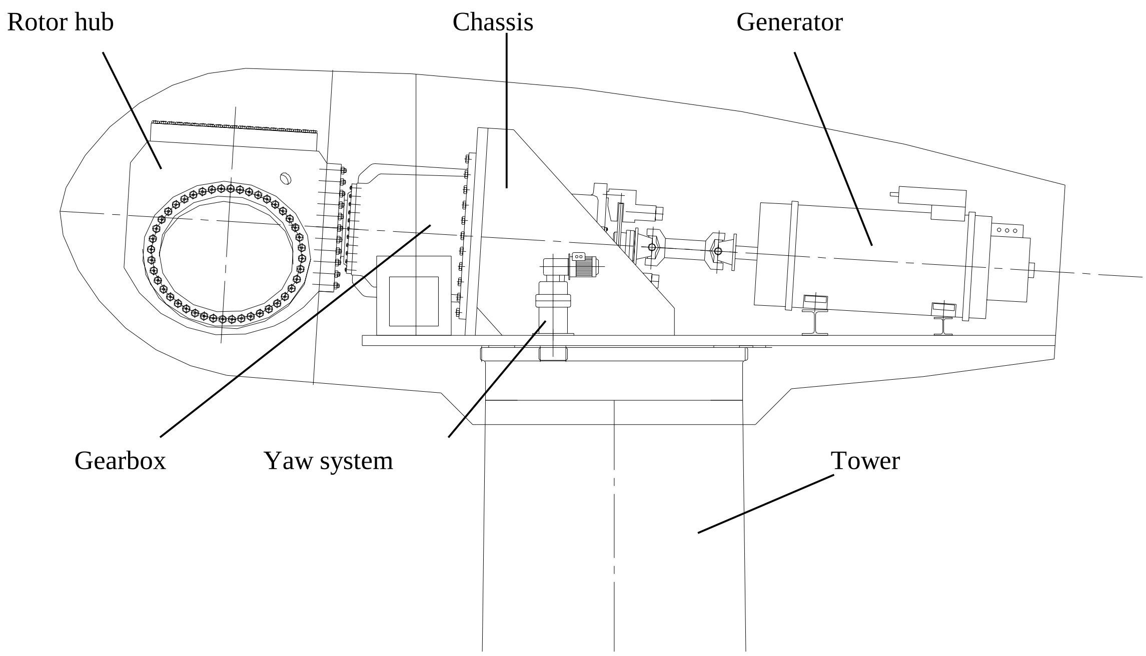
3.17 Technical Description and Data

GENERAL

The Windtec 1566 is a three-bladed, horizontal axis Wind Turbine, utilizing variable rotational speed and full span pitch control. This means, that the Windtec 1566 can be operated at optimum aerodynamical efficiency throughout the whole operational range. At a wind speed of 11.0 - 12.0 m/s the machine reaches its rated output of 1566 kW. The combination of both, electrical torque control and pitch control allows the wind turbine to be operated from 11.0 through 27.0 m/s with almost constant power output.

The main advantages of the Windtec 1566 Wind Turbine are:

- New variable speed power electrics with high efficiency, power factor control, and negligible harmonics distortion levels.
- Installation of the wind turbine without crane for any tower height, due to its modular design and utilization of an innovative type of concrete tower.
- Rotor blade with integrated lightning protection.
- Substantially improved economics compared to the state-of-the-art turbines.



Drawing 1: Mechanical scheme

Rotor blade

The rotor has a diameter of 67.0 m with a length of 32.4 m for the individual rotor blade. An extremely high aerodynamical efficiency is achieved by utilizing Wortmann type airfoils. The rotor blade is made of glass fiber/carbon fiber/epoxy resin, and designed in a multicell spar/shell structure.
The individual rotor blades have an integrated lightning protection, consisting of a metal tip, a conductor along the trailing edge, and a grounding cable connecting the blade with the nacelle.

Rotor hub

The rotor hub is a cast design, connected to the rotor shaft. The pitch bearings and the individual pitch drives are attached to the rotor hub, utilizing an independent drive for each rotor blade.

Pitch and braking system

The pitch system works as both, a primary braking system and a speed controller during nominal output performance of the wind turbine. It consists of 3 individual servo motors which set the blade pitch angle via a gearbox/pinion gear arrangement. With this arrangement each blade will work as an independent braking system, which can brake the machine by itself. The redundant power supply of the pitch system guarantees a threefold autonomous aerodynamic braking arrangement.
By means of a central electronic control unit the individual pitch drives are synchronized to guarantee an uniform pitch angle for all rotor blades during normal operation.
A disk brake at the high speed shaft of the gearbox works as an emergency brake as well as a parking brake for service purposes.

Gearbox

The loads are transferred into the chassis via a multistage gearbox as well as the rotor speed is increased to the required generator speed. The gearbox consists of two planetary stages plus a high speed helical stage. The rotor shaft is integrated into the gearbox casing, which makes the rotor hub directly connected to the input shaft of the gearbox.
An external oil aggregate supplies the necessary cooling capacity under high ambient temperature conditions.

Power electrics

A double-fed induction generator allows the Windtec 1566 to be operated in a variable speed mode. The double-fed induction generator consists of a wound rotor induction generator and an IGBT inverter, which excites the rotor of the generator with variable voltage as well as variable frequency.

By implementing a double-fed induction generator the following advantages over conventional applications for variable speed are achieved:

- high electrical efficiency
- reduced total harmonics distortion level to a negligible minimum

Power output and reactive power can be infinitely controlled throughout the whole operating range according either to a preset value or by external demand.
Generator as well as inverter are equipped with various temperature sensors and with space heaters to avoid condensation.

Chassis, cover

The chassis, which is a fabricated steel structure, is the core element in the nacelle assembly. Gearbox, generator, and yaw system are attached to the chassis.
To protect the machinery against environmental impacts, and to reduce noise emission, the nacelle is totally enclosed by a cover made of GRP with integrated steel rods as a part of the lightning protection system.

Yaw system

The chassis sits on a sliding bearing made of sliding elements, simply to be readjusted. The yaw system is driven by four drive units based on the actual measurement of a yaw misalignment sensed by the wind-vane.

Control

The control system consists of three microprocessor units with appended I/O units. All these units are communicating through a serial interface. The individual units are located in the hub, in the nacelle, and in the tower base, where they locally control the relevant functions. The microprocessor located in the tower base is equipped with a separate serial interface to communicate with an external monitoring system.

Tower

The Windtec 1566 has a tubular tower with internal access. The tower is offered with a standard length of 63 meters. According to the given shipping conditions resp. the chosen tower height the tower will be either made of steel or concrete.
In combination with the modular design of the nacelle and the concrete tower, the turbine can be installed without a mobile crane.

Access ladder including safety wire, rest platforms, and power cables are in any case located inside the tower. Inverter, main circuit breaker, and parts of the controller system including the interface for remote monitoring are located in the tower base.

Safety system

The Windtec 1566 is equipped with both, electrical and mechanical safety devices which will stop the wind turbine during normal operation as well as in case of any emergency situation.

The safety devices are in accordance with the Germanischer Lloyd Regulations.

Lightning Protection

The rotor blades are equipped with a lightning protection system as above.
The cover of the nacelle has integrated steel rods and a lightning rod rising above the top of the nacelle. Altogether, the integrated steel rods, the lightning rods as well as all components attached to the chassis are directly connected with the chassis by means of a grounding cable.
The chassis and the tower are connected via a cable loop. In the tower base all grounding cables are connected with the grounding system incorporated in the foundation and the surrounding soil.

TECHNICAL DATA

General data

Rated power, kW	1500
Rotor diameter, m	67.0
Swept area, m²	3526
Up to avg. wind speed, m/s	8.5
> Cut-in wind speed	3.5
> rated wind speed	12.0
> cut-out wind speed	27.0
> survival wind speed	60.0
Regulations for certification	Germanischer Lloyd
Wind class	II
service life, years	20
Standard hub height, m	65; 89

Rotor

Number of rotor blades	3
Diameter, m	67.0
Rotational speed, rpm	12 - 23.5
Rated rotational speed, rpm	22.0
Tip speed at 8m/s wind speed, m/s	56
Rotational direction	clockwise
Position relative to tower	upwind
Type of hub	rigid
Material of hub	cast
Method of speed control	full span pitch control
cone angle, deg	0
tilt angle, deg	4.0

Rotor blade

Length, m	32.4
Material	Epoxy/glass fibre/carbon fibre
Type of airfoil	Wortmann FX xx
Lightning protection	integrated

Pitch Drives

Type	gearbox / servo motor
Max. pitch rate, deg./sec	16
Type of pitch bearings	4-point contact bearing

Drive train

Input torque, kNm	776
Type of gearbox	planetary / helically
Transmission rate	1:87,7
Type coupling	cardan shaft

Braking system

Primary braking system	full span blade feathering
Service/emergency brake	disk brake

Yaw system

Type of bearing	sliding bearing
Type of drive	gearbox/motor
Number of drive units	4

Control system

Type	PLC
Function	control, safety features

Power Electrics

Type of generator	double-fed induction generator
Type of inverter	IGBT, 4-quadrant
Rated power output, kVA	1670
Rated voltage, V	690
Power factor (cosφ)	standard 1.0; controllable
Harmonics distortion	imperceptible
Method of torque control	flux vector control

Tower

Type	tubular, with internal access
Material	Concrete or steel
Height, m	63; 87
Corrosion protection	impregnated and/or painted

Power Curve

wind speed at hub height [m/s]	electrical power output [kW]
	1566
3.5	5.0
4.0	27.7
5.0	88.0
6.0	173.4
7.0	293.7
8.0	454.6
9.0	661.7
10.0	920.9
11.0	1230.0
12.0 - 27.0	1500

Basis: air density ... 1.225 kg/m³

Total energy yield

Average wind speed hub height [m/s]	**Total energy yield** [MWh]
	1566
5.0	
5.5	
6.0	2.903
6.5	3.496
7.0	4.089
7.5	4.660
8.0	5.208
8.5	5.721

Basis: Weilbull parameter 2.0; air dendity 1.225 kg/m³; availability .. 100%

1. Results and conclusions

The main result of the research works are:

- **1,5 MW wind turbine design as described in detail under item 3.17, utilizing:**
  - A light weight integrated drive train
  - A high efficiency and low cost variable speed power electrics system
  - Erection of the turbine, utilizing only a small auxiliary mobile crane.

  These results belong to WINDTEC

- **New rotor blade design and manufacture, utilizing carbon fiber:**
  These results belong to LM Aero Construct

- **1,5 MW Prototype machine:**
  The prototype belongs to Verbund.

2. Exploitation plans

3. Photograph

WINDTEC 1566, Zurndorf