APPENDIX B WIND TURBINE SPECIFICATIONS REPORT

Technical Description of the 1.6-100 Wind Turbine and Major Components

The wind turbine is a three bladed, upwind, horizontal-axis wind turbine with a rotor diameter of 100 m. The turbine rotor and nacelle are mounted on top of a tubular tower giving a rotor hub height of 80m. The machine employs active yaw control (designed to steer the machine with respect to the wind direction), active blade pitch control (designed to regulate turbine rotor speed), and a generator/power electronic converter system.

The wind turbine features a distributed drive train design wherein the major drive train components including main shaft bearings, gearbox, generator, yaw drives, and control panel are attached to a bedplate (see Figure 1).

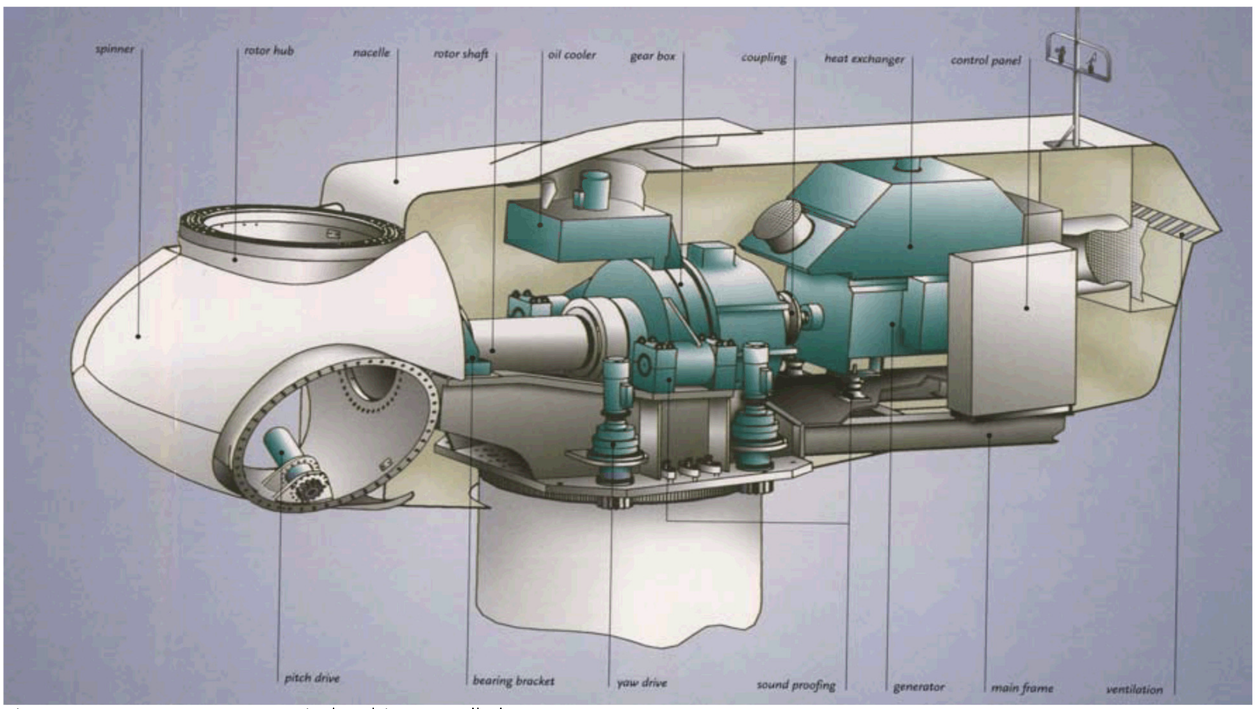

Figure 1: GE Energy 1.6-100 wind turbine nacelle layout

Rotor

The rotor diameter is 100 m, resulting in a swept area of 7,854 m, and is designed to operate between 9.75 and 16.18 revolutions per minute (rpm). Rotor speed is regulated by a combination of blade pitch angle adjustment and generator/converter torque control. The rotor spins in a clock-wise direction under normal operating conditions when viewed from an upwind location.

Full blade pitch angle range is approximately 90°, with the 0°-position being with the airfoil chord line flat to the prevailing wind. The blades being pitched to a full feather pitch angle of approximately 90° accomplishes aerodynamic braking of the rotor; whereby the blades “spill” the wind thus limiting rotor speed.

Blades

There are three rotor blades used on each wind turbine. The airfoils transition along the blade span with the thicker airfoils being located in-board towards the blade root (hub) and gradually tapering to thinner cross sections out towards the blade tip.

Blade Pitch Control System

The rotor utilizes three (one for each blade) independent electric pitch motors and controllers to provide adjustment of the blade pitch angle during operation. Blade pitch angle is adjusted by an electric drive that is mounted inside the rotor hub and is coupled to a ring gear mounted to the inner race of the blade pitch bearing (see Figure 1).

GE's active-pitch controller enables the wind turbine rotor to regulate speed, when above rated wind speed, by allowing the blade to "spill" excess aerodynamic lift. Energy from wind gusts below rated wind speed is captured by allowing the rotor to speed up, transforming this gust energy into kinetic which may then be extracted from the rotor.

Three independent back-up units are provided to power each individual blade pitch system to feather the blades and shut down the machine in the event of a grid line outage or other fault. By having all three blades outfitted with independent pitch systems, redundancy of individual blade aerodynamic braking capability is provided.

Hub

The hub is used to connect the three rotor blades to the turbine main shaft. The hub also houses the three electric blade pitch systems and is mounted directly to the main shaft. Access to the inside of the hub is provided through a hatch.

Gearbox

The gearbox in the wind turbine is designed to transmit power between the low-rpm turbine rotor and high-rpm electric generator. The gearbox is a multi-stage planetary/helical gear design. The gearbox is mounted to the machine bedplate. The gearing is designed to transfer torsional power from the wind turbine rotor to the electric generator. A parking brake is mounted on the high-speed shaft of the gearbox.

Bearings

The blade pitch bearing is designed to allow the blade to pitch about a span-wise pitch axis. The inner race of the blade pitch bearing is outfitted with a blade drive gear that enables the blade to be driven in pitch by an electric gear-driven motor/controller.

The main shaft bearing is a roller bearing mounted in a pillow-block housing arrangement. The bearings used inside the gearbox are of the cylindrical, spherical and tapered roller type. These bearings are designed to provide bearing and alignment of the internal gearing shafts and accommodate radial and axial loads.

Brake System

The electrically actuated individual blade pitch systems act as the main braking system for the wind turbine. Braking under normal operating conditions is accomplished by feathering the blades out of the wind. Any single feathered rotor blade is designed to slow the rotor, and each rotor blade has its own back-up to provide power to the electric drive in the event of a grid line loss.

The turbine is also equipped with a mechanical brake located at the output (high-speed) shaft of the gearbox. This brake is only applied as an auxiliary brake to the main aerodynamic brake and to prevent rotation of the machinery as required by certain service activities.

Generator

The generator is a doubly-fed induction type. The generator meets protection class requirements of the International Standard IP 54 (totally enclosed). The generator is mounted to the bedplate and the mounting is designed so as to reduce vibration and noise transfer to the bedplate.

Flexible Coupling

Designed to protect the drive train from excessive torque loads, a flexible coupling is provided between the generator and gearbox output shaft this is equipped with a torque-limiting device sized to keep the maximum allowable torque below the maximum design limit of the drive train.

Yaw System

A roller bearing attached between the nacelle and tower facilitates yaw motion. Planetary yaw drives (with brakes that engage when the drive is disabled) mesh with the outside gear of the yaw bearing and steer the machine to track the wind in yaw. The automatic yaw brakes engage in order to prevent the yaw drives from seeing peak loads from any turbulent wind.

The controller activates the yaw drives to align the nacelle to the average wind direction based on the wind vane sensor mounted on top of the nacelle.

A cable twist sensor provides a record of nacelle yaw position and cable twisting. After the sensor detects excessive rotation in one direction, the controller automatically brings the rotor to a complete stop, untwists the cable by counter yawing of the nacelle, and restarts the wind turbine.

Tower

The wind turbine is mounted on top of a tubular tower. The tubular tower is manufactured in sections from steel plate. Access to the turbine is through a lockable steel door at the base of the tower. Service platforms are provided. Access to the nacelle is provided by a ladder and a fall arresting safety system is included. Interior lights are installed at critical points from the base of the tower to the tower top.

Nacelle

The nacelle houses the main components of the wind turbine generator. Access from the tower into the nacelle is through the bottom of the nacelle. The nacelle is ventilated. It is illuminated with electric light. A hatch at the front end of the nacelle provides access to the blades and hub. The rotor can be secured in place with a rotor lock.

Anemometer, Wind Vane and Lightning Rod

An anemometer, wind vane and lightning rod are mounted on top of the nacelle housing. Access to these sensors is accomplished through a hatch in the nacelle roof.

Lightning Protection

The rotor blades are equipped with a lightning receptors mounted in the blade. The turbine is grounded and shielded to protect against lightning, however, lightning is an unpredictable force of nature, and it is possible that a lightning strike could damage various components notwithstanding the lightning protection deployed in the machine.

Wind Turbine Control System

The wind turbine machine can be controlled automatically or manually from either an interface located inside the nacelle or from a control box at the bottom of the tower. Control signals can also be sent from a remote computer via a Supervisory Control and Data Acquisition System (SCADA), with local lockout capability provided at the turbine controller.
Service switches at the tower top prevent service personnel at the bottom of the tower from operating certain systems of the turbine while service personnel are in the nacelle. To override any machine operation, Emergency-stop buttons located in the tower base and in the nacelle can be activated to stop the turbine in the event of an emergency.

Power Converter

The wind turbine uses a power converter system that consists of a converter on the rotor side, a DC intermediate circuit, and a power inverter on the grid side.

The converter system consists of a power module and the associated electrical equipment. Variable output frequency of the converter allows operation of the generator.

Technical Data for the 1.6-100

Rotor

Diameter	100 m
Number of blades	3
Swept area	7,854 m^2
Rotor speed range	9.75 to 16.18 rpm
Rotational direction	Clockwise looking downwind
Maximum tip speed	84.7 m/s
Orientation	Upwind
Speed regulation	Pitch control
Aerodynamic brakes	Full feathering

Pitch System

Principle	Independent blade pitch control
Actuation	Individual electric drive

Yaw System

Yaw rate	0.5 degree/s

1.6-100 Calculated Third Octave Band Apparent Sound Power Level LWA,k

Table 1 provides reference values per IEC 61400-11, based on the total apparent sound power level (A-weighted) defined in the general product acoustic specification for this turbine type. The uncertainties for octave sound power levels are generally higher than for total sound power levels. Guidance is given in IEC 61400-11, Annex D. The third octave-band spectra are for information only.

1.6-100 with 80 m HH - Normal Operation 3rd Octave Band Spectra									
Standard WS at 10m [m/s]		5	5.5	6	6.5	7	8	9	10-Cutout
Hub Height WS at 80 m [m/s]		7	7.7	8.4	9.1	9.7	11.1	12.5	14-Cutout
Frequency [Hz]	25	60.2	62.2	64.2	65.9	67.6	69.1	69.2	69
	32	63.2	65.1	67.1	68.8	70.5	72	72.1	71.9
	40	66.2	68.2	70.1	71.9	73.5	75.1	75.1	74.9
	50	69	71	73	74.7	76.4	77.9	78	77.8
	63	72	73.9	75.9	77.6	79.3	80.9	80.9	80.7
	80	75	77	78.9	80.7	82.4	83.9	83.9	83.7
	100	77.5	79.5	81.5	83.2	84.9	86.4	86.5	86.3
	125	80	82.2	84.2	86	87.9	89.8	90.1	90.2
	160	81.4	83.8	85.7	87.1	89.1	91.4	92.1	92.5
	200	82.2	84.7	86.1	86.7	88.7	91.3	92.2	92.9
	250	83.7	86.2	87.2	87.1	88.6	90.7	91.6	92.2
	315	84.7	87.3	88.3	87.9	88.7	90	90.6	91
	400	85	87.5	88.8	88.7	89.1	89.6	89.8	89.9
	500	85.2	87.9	89.6	90.1	90.6	90.7	90.5	90.3
	630	84.8	87.5	90	91.7	92.4	92.6	92.2	91.8
	800	83.9	86.6	89.7	92.4	93.7	94.3	93.9	93.5
	1000	82.5	85.4	89.1	92.6	94.5	95.6	95.3	95
	1250	81.4	84.1	88.1	92.5	94.9	96.7	96.5	96.3
	1600	80.7	82.5	86.1	90.7	93.5	96	95.9	95.8
	2000	80.9	82.3	84.9	88.3	91.4	94.5	94.7	94.7
	2500	80.5	81.9	83.8	86.1	88.9	91.9	92.3	92.3
	3150	78.8	80.2	81.8	83.7	85.9	88.4	88.7	89.1
	4000	75.6	76.9	78.4	80.2	82.1	83.8	84	83.9
	5000	71.4	72.5	73.9	75.5	77.2	78.7	78.7	78.4
	6300	65.2	65.9	67	68.6	70.3	71.7	71.8	71.2
	8000	55.3	55.5	56.2	57.9	59.7	61.5	62.9	60.8
	10000	42.9	42.3	42.7	44.4	46.5	48.6	49	48.1
	12500	26.9	25.2	25.1	27.3	29.7	33.6	32.1	32.2
	16000	3.7	0.4	-0.4	2.2	5.2	8.9	9	9.3
	20000	-21.9	-27.3	-29	-25.9	-22.3	-18.3	-17.4	-16.8
Total apparent sound power		94.8	97.3	99.5	101.5	103.3	104.9	105	105

Table 1: Calculated Apparent Third Octave Band Sound Power Level (A-weighted), 1.6-100 with 80 m hub height as function of Wind Speed v_{10m}

Tonal Audibility

At the reference measuring point R_o, a ground distance from the turbine base equal to hub height plus half the rotor diameter, the 1.6-100 turbine has an expected value for tonal audibility of $\Delta L_{a,k} < 2$ dB, irrespective of wind speed, hub height, and grid frequency.[2]

Uncertainty Levels

The apparent sound power levels given above are calculated mean levels. If a wind turbine noise performance test is carried out, it needs to be done in accordance with the regulations of the international standard IEC 61400-11, ed. 2.1: 2006. Uncertainty levels associated with measurements are described in IEC/TS 61400-14.

Per IEC/TS 61400-14, L_{WAd} is the maximum apparent sound power level resulting from ***n*** measurements performed according to IEC 61400-11 standard for 95 % confidence level: $L_{WAd} = \overline{L_{WA}}$ + K, where $\overline{L_{WA}}$ is the mean apparent sound power level from ***n*** IEC 61400-11 testing reports and **K = 1,645 · σT**.

The testing standard deviation values $\boldsymbol{\sigma_T}$, $\boldsymbol{\sigma_R}$ and $\boldsymbol{\sigma_P}$ for measured apparent sound power level are described by IEC/TS 61400-14 where $\boldsymbol{\sigma_T}$ is the total standard deviation, $\boldsymbol{\sigma_P}$ is the standard deviation for product variation and $\boldsymbol{\sigma_R}$ is the standard deviation for test reproducibility.

Assuming $\boldsymbol{\sigma_R}$ < 0.8 dB and $\boldsymbol{\sigma_P}$ < 0.8 dB typical values, leads to calculated **K < 2 dB** for 95 % confidence level.

IEC 61400-11 and IEC/TS 61400-14 Terminology

- $\boldsymbol{L_{WA,k}}$ is wind turbine apparent sound power level (referenced to 1^{-12} W) measured with A-weighting as function of reference wind speed v_{10m}. Derived from multiple measurement reports per IEC 61400-11, it is considered as a mean value.
- $\boldsymbol{\sigma_P}$ is the product variation i.e. the 1.56-100 unit-to-unit product variation; typically < 0.8 dB
- $\boldsymbol{\sigma_R}$ is the overall measurement testing reproducibility as defined per IEC 61400-11; typically < 0.8 dB with adequate measurement conditions and sufficient amount of data samples
- $\boldsymbol{\sigma_T}$ is the total standard deviation combining both $\boldsymbol{\sigma_P}$ and $\boldsymbol{\sigma_R}$
- **K = 1,645** · $\boldsymbol{\sigma_T}$ is defined by IEC/TS 61400-14 for 95 % confidence level
- $\boldsymbol{R_o}$ is the ground measuring distance from the wind turbine tower axis per IEC 61400-11
- $\boldsymbol{\Delta L_{a,k}}$ is the tonal audibility according to IEC 61400-11, described as potentially audible narrow band sound