Technical description

2015-1-ES01-KA202-015935

Co-funded by the Erasmus+ Programme of the European Union

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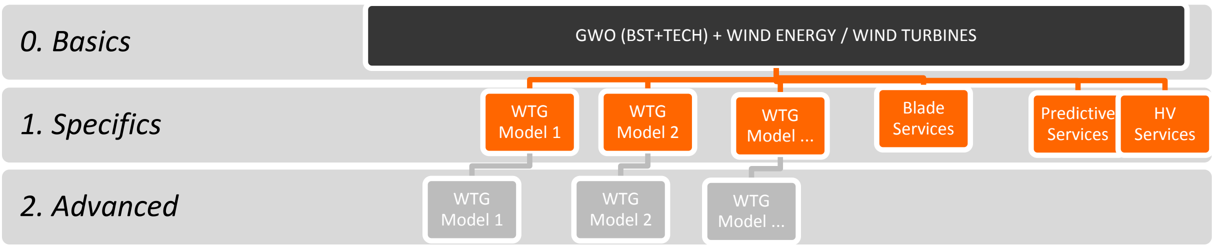
Contenido

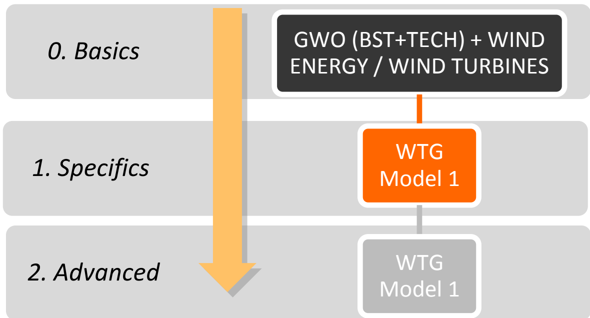
TRAINING PATHS

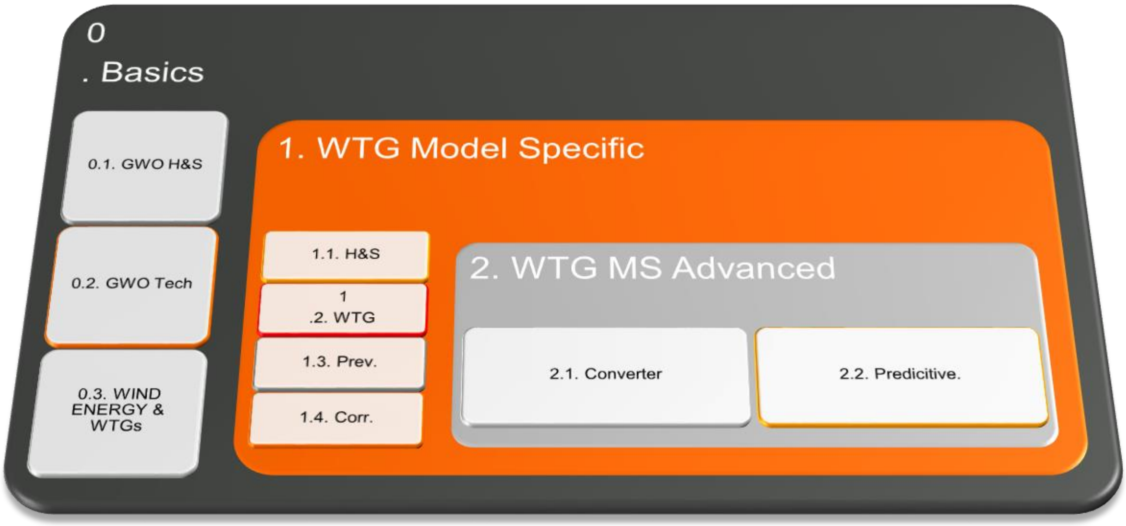


The WTG selected is the DFIG type, later presented for being the most common in the market.

CONTENTS INCLUDED IN PATH #1

PATH #1. WIND FARM O&M TECHNICIAN





1. WINDTURBINE MANUFACTURER SPECIFICS

1.2. WINDTURBINE

Designed to provide to OM technicians general knowledge about a specific wind turbine model, mechanical & electrical components as well as basics about control & Scada systems.

1.2.1. Lesson 1 - Introduction to the wind turbine model

The objective of this lesson is to introduce the wind turbine to the new wind technicians

During this lesson the trainee will learn to:

(1) The different type of wind turbines

(2) The technology basic key points.

(3) General description of systems and components

(4) Operational states

1.2.1.1. Technology basic key points

The generator is the central element of the wind turbine electric system and the component from which the rest of elements and supervision and control systems are dimensioned. There are mainly no restrictions for the type of generator (direct current or alternating current),but alternating current machines are exclusively chosen not only for its power/weight relation which is more favorable (in this case, it is an important factor considering that it conditions the tower mechanical resistance), but also for its ability to generate at higher voltage and, above all, they present lower maintenance costs and a higher availability than direct current generators due to the lack of collector. Only in the case of very low power generators feeding direct current distribution circuits, with energy storage in batteries is thinkable the use of direct current generators. This type of systems is not the object of this book, so from now on we will refer exclusively to alternating current generators.

There are two basic types: the ones which use asynchronous or induction machines and the ones which use synchronous machines. In both cases there are different variations which will be examined further on in detail. Depending on the type of turbine and the type of control, the generators can be directly connected to the grid (occasionally through a transformer), or through a frequency converter.

The main problem associated to the synchronous machines connected directly to the grid is that, being constant their frequency the spinning speed must as well be, so this entail important mechanical strains in the gearbox system and oscillations in the electric power generator. For this reason, the synchronous generator is never used in systems that are directly connected to the grid. Nevertheless, this type of generators is used in the case of systems connected to the grid through a frequency converter; the function of the frequency converter is to separate the frequency of the generator from the grid one, allowing the generator operation at variable speed. The frequency converter also allows the control over the reactive power injected to the grid, as it happens in any other conventional power plant, which is essential in systems of a certain power.

In the case of asynchronous generators, the situation is slightly different. The rotor speed can vary lightly although the frequency at the machine terminals is constant. This, on the one hand, offers certain flexibility to the ensemble and, on the other hand, reduces the strains over the shaft transforming in kinetic energy part of the brusque variations of the wind speed. For these reasons and their great robustness, the systems with an induction generator connected directly to the grid have been and are profusely used. There are as well diagrams in which the generator is connected to the grid through an electronic frequency converter. The asynchronous generators with a rotor winding with an electronic converter connected to the rotor have been widely developed in the industry, because they combine the advantages of generating at a fixed frequency with a wide margin of speed variation and a lower size of the electronic converter.

Below the principal elements of the Wind Turbines Generators are presented, stated with the

Fixed Speed Wind Turbine Generators

- **Synchronous generators**

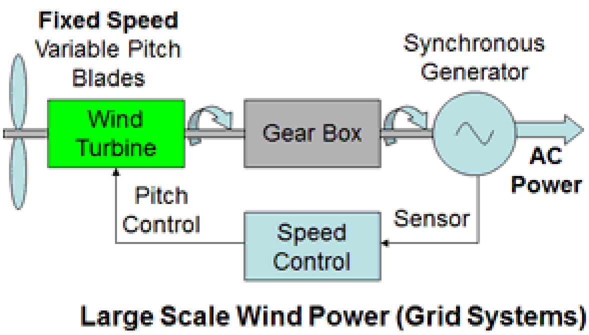


Figure 1. Fixed Speed WTG with synchronous generator

A typical fixed speed system employs a rotor with three variable pitch blades which are controlled automatically to maintain a fixed rotation speed for any wind speed. The rotor drives a synchronous generator through a gear box and the whole assembly is housed in a nacelle on top of a substantial tower with massive foundations requiring hundreds of cubic meters of reinforced concrete.

Fixed speed systems may however suffer excessive mechanical stresses. Because they are required to maintain a fixed speed regardless of the wind speed, there is no "give" in the mechanism to absorb gusty wind forces and this results in high torque, high stresses and excessive wear and tear on the gear box increasing maintenance costs and reducing service life. At the same time, the reaction time of these mechanical systems can be in the range of tens of milliseconds so that each time a burst of wind hits the turbine, a rapid fluctuation of electrical output power can be observed. Furthermore, variable speed wind turbines can capture 8-15% more of the wind's energy than constant speed machines. For these reasons, variable speed systems are preferred over fixed speed systems. See more about the properties of synchronous generators.

- **Squirrel cage induction generators**

One of the major advantages of the asynchronous machine is its capacity to provide temporarily with mechanical torque higher than the full charge without losing the synchronism. In the case of engines, the rules establish that the machine should provide a torque in the shaft of 160% over the full charge for at least 15 seconds. This ability is of great importance in wind generation systems, where the shaft torque due to a gust could suffer notable oscillations. When this happens, the machine increases its slipping in absolute value and accelerates lightly, which has a double effect: on the one hand, the internal torque increases, as well as the power injected to the grid; on the other hand, at increasing the spinning speed, part of the energy of the gust is stored in form of kinetic energy which is additional to the group turbine-multiplier-generator. The asynchronous machines of normal designs have an intrinsic overload ability, given for the quotient between its maximum torque and its nominal torque, it is between 2 and 2,2. But independently of this intrinsic overload ability, the real overload ability depends on the maximum admissible temperature in the windings, and this one depends on the cooling conditions and specially on the ambient temperature.

The generators don’t have only to provide with active power. The loads connected to the electric system and its proper elements like transformers or lines, also present certain reactive power consumption. Nevertheless, the power factor of the asynchronous generator connected directly to the grid is always inductive. And the induction machine in its classic version (that is, with the rotor short-circuited) has only energy supply from the stator, it is from there that it must absorb from the grid the reactive power needed to keep the rotating magnetic field in the spark gap. The existence of this rotating field is necessary condition for the electromotive forces to be induced in the rotor and therefore, for the electromagnetic conversion.

The use of connection static switches to the grid produces voltage harmonics that could cause great consumptions of intensity in the generator compensation condensers of reactive power (in this sense, it should be considered that the impedance that a condenser presents is reduced with the frequency increase). To prevent this phenomenon, the condensers connection is made when the generator connection process has finished, and the static switch is bridged. (**Figure 2**)

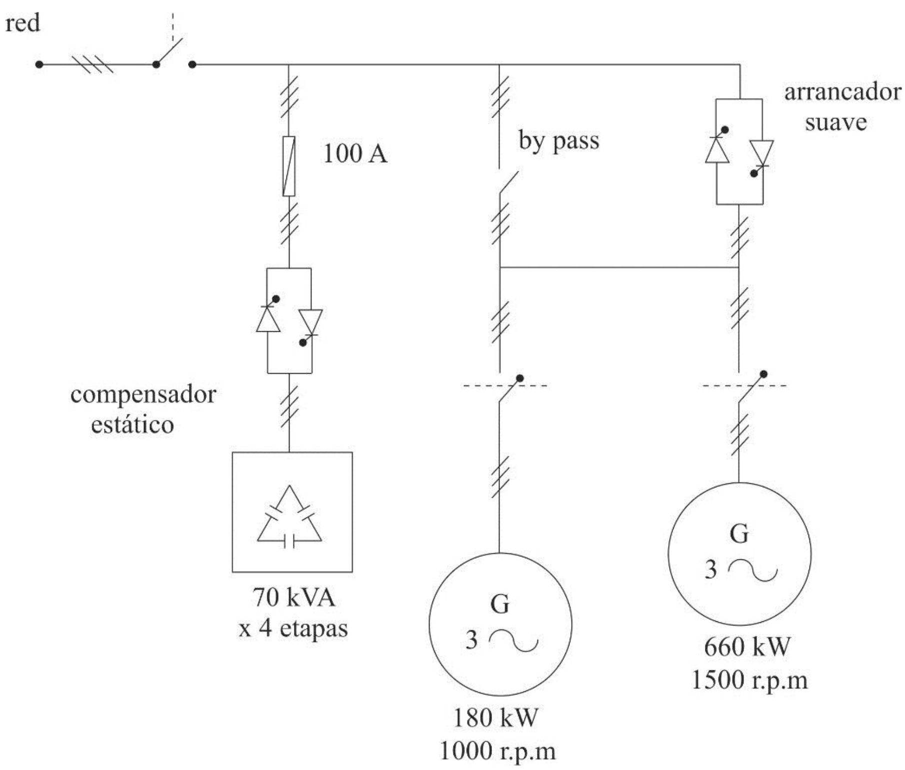


Figure 2. Connection diagram of a two asynchrone generator system with continuous voltage variation

Variable Speed Wind Turbine Generators

A variable speed generator is better able to cope with variable wind conditions because its rotor can speed up or slow down to absorb the forces when bursts of wind suddenly increase the torque on the system. The electronic control systems will keep the generator's output frequency constant during these fluctuating wind conditions. There are basically two type of variable speed WTGs.

- **Doubly Fed Induction Generator – DFIG**

DFIG technology is currently the preferred wind power generating technology. The basic grid connected asynchronous induction generator gets its excitation current from the grid through the stator windings and has limited control over its output voltage and frequency. The doubly fed induction generator permits a second excitation current input, through slip rings to a wound rotor permitting greater control over the generator output.

The DFIG system consists of a 3-phase wound rotor generator with its stator windings fed from the grid and its rotor windings fed via a back to back converter system in a bidirectional feedback loop taking power either from the grid to the generator or from the generator to the grid. See the following diagram.

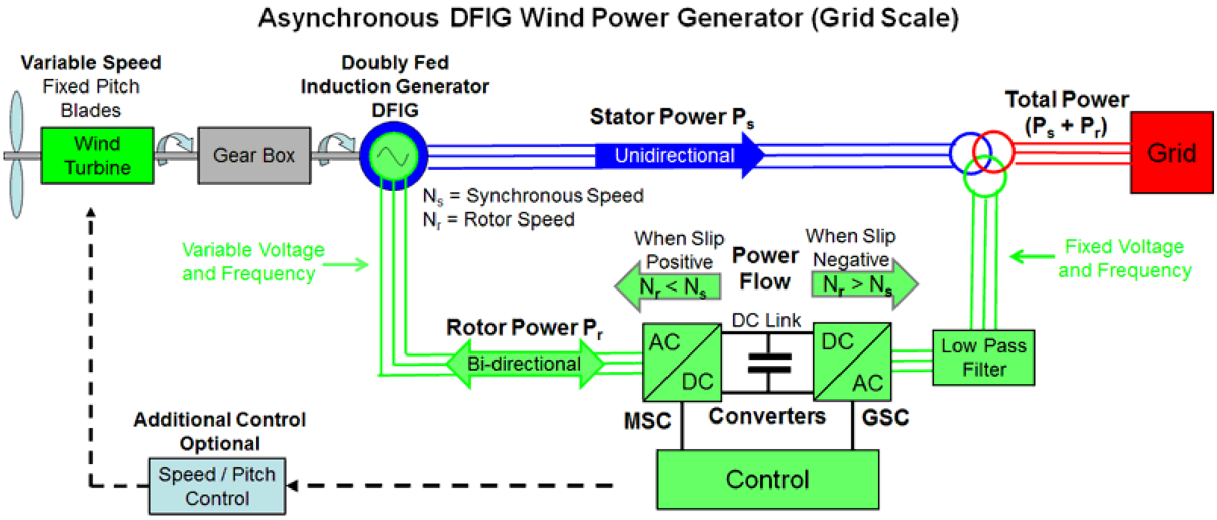


Figure 3. Wind turbine asynchronous DFIG Generator

- **Synchronous Generator with In-Line Frequency Control (Full Converter)**

Rather than controlling the turbine rotation speed to obtain a fixed frequency synchronized with the grid from a synchronous generator, the rotor and turbine can be run at a variable speed corresponding to the prevailing wind conditions. This will produce a varying frequency output from the generator synchronized with the drive shaft rotation speed. This output can then be rectified in the generator side of an AC-DC converter and then inverted back to AC in an inverter in grid side, both rectifier and inverter constitutes the converter which is synchronized with the grid frequency. See following diagram.

The grid side converter can also be used to provide reactive power (VArs) to the grid for power factor control and voltage regulation by varying the firing angle of the thyristor switching in the inverter and thus the phase of the output current with respect to the voltage. **See an explanation and more details of why reactive power is needed in the section about Power Quality and Voltage Support as used in the utility grid**.

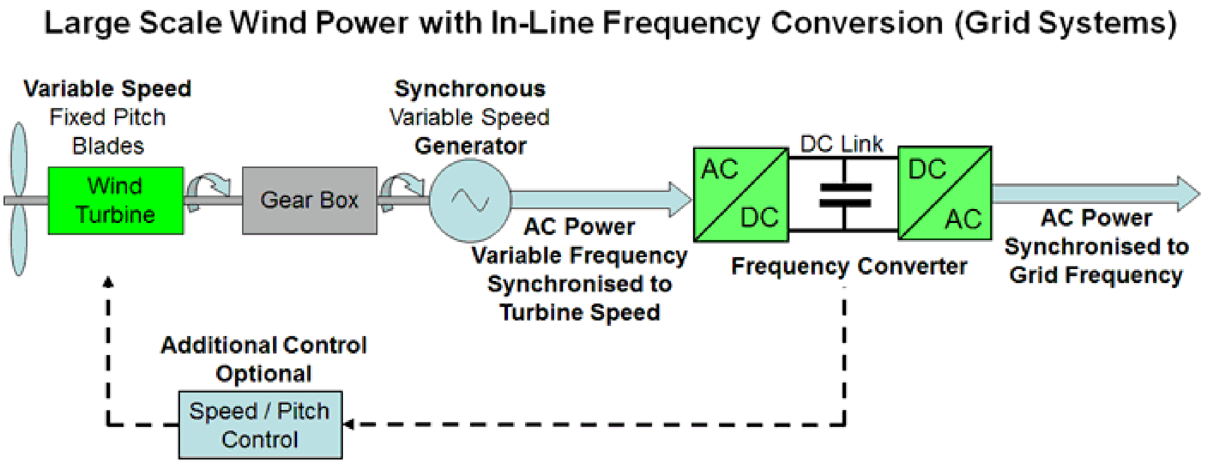


Figure 4. Wind turbine diagram with Synchronous Variable Speed Generator and Frequency converter

The range of wind speeds over which the system can be operated can be extended and mechanical safety controls can be incorporated by means of an optional speed control system based on pitch control of the rotor vanes as used in the fixed speed system described above.

One major drawback of this system is that the components and the electronic control circuits in the frequency converter must be dimensioned to carry the full generator power. The doubly fed induction generator DFIG overcomes this difficulty.

There are two types of full converter with line frequency control: wound and permanent magnet rotors, this one is becoming more popular due mainly to the reduction of weight and cost over the first solution. Its main problem is the scarcity of rare earths materials used in the production of permanent generators.

1.2.1.2. General description of systems and components

A wind turbine generator mainly consists of a tower which supports the nacelle and the rotor. The rotor is made of blades which are attached to the hub and transmits the kinetic energy from the wind to the electrical generator placed inside the nacelle.

On the top of the nacelle a meteorological station is placed to meter the wind conditions and transfer the information to the wind turbine control.

In the figure below the main components of a wind turbine generator are described and identified.

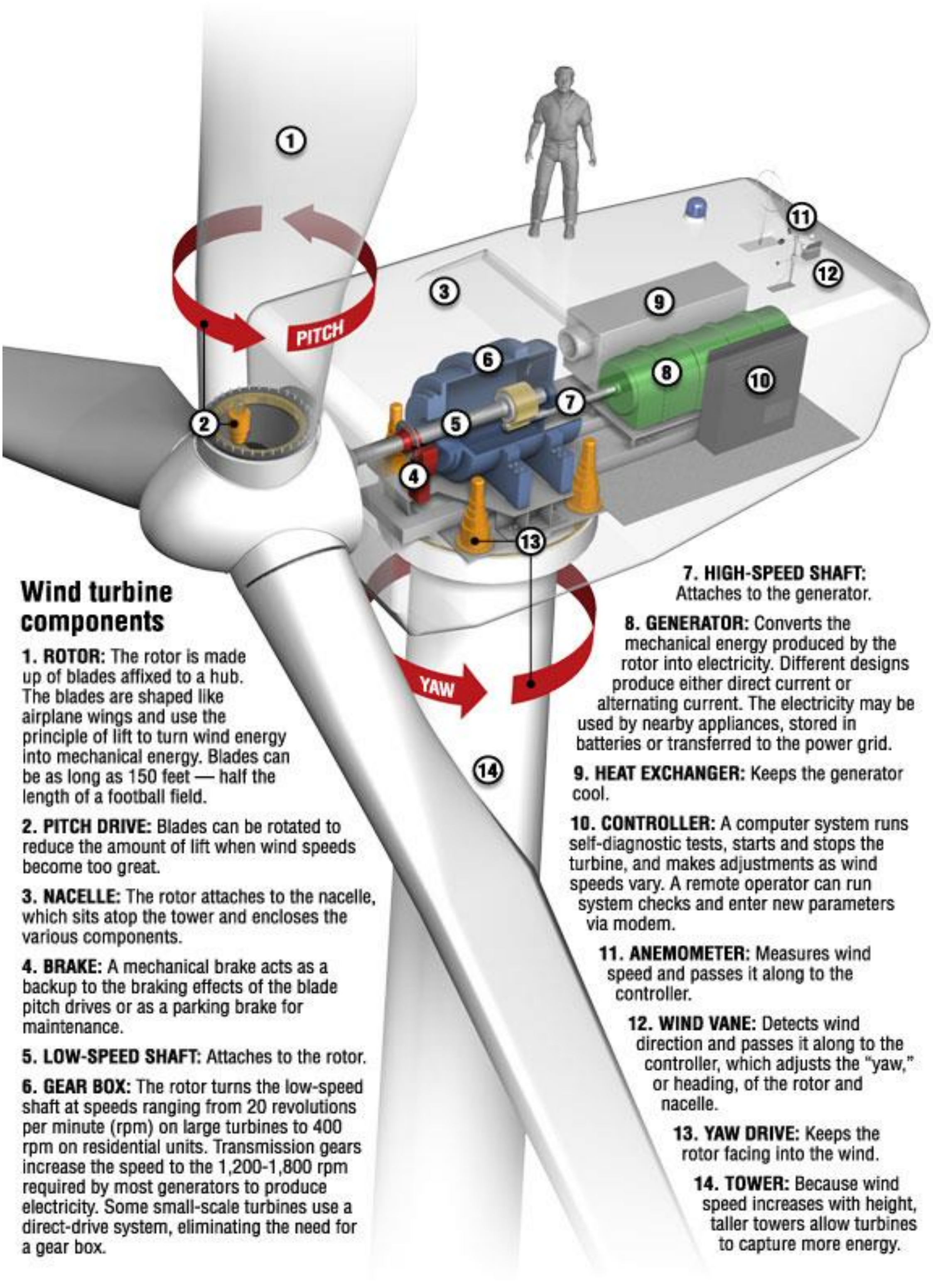

PITCH
YAW
Wind turbine components
1. ROTOR: The rotor is made up of blades affixed to a hub. The blades are shaped like airplane wings and use the principle of lift to turn wind energy into mechanical energy. Blades can be as long as 150 feet — half the length of a football field.
2. PITCH DRIVE: Blades can be rotated to reduce the amount of lift when wind speeds become too great.
3. NACELLE: The rotor attaches to the nacelle, which sits atop the tower and encloses the various components.
4. BRAKE: A mechanical brake acts as a backup to the braking effects of the blade pitch drives or as a parking brake for maintenance.
5. LOW-SPEED SHAFT: Attaches to the rotor.
6. GEAR BOX: The rotor turns the low-speed shaft at speeds ranging from 20 revolutions per minute (rpm) on large turbines to 400 rpm on residential units. Transmission gears increase the speed to the 1,200-1,800 rpm required by most generators to produce electricity. Some small-scale turbines use a direct-drive system, eliminating the need for a gear box.
7. HIGH-SPEED SHAFT: Attaches to the generator.
8. GENERATOR: Converts the mechanical energy produced by the rotor into electricity. Different designs produce either direct current or alternating current. The electricity may be used by nearby appliances, stored in batteries or transferred to the power grid.
9. HEAT EXCHANGER: Keeps the generator cool.
10. CONTROLLER: A computer system runs self-diagnostic tests, starts and stops the turbine, and makes adjustments as wind speeds vary. A remote operator can run system checks and enter new parameters via modem.
11. ANEMOMETER: Measures wind speed and passes it along to the controller.
12. WIND VANE: Detects wind direction and passes it along to the controller, which adjusts the "yaw," or heading, of the rotor and nacelle.
13. YAW DRIVE: Keeps the rotor facing into the wind.
14. TOWER: Because wind speed increases with height, taller towers allow turbines to capture more energy.

Figure 5. Wind turbine generator main components

Nacelle

The picture below is a nacelle viewed from the top where all the main components in charge of transformation of the kinetic energy from the wind into electrical energy are identified. The nacelle contains all the machinery of the wind turbine necessary to transmit the mechanical energy from the hub of the rotor to the generator. It also contains a braking system to slow or stop the rotor, a system to control the nacelle orientation on its yaw axis, since the nacelle is connected to the tower via bearings to rotate while tracking the wind direction, and a control unit automating the operation procedures according to the wind conditions or maintenance needs.

On the nacelle top there are meteorological instruments installed which are essential to monitor the speed of the wind (anemometer) and its direction (wind vane).

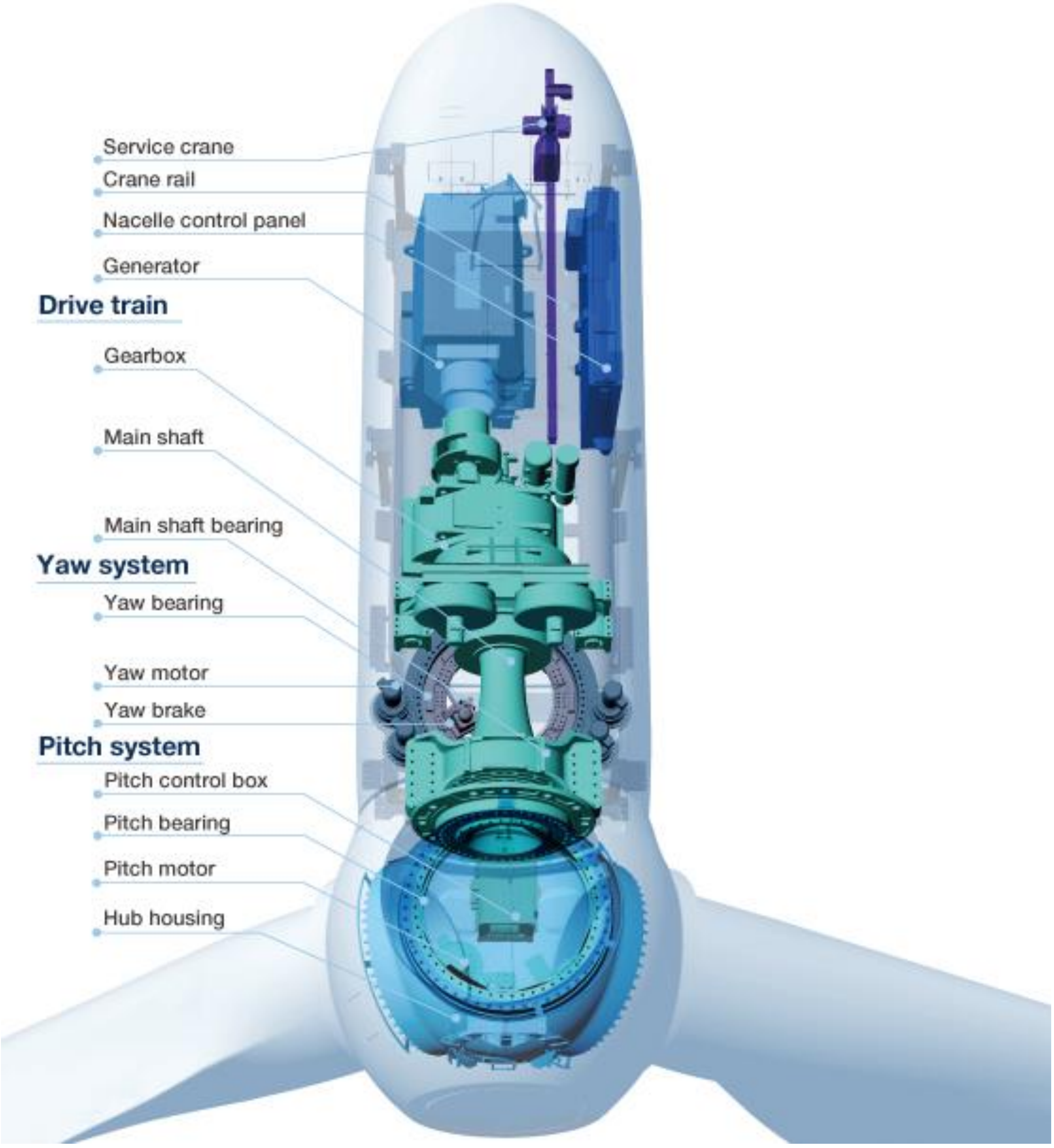


Figure 6. Wind turbine nacelle

3. Control system and sensors

The control system acts on:

- CONVERTER, back to back
- YAW system
- PITCH system
- BRAKE system

Following this diagram:

The following diagram shows the control system of a wind turbine generator and the information circulation between control stages.

The input interface shows all the information acquired in the sensors of the wind turbine generator, which includes environmental data, hydraulic and position data, and the feedback resulting from the wind turbine generator control communicating it to the PLC. The PLC is a programmable logic controller which converts signal from the sensors and transmits the information to the output interface. Its function is to monitor the instruments outputs to control and optimize the wind turbine operation. The information which exits the PLC runs through the control system to the Wind turbine to adjust its operation parameters depending on the current information about the wind characteristics and the wind turbine information.

The PLC also transmits the information through a Communicating Interface to the SCADA which stores all the information that is generated and allows its management and intervention.

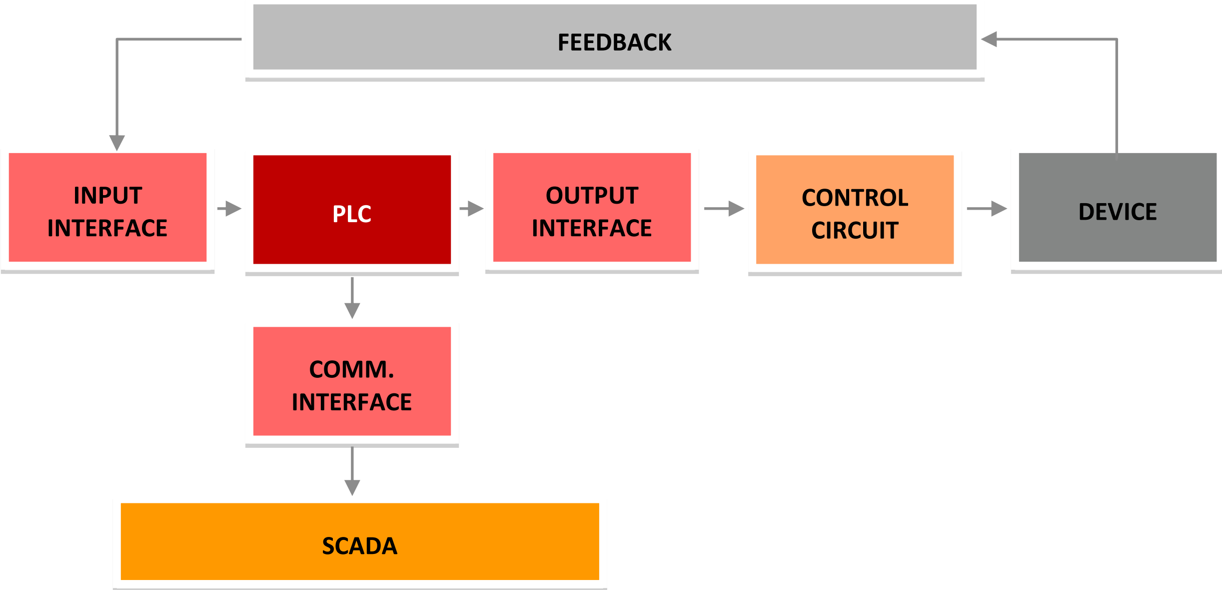


Figure 7. Control system diagram

Sensors

There are different types of sensors in a wind turbine generator that provide with environmental, hydraulic and position data. The environmental sensor obtains values of ambient temperature, wind speed and direction. Among the main hydraulic sensors provide information about the pressure in the hydraulic circuits as well as temperature, oil level and leaks. The position sensors are crucial for wind turbine control to correct the position of the wind turbine rotor.

The information of these sensors is transmitted to the PLC to better adjust the operation parameters of the wind turbine generator.

ENVIRONMENTAL	HYDRAULICS	POSITION
Anemometer	Pressure switch	Rotor inductive
Vane	Pressure transducer	Yaw inductive
Temperature switch	Level	Generator encoder
PT100	Leaks	Pitch linear transducer
	PT100	

Chart 1. Wind Turbine Sensors

Environmental sensors

Ultrasonic anemometer	
- Based on Doppler effect - It is able to measure wind direction, wind speed and temperature with accuracy - Self-heated - Electric storms and aircrafts sounds can affect its measurements.	
Revolving-cup electric anemometer	
- Measures wind speed - Based on revolving cups that drive an electric generator. The pulses generated are registered in a pulse counter module. - Low accuracy compared with ultrasonic models. - Self-heated	
Vane	
- Measures wind speed - Low accuracy compared with ultrasonic models. - Self-heated	
Temperature switch	
- Is a sensor that acts when the air reaches to a specific temperature, previously set up. - Is a digital sensor, therefore must be connected to a digital input module. - Is used to control the fans and the heaters in electrical HUB, TOP and GROUND cabinets.	

PT100	
- A PT100 is a resistance temperature detectors (RTDs), based on the relationship between the electrical resistance of pure materials and their temperature. - In this case, the pure material is Platine (Pt), with a resistance of 100 Ω at 0ºC. The incremental ratio is 0,39 Ω/ºC. - Its performance can be checked by a multimeter - Is a resistance sensor, therefore must be connected to a PTs specific input module	

Position sensors

Encoder	
- Is a speed and position sensor located at generator rear side and produces a digital signal (pulses) - Is important to measure the rotor position (phase), to inform about speed limits (overspeed - OGS) and is usually related to converter alarms, synchronization errors and discrepancy between main shaft speed and the generator speed.	
Pitch linear transducer	
- Is a linear transducer that indicates the position of the pitch cylinder, in case of having a hydraulic pitch. It permits the indirect measurement of the blade angle by means a trigonometric conversion. - Produces an analogue signal between 0…10V depending on the position, therefore is connected to the analogue inputs module of HUB cabinet - There is one for each blade - Is usually involved in alarms related to discrepancies between the theoretical (command) and the real value, discrepancies between blades angles, under pressure...	

Yaw inductive	

- Detects if the nacelle is orienting counter clockwise or counterclockwise.
- Detects if the nacelle accumulates too many turns on the same direction, that could lead to excessive wire wrapping.
- For these purposes, it has 2 sensors inside:
    - Twisting sensor
    - Incremental encoder
    -
	

1.2.1.3. Operational states

The following classification can be listed:

Figure 8. Wind Turbine Operational state

0. RUNNING & GENERATING ENERGY

- Wind turbine is running and connected to the grid.

- No active alarms
- Running in normal operating ranges (wind, temperature…)

1. RUNNING

- Wind turbine is running but not connected to the grid
- Wind turbine Is available to run but environmental conditions (wind, temperature…) do not allow the connection to the grid.
- Pitch angle >40º, if it exists.

2. PAUSE

- Pitch angle >83º
- Hydraulic group running
- Emergency series OK.
- Yaw active.

3. STOP

- Pitch angle >87º
- Transition to Emergency state

4. EMERGENCY

- Pitch angle 90º (flag position)
- Emergency series NO OK
- Relevant alarms active
- Brake applied in case of pressing emergency button

The functions available in each state can be summarize as follows:

	EMERGENCY	STOP	PAUSE	RUN.	RUN. (GRID)
VOG/OGS	Active	Active	Active	Active	Active
GEARBOX HEATING	No	Active	Active	Active	Active
HYDRAULIC SYSTEM	No	Active	Active	Active	Active

OIL COOLING	No	Active	Active	Active	Active
YAW SYSTEM	No	No	Active	Active	Active
PITCH SYSTEM	No	No	Active	Active	Active
SPEED CONTROL	No	No	No	Active	Active
POWER CONTROL	No	No	No	No	Active
BRAKE APPLIED	No	No	No	No	No

Chart 2. Functions available during every operation state of the WTG

5. WTG DE-ENERGIZED

- No changes in states available
- The brake is not applied, rotor is spin-free
- Pitch angle = 90º
- Brake circuit has oil pressure
- Emergency buttons working powered by batteries, activating the rotor brake.

<u>Transition between states</u>

By safety reasons, it is only possible the transition to the next operating state, step by step. That is to say, it is not possible to pass from an Emergency state to a Running one.

Alarms make the turbine move always to the most restrictive state associated to the specific alarm severity.

<u>Emergency stops</u>

The emergency series are utilized by the wind turbine to detect an emergency and to act quickly to protect itself. As a result, the emergency stop is activated.

The alarm severity is the criteria that WTG follows to select the right state (PAUSE, STOP or EMERGENCY)

That criteria is based on priorities according to safety and production limitations:

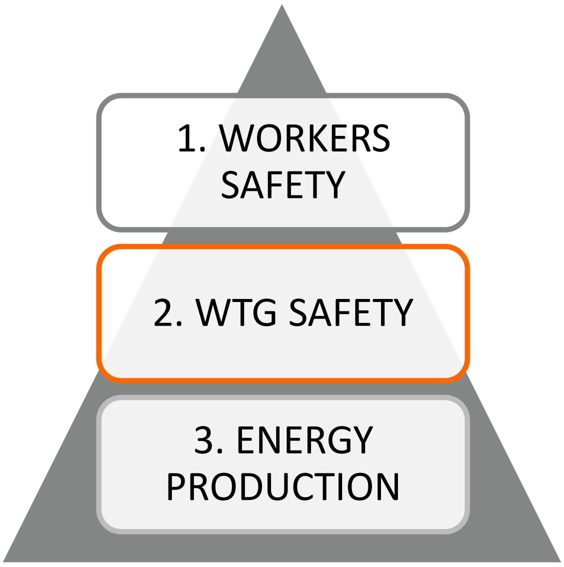


Figure 9. Priorities in safety

Emergency series

Emergency serie is a circuit that controls the transition to emergency state. When the circuit is closed, the emergency serie is “OK”. If the circuit serie is open the alarm that appears is “EMERGENCY SERIE NO OK”.

There are 2 emergency circuits, one in the TOP and the other one in the HUB. There is no electrical connection between them. The TOP of the wind turbine generator is the upper part of the nacelle which encloses all the mechanical machinery. In this case, the TOP emergency circuit will be placed inside the nacelle. The HUB is where the three rotor blades are affixed and also connects the rotor to the nacelle

There is a communication between these series through the control system.

When the emergency circuits are opened, the power supplies of 690 Volts to the motors and the 230 Volts to the electro-valves are disconnected, and the PLC is informed.

The components of emergency series are:

In the TOP emergency serie there are four emergency buttons that in case of emergency automatically trigger opening the emergency serie circuit and therefore, activating the emergency stop.

TOP

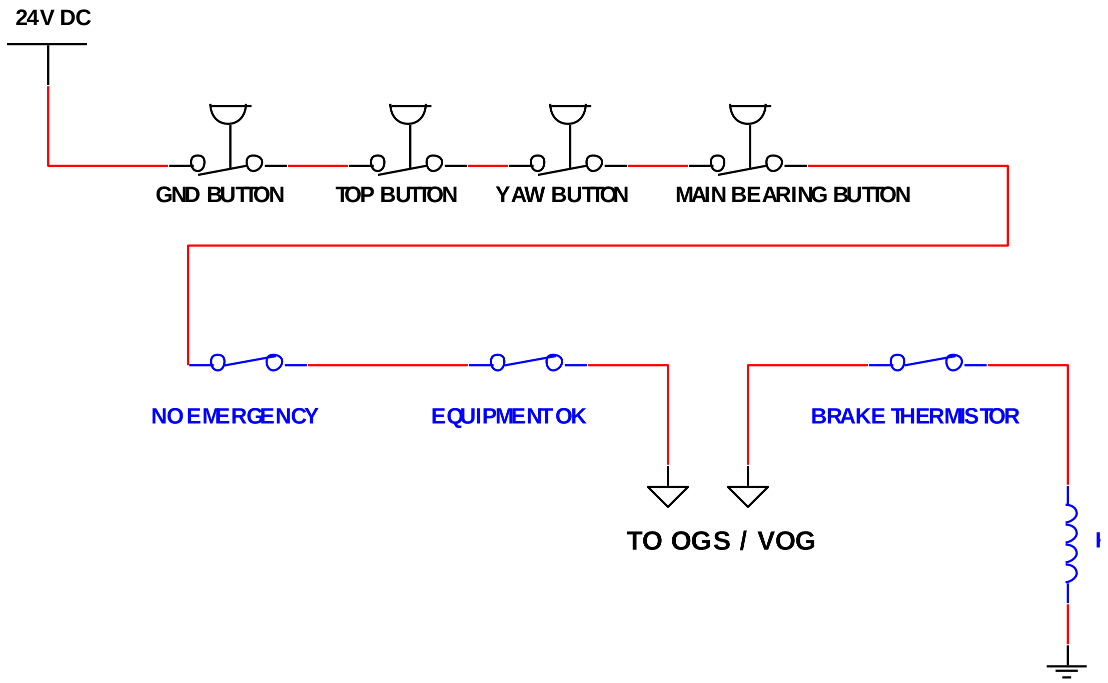


Figure 10. Top emergency serie

HUB

The HUB emergency serie will be activated when the pressure switch of one of the blades triggers.

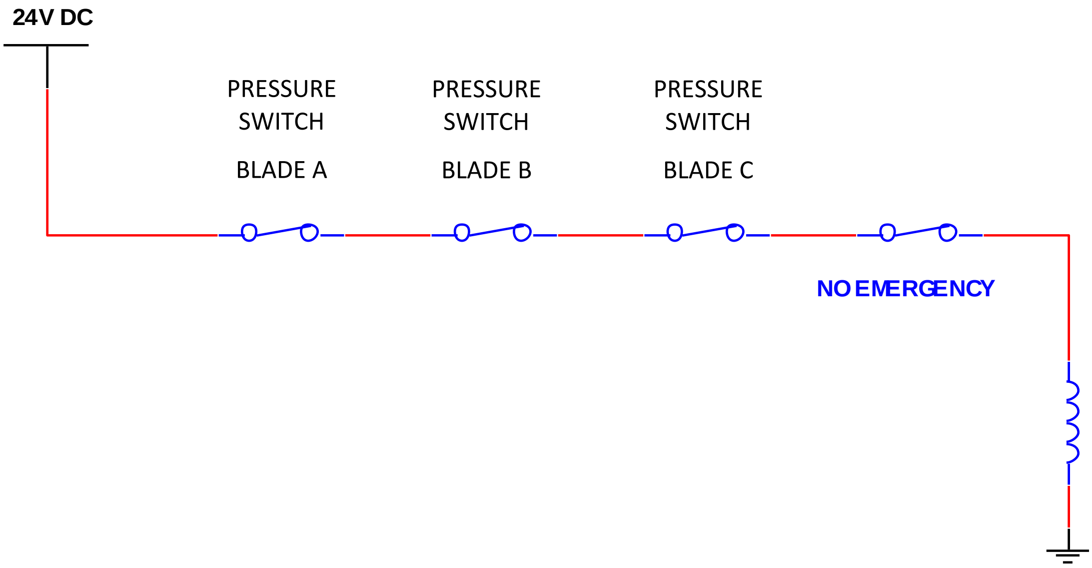


Figure 11. HUB emergency serie

Alarms reset

Alarms can only be reseted if their causes have disappeared.

There are 3 types of alarms reset:

- AUTOMATIC. The wind turbine resets the alarm once the cause has disappeared after a predetermined time.
- REMOTE. The SCADA operator resets the alarm by remote control/supervision systems.
- LOCAL. The alarm reset is done by a technician on site.

1.2.1.4. WTG Safety systems

- Overspeed Guard System (OGS)

  The OGS measures the rotor speed (revolutions) at low speed shaft. In case of having too many revolutions, opens the emergency circuit and leads that the wind turbine goes to emergency state.

The OGS is a redundant-independent system (isolated to the control system) and uses an external signal coming from PLC to make a self-check. It has two inductive sensors that provide with two different signals, one of them is controlled and transmitted by a PLC and the one is read directly by the OGS. The OGS has two outputs, one of them goes to the emergency serie, so in case there is overspeed measured in the low speed shaft it triggers the emergency circuit.

The other output signal goes to the wind turbine control PLC where it is processed with the other sensor signals.

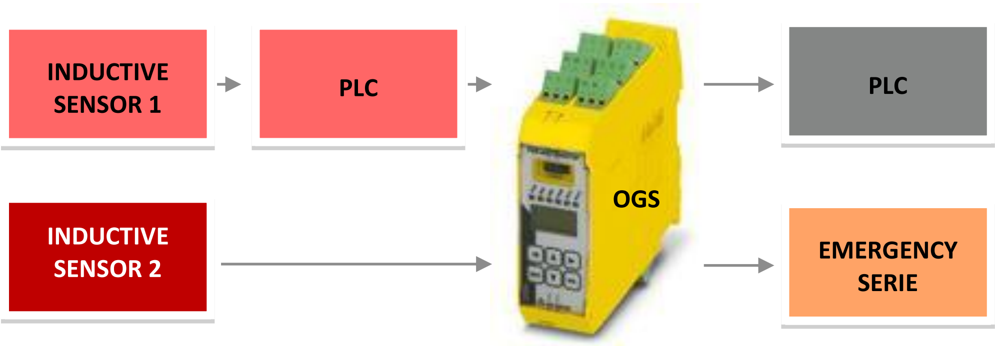


Figure 12. Overspeed guard sensor operation diagram

- High voltage gas-insulated switchgear (HV GIS) trip circuit

  This circuit trips the HV GIS and disconnect the transformer to the grid. It is a relevant circuit that must be checked before the energization.

There are 2 types of HV GIS trip circuits:

- A: HV GIS with tripping coil
- B: HV GIS with tripping relay

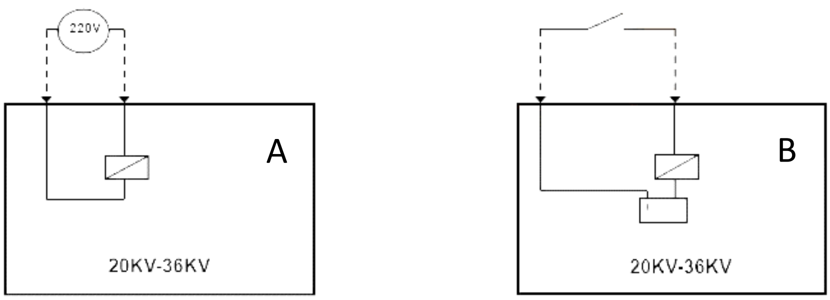


Figure 13. HV GIS trip circuits

As it can be observed in the figure above there are two different tripping circuits for the

The following figure presents a diagram of the safety system:

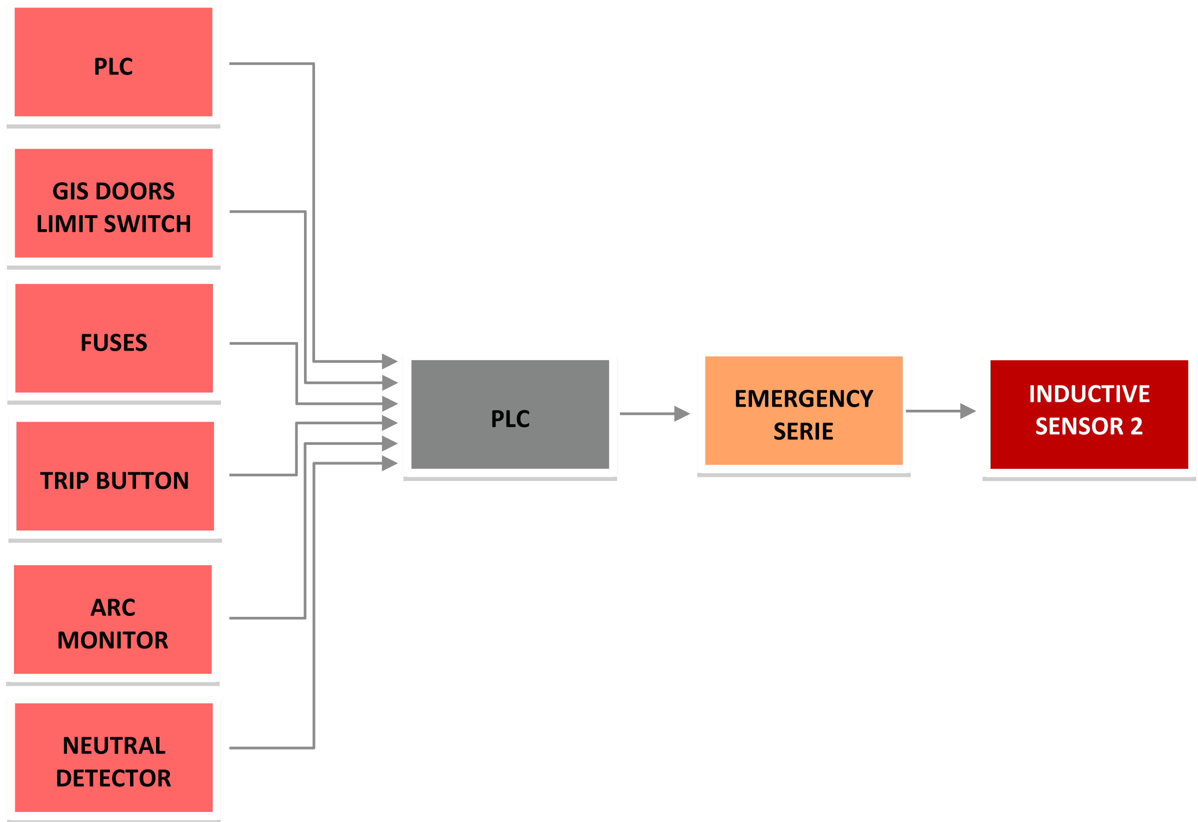


Figure 14. Safety system diagram

As it can be observed in the diagram above if any of the elements in the red boxes give an alarming value, for instance the information transmitted from the neutral detector, control PLC or Arc monitor, or any of the other elements (Trip button, fuses or GIS trip circuit), the PLC of the safety system transfers the information to the emergency serie which opens the emergency circuit and sets the wind turbine generator at emergency stop state.

Figure 15. Data logger

Vibration protection

Wind turbines usually have a vibration protection system that protects its structure against abnormally and severe tower oscillations.

There are 2 types of sensors:

- Pendulum. It opens an electric contact if the oscillation is excessive, opening the emergency serie. The adjustment of this sensor is made by varying the distance of the suspended mass
- Vibration sensor. Based on accelerometers that register the vibration in acceleration units (m/s2, g's…) in two axis.

Voltage dips protection

Wind turbines based on all kind of generator technologies must meet all national electrical grids regulations and requirements related to voltage dips.

When a voltage dip occurs, wind turbines have uninterruptible power supplies (UPS) and protections (Active Crowbar) that allow them keep running.

If the voltage dip were long, wind turbine would be moved to an emergency state, disconnected to the grid and blades would turn to 90ºC (in models with changeable pitch) to stop it.

1.2.2. Lesson 2 – H&S specific

The objective of this lesson is to get the knowledge related to general safety considerations:
(1) Available H&S manuals, and their structure
(2) Voltage levels at each cabinet/area
(3) How to use the lift and ladder in safe manner
(4) The wind speed limits to work on the different WTG compartments

Please go to the Health and Safety document.

1.2.3. Lesson 3 - WTG operation procedure

The objective of this lesson is to learn the working operating procedures:
During this lesson, the trainee will learn:
(1) The different types of WTG access
(2) How to control the WTG from the different cabinets
(3) The locking procedures on the low and high-speed shaft
(4) How to access the hub and the roof
(5) How to use the chain hoist

1.2.3.1. Locking procedures on the low and high-speed shaft

This operation may only be performed BY THE AUTHORISED MAINTENANCE PERSONNEL, and in a maximum wind speed of 12 m/s.

Where a maintenance operation requires a mobile part of the machinery to be immobilized, the rotor must be locked in the following manner:

1. Go to the control → Pitch and Brake option. The brakes should be applied until the blades are in the work position. At his moment locking arms must be fitted. NEVER INSERT THE BOLTS UNTIL THE TURBINE IS FULLY STOPPED.

2. Procedure for fitting the locks:

- If the wind can move the rotor: If it is windy, the rotor will be turning very slowly, when the rotor reaches the "Y" position with the cone fiber window facing upwards, apply the brakes, selecting the hole in which the locking bolts are inserted. If the hole on the rotor disc does not line up with the locking arm, you must release the brakes and allow the rotor to turn a little further until it lines up. Then apply the brakes again, and when the rotor is at a complete standstill, insert the bolts.

Figure 16. Locking arm

- When the bolts are completely in or out, the latch must be put in the locking position.
  Warning: Never position yourself in the trajectory of the bolts; they could cause you to become trapped

- If the wind not is able to move the rotor when the blades at 90º: the degree of pitch must always be lowered (slowly, step by step) until it begins to rotate. As in the previous case, using the brakes, align the locking holes with the bolts and insert the bolts by activating the manual hydraulic pump. The pump handle is then placed in the "Lock" position.
- If the wind cannot move the rotor with the blades at 0º: If there is a complete absence of wind, the rotor will need to be moved by the universal joint, using a wrench and the screws which join it to the generator flange (always in a tightening direction so as not to loosen the screws).
- After fitting the locking bolts, turn the blades to an angle of 90 degrees.

1.2.3.2. How to access the hub and the roof

This operation may only be performed BY THE AUTHORISED MAINTENANCE PERSONNEL, and in a maximum wind speed of 12 m/s.

1.2.3.3. How to use the chain hoist

General safety rules.

When using the hoist, WTG must be always stopped, vehicles must be parked out of the hoist operating area, technicians must wear safety helmet and must keep far from suspended loads.

Operation

Technician in Nacelle

- Before using the hoist, check its working condition. Ensure that the anchorage and collecting chain box are in good condition. If any problem is found, it must be solved before using the hoist.

- Open the door, remove the chain and the safety bar and take the hoist to the outside of the machine.

RISKS AND PREVENTIVE ACTIONS

- Before opening the door, the worker must ensure itself to a fixed point (frame, generator…) using the safety rope and the harness.
- Be careful with the wind speed (see safety manual).
- Once the hoist has been taken out the machine, ensure that it is well placed and place the safety elements (bar and chain).
- During the hoist operation (lifting or down), with one hand the worker must operate the motor control (button pad), and he will be always visually checking the load which is being moved with the hoist.

Figure 17. Hoist button pad

RISKS AND PREVENTIVE ACTIONS

- It is forbidden to push the button pad of the motor control with any other part of the body rather than the hands.
- Hoist chain never must be grabbed with the hand.

Technician at tower base.

- Before using the lifting bags, check their condition, removing any of them with any problem.
- Before using the hoist, ensure the right load fastening and that the load doesn't exceed the nominal load capacity of the hoist.
- Load operation from or to the Nacelle must be carried out in the charge and discharge area, placed out of the area where objects can fall from the upper sections of the tower or the nacelle.
- Once the loads are well placed, call the worker inside the Nacelle to lift the load with the hoist some meters, until we can move the load to the vertical of the Nacelle back door.
- Once the load has stabilized, we can order the lift.

Communication

Communication between technician in the nacelle (who is operating the hoist control) and the other one at tower base must be clear, trying to avoid any kind of communication that can induce an error. This communication can be:

- Using the radio (walkie-talkie).
- Using hand signals:

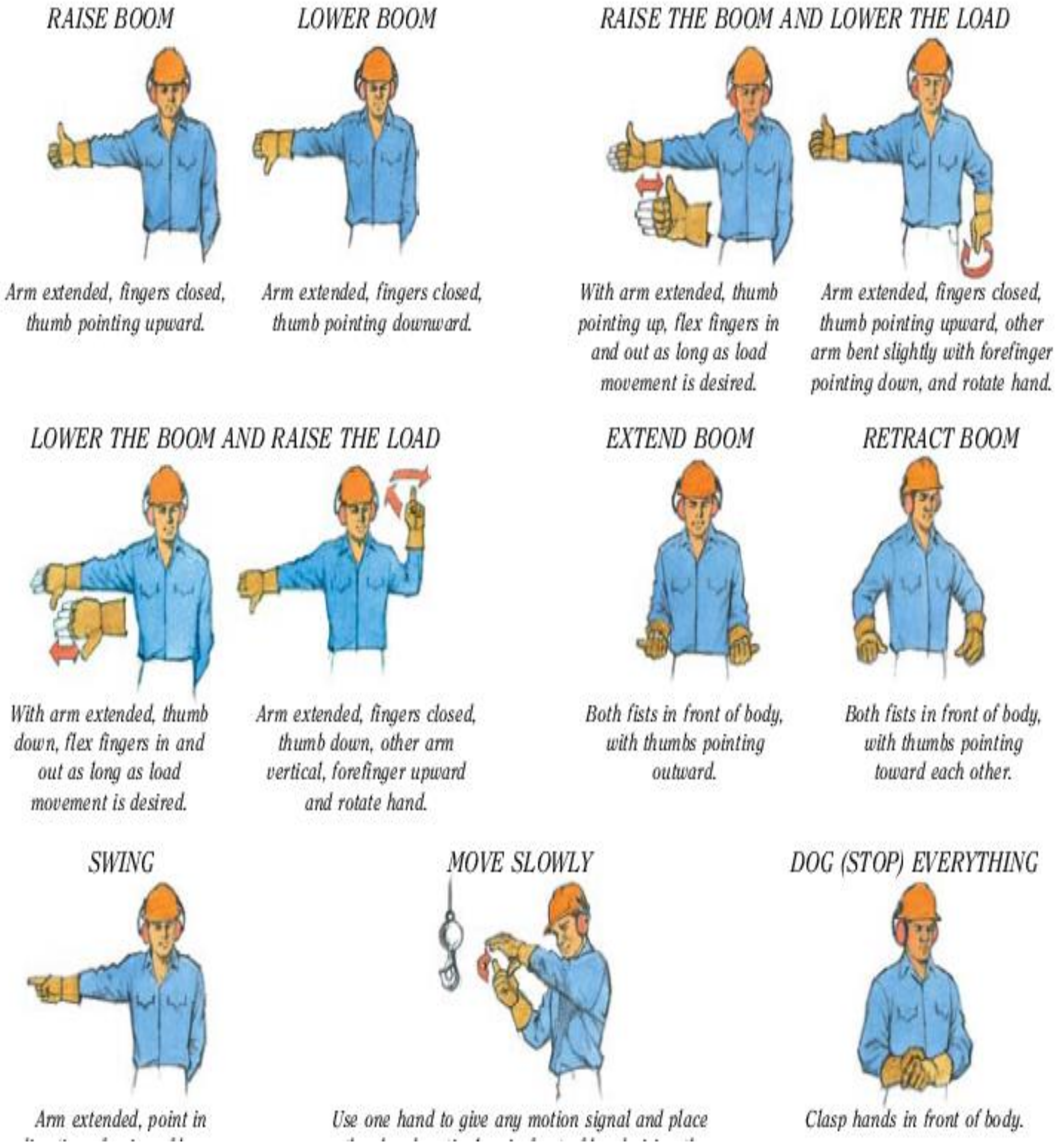


Figure 18. Communication with hand signals

- Both methods at the same time.

1.2.4. Lesson 4 - Mechanical systems (WTG specific)

The objective of this lesson is to show the mechanical systems

During this lesson, the trainee will learn:

(1) To identify the different mechanical components of the turbine

(2) To understand the functionality of the different systems at the drive train

(3) The yaw system and its functionality

(4) Blades and pitch system

1.2.4.1. Drive Train

The rotor takes up the kinetic energy, changes it into mechanical energy and transfers it to the gearbox via the rotor shaft. The generator is connected to the gearbox via a coupling and converts the mechanical energy into electric power.

The typical drive train of a Wind Turbine Generator System (WTGS) consists of:

- Rotor shaft
- Main bearing/s
- Gearbox
- Secondary brake
- Coupling
- Generator

Rotor Shaft

The rotor shaft, also referred to as the low-speed shaft, is a component of the drive train. The rotor blades, hub and rotor shaft form a functional unit. The rotor shaft is forged and has the task of taking up the driving power of the rotor and transferring it to the gearbox. The rotor shaft is inclined about 4°-5° to prevent blades from crashing to the tower because of their flexion in case of having strong winds (high loads in blade tip).

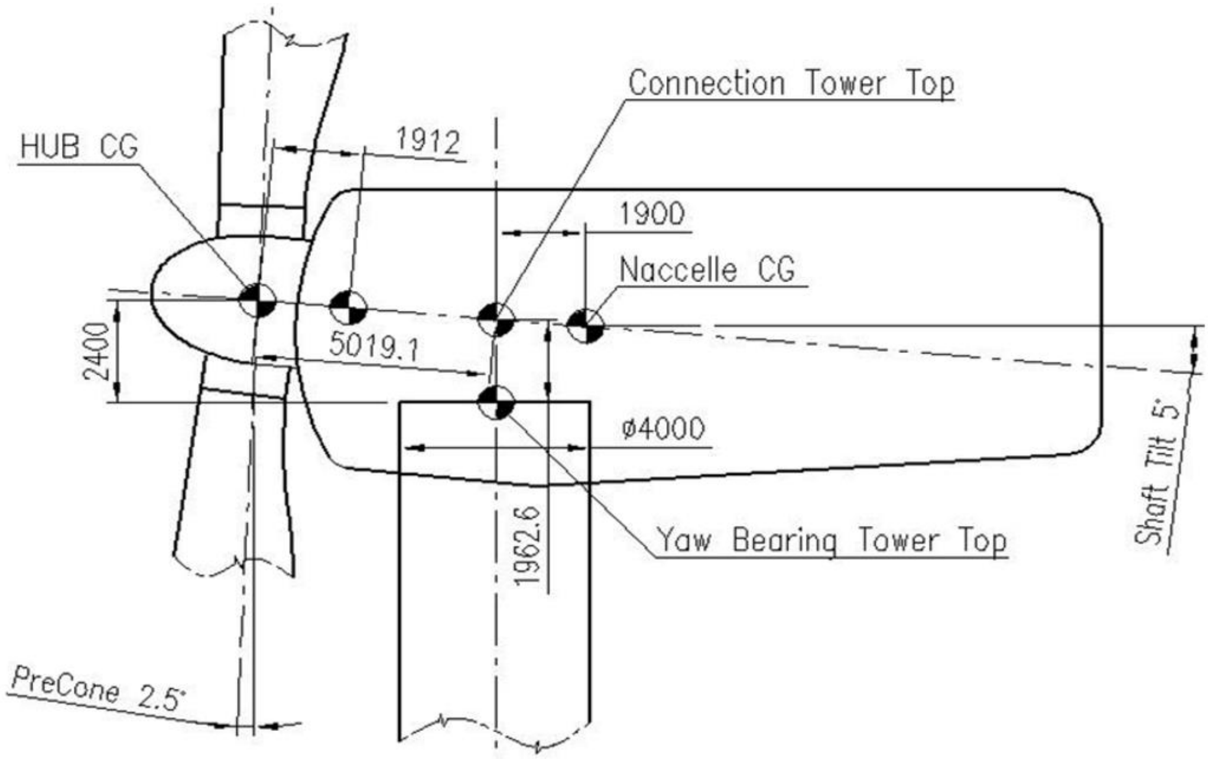


Figure 19. Rotor shaft inclination

The rotor shaft is connected to the hub by a bolted connection on the rotor shaft flange.

The rotor shaft and the main gearbox are connected by a special flange system that enables simple disconnection and assembly of both components.

Figure 20. Rotor shaft

The turn of the rotor is locked by the rotor lock. It consists of a perforated disk, which is mounted on the rotor shaft in the connection the between rotor shaft and hub, and a locking pin, which is mounted in the top part of the base frame over the front main bearing.

The locking pin can be moved manually, by an electric actuator or by a hydraulic cylinder, depending on the WTG model.

The locking pin is inserted into a hole in the perforated disk to lock the rotor.

Figure 21. Locking pin connecting shaft and hub

Rotor speed

The WTG design and nominal power have a relevant influence on rotor speed. Depending on the diameter of the rotor, the turning speed varies to keep a defined blade tip speed (an excessive speed could lead to noise, aerodynamics and structural problems).

For large rotors, the speed is normally about 10-20 rpm. For smaller ones, the speed increases up to 30 rpm.

Speed sensors

There are over-speed monitors based on inductive proximity switches. They pick up the values at the rotor shaft.

The sensors are mounted at a distance of approx. 2-3 mm. If the distance were out of range, incorrect speed signals would be recorded, and the PLC would lead to a WTG shutdown.

Main Bearing/s

The rotor shaft is mounted in one or two bearings, depending on the wind turbine model.

Usually they are double row taper roller type. Both bearings are inserted in the cast base frame. The housing/s and the hub are manufactured of ductile cast iron.

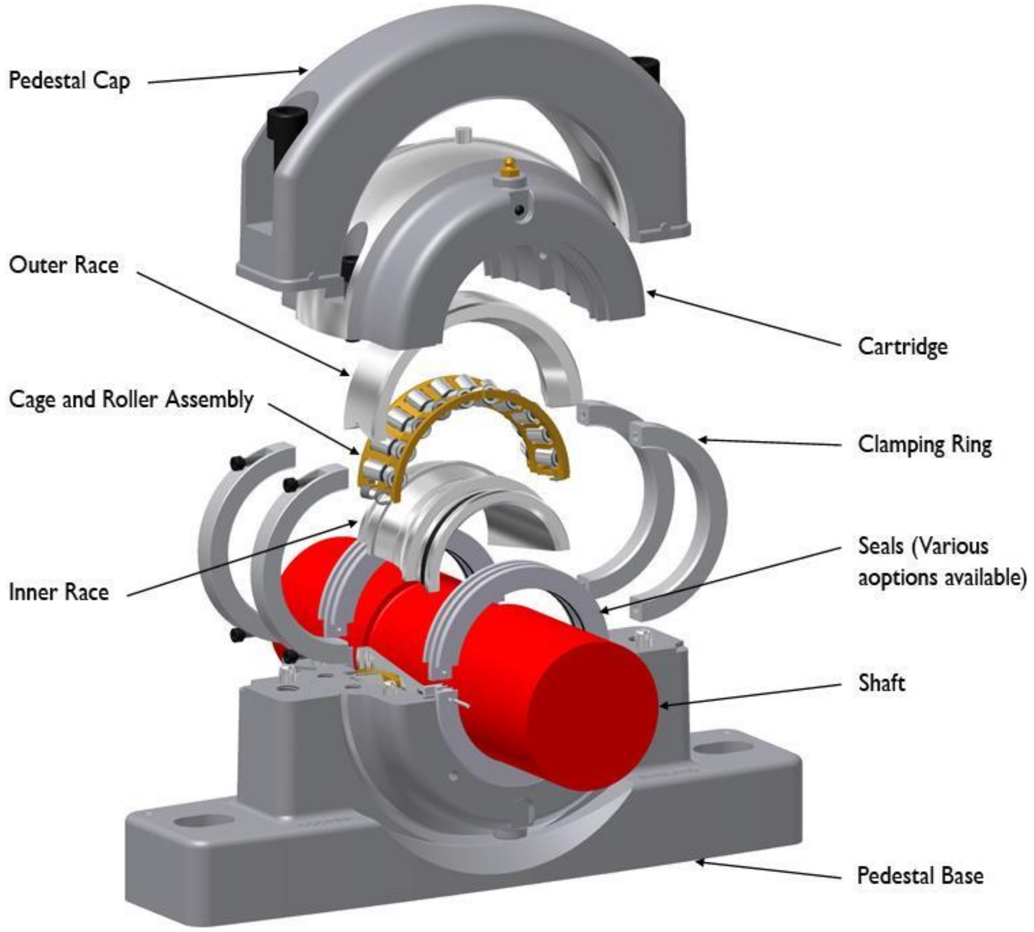


Figure 22. Main bearing

The main bearing/s takes up the axial and radial forces from the rotor and protects the shafts of the gearbox.

The main bearing/s is lubricated by a special-purpose grease for large anti-friction bearings. The automatic lubrication system is filled with the respective quantities of grease according to the preventive program. Any grease leak is collected in a bin installed previously and must be removed during maintenance work.

Gearbox

This section does not apply to synchronous WTGs without gearbox.

Components

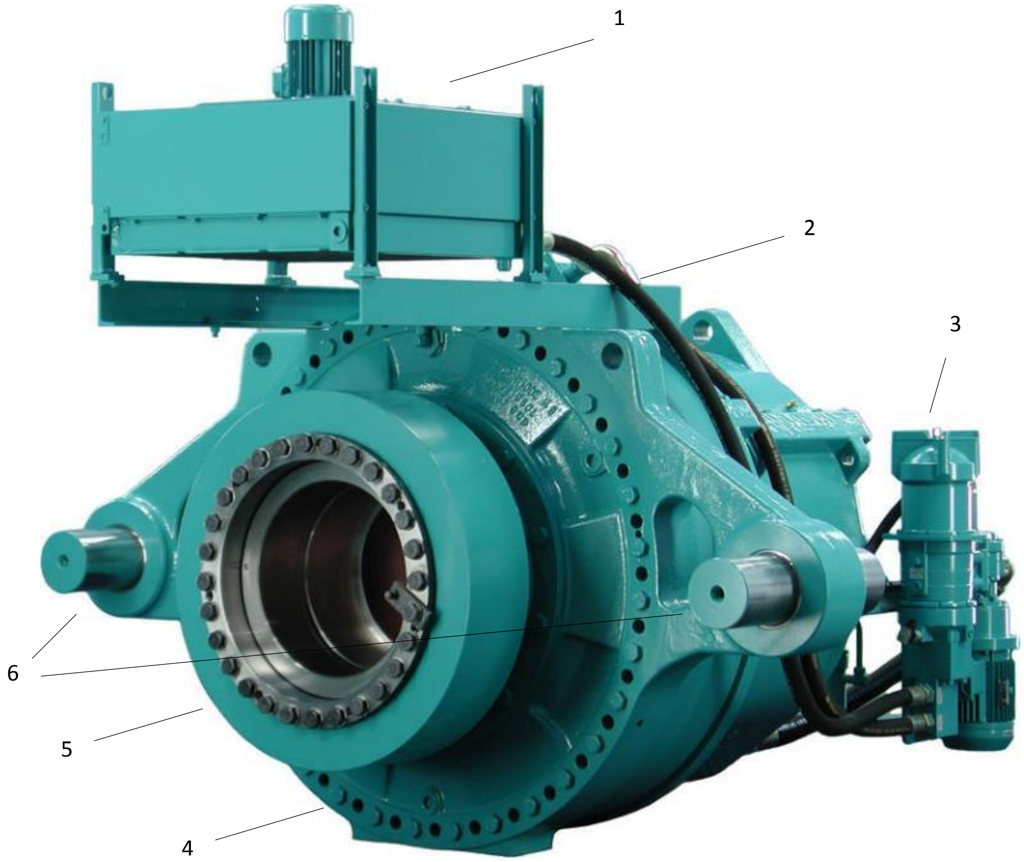


Figure 23. WTG gearbox

1	Intercooler	4	Cast housing
2	Oil cooling circuit	5	Special flange for main shaft
3	Oil filtering system	6	Torque arms

Task and Function of the Gearbox in the WTG.

The gearbox is used to convert the energy of the rotor from low speed and high torque on the input side of the gearbox to high speed and low torque on the generator side. The gearbox is a multi-stage system consisting of at least one planetary stages and at least one helical gear stage.

The gearbox multiplies the rotational speed by a factor call “gear ratio”. The gear ratio of the gearbox can usually vary from 50 to 150 depending on the WTG model and wind class. This value also depends on the rotor diameter (due to blade tip tangential speed), generator nominal speed, and the specific machine design.

Other typical characteristics of a gearbox, depending on its size, are:

- Weight: 5-20 Tn
- Oil quantity: 200-700 liters.

The housing of the gearbox consists of cast iron. The gearbox is equipped with ball, cylindrical roller and tapered-roller bearings, which are selected depending on the speed and load of the individual stages.

For inspection purposes, there are several apertures that allow a visual check of the gear-tooth systems and bearings.

In addition, there are some parameters that are permanent monitored in a gearbox:

- Oil temperature
- Oil level
- Oil pressure
- Differential pressure for monitoring the oil filters
- Temperature of the bearings in the helical gear stage

Gearbox subsystems:

Torque arms.

Transmit and absorb the spinning of gearbox to base frame.

The gearbox is supported by a torque arm and corresponding pedestal bearings on the top part of the base frame. The impact noise and vibration insulation over the entire rotor speed range of the turbines is affected by means of specially developed elastomer elements between the gearbox and base frame.

Gears, shafts and housing:

Structure of a typical WTG gearbox:

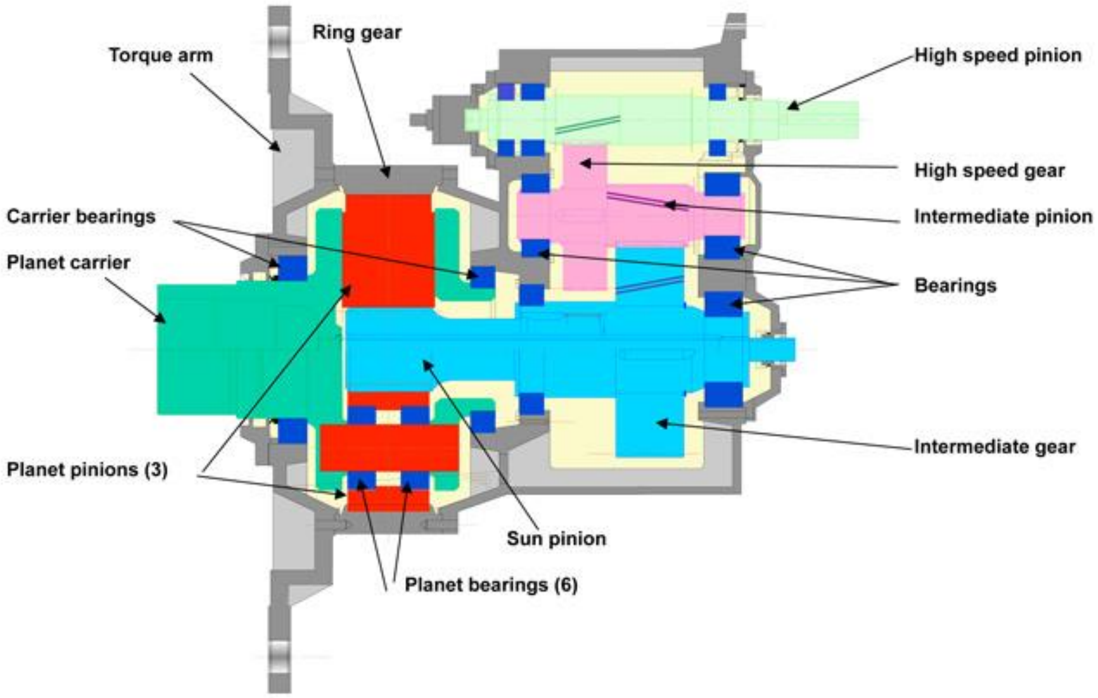


Figure 24. Inner structure of a WTG gearbox

Planetary gear stage:

The torque from the rotor shaft drives the planet carrier of the planetary gear stage. The planet wheels are driven at the same time. The planet wheels mesh with the ring gear mounted on the housing, which results in forced rotation of the intermediate gear through the simultaneous meshing of the planets with the sun pinion.

1st & 2nd helical gear stages (Intermediate and high speed):

Helical gear stages limit the axial displacement and allows the output speed to be adjusted to the respective generator speed.

Helical gear stages are better to avoid noises and to run working at high speeds.

Lubrication System of the Gearbox

The bearings in the gearbox are lubricated with oil. The most common oil types are:

Mineral oil

- Viscosity 320 cSt
- Estimated lifetime: 3-4 years
- Slower degradation process
- Viscosity reduces dramatically at high temperatures

Synthetic oil

- Viscosity 320 cSt
- Estimated lifetime about 6-8 years
- Faster degradation process
- Oil changes are made by oil condition
- Viscosity is constant if oil is a good condition

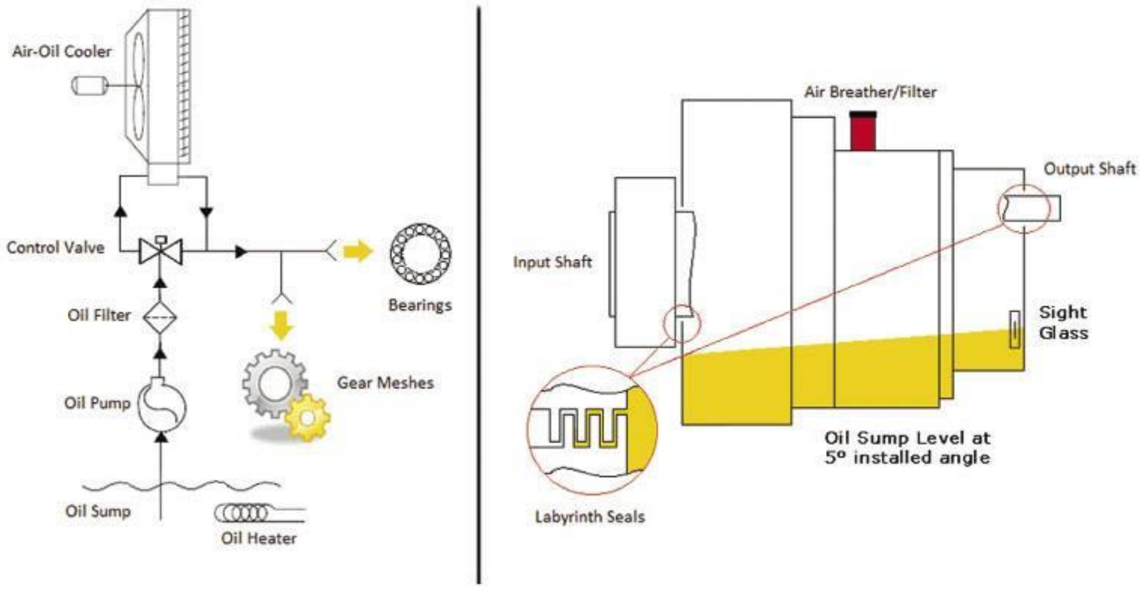


Figure 25. Lubrication system of the gearbox

The pressure level at the gearbox input is about 2 bars. The lubrication system of the gearbox is equipped with an oil pump and designed as a circulating forced-oil lubrication system.

The oil pump is connected upstream to the filter.

The whole system is shown below:

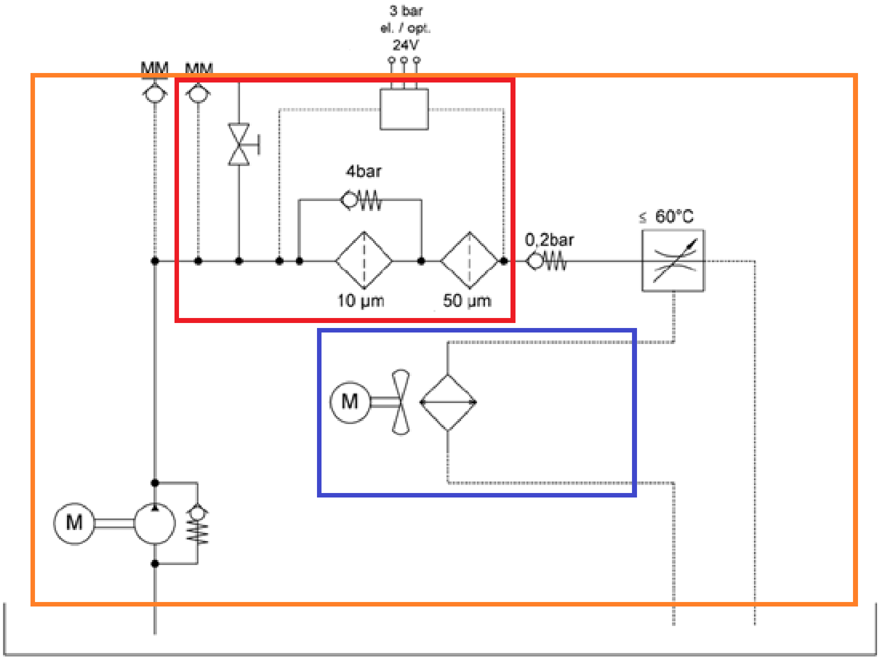


Figure 26. Lubrication circuit of the gearbox

In most cases, an extra mechanical pump is connected to the drive train via a back gear to guarantee forced lubrication.

Above 5-10 °C, the oil flow of the mechanical pump is diverted from the bypass flow to the main flow by means of an electrically actuated 3/2 directional control valve.

Oil Cooling

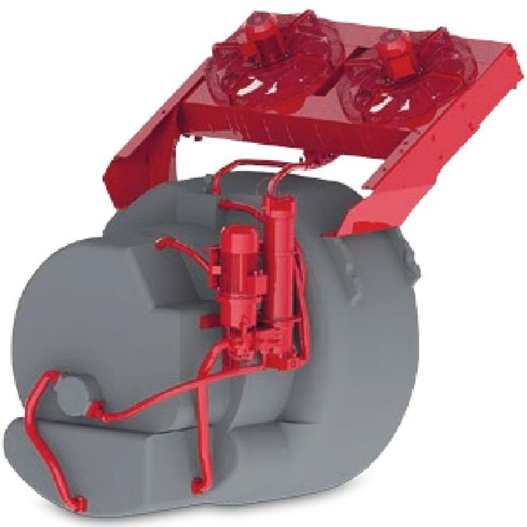


Figure 27. Oil cooling system

The oil cooling system keeps the oil temperature inside the designed operational ranges and consists of a circuit that passes the oil through an oil/air intercooler installed at the bottom of the gearbox. Depending on the wind turbine model, there can be one intercooler or two.

A thermo-bypass valve is mounted on the outlet at the bottom of the filter housing. This opens at an oil temperature < 45 °C and returns the oil directly to the gearbox. The thermo-bypass valve partly opens from 45 °C and conducts one part of the oil to the oil/air cooler and the other part to the gearbox input. The thermo-bypass valve ensures that the gearbox is always supplied with oil. The thermo-bypass valve is completely closed above 60 °C, so that the entire oil flow is conducted to the two oil/air coolers, which are of the same construction and connected in parallel.

Figure 28. Cooling unit

Depending on the load condition and ambient temperature, one cooling unit is sufficient to ensure that the permissible oil temperature is complied with. The volumetric flow of the oil is distributed by means of integrated temperature and pressure-controlled bypass valves depending on the arising pressure losses in the two cooling units.

Air filtering

Air filtering consists of a particle-removal element capable of eliminating silt seized particles and a desiccating media – often comprised of silica gel – to remove all traces of moisture from the air as it enters the gearbox. This type of breather provides bi-directional water removal. As the gearbox cools, for example, during a shut down, it draws air in and passes it through a foam element to dissipate air flow across the silica gel media. As the moisture laden air passes through the silica gel, moisture is absorbed by the silica gel. As the air exits the silica gel desiccant bed, the air also passes through a high efficiency particle removing media that removes all silt sized particles before passing down the central standpipe into the gearbox.

When air flow is reversed, for instance during gearbox start-up and warm up, the expanding air passes in the reverse direction causing the headspace of the gearbox to purge moisture and humidity that may have built up during shut down. By impregnating the silica gel with an indicator sensitive to the degree of moisture saturation, the change out interval for a desiccant breather can be optimized simply by observing the color change within the desiccant.

This is a helpful indicator for when to change the breathers. A color change from the bottom up is indicative of moisture ingress from the environment, while a color change from the top down indicates internal moisture perhaps caused by another ingression source such as a defective shaft seal.

Figure 29. Air filter

Temperature transducers (PT100)

Two PT100 sensors are mounted in gearbox:

- Oil temperature sensor
- High speed shaft bearing temperature sensor

Pressure Transducers

Two pressure transducers record the current pressure in the system at the pump and the gearbox input.

The pressure transducers supply an analog signal in the measuring range 0-16 bar. The signals are transmitted to the control system of the WTG.

Pressure switch

The function of the pressure switch is just to check that oil flows and it is set up at 1 bar.

Oil level indicator

There is an oil level indicator at the rear side, measuring the oil quantity that the gearbox contains. Its frequent checking is very important

Oil Heating

At low temperatures (below approx. 5 ºC), the viscosity of the oil increases and it is hard to pump it. Without oil heating, in some cases the electric pump could not have enough power to pump it. So, it is important to measure oil temperature through a PT100 sensor and to heat it if the temperatures fall below 5ºC by means of electric resistances. The nominal power of these resistances is about 1-2 kW.

The oil temperature to start working is about 8-9ºC.

Oil particle filter system

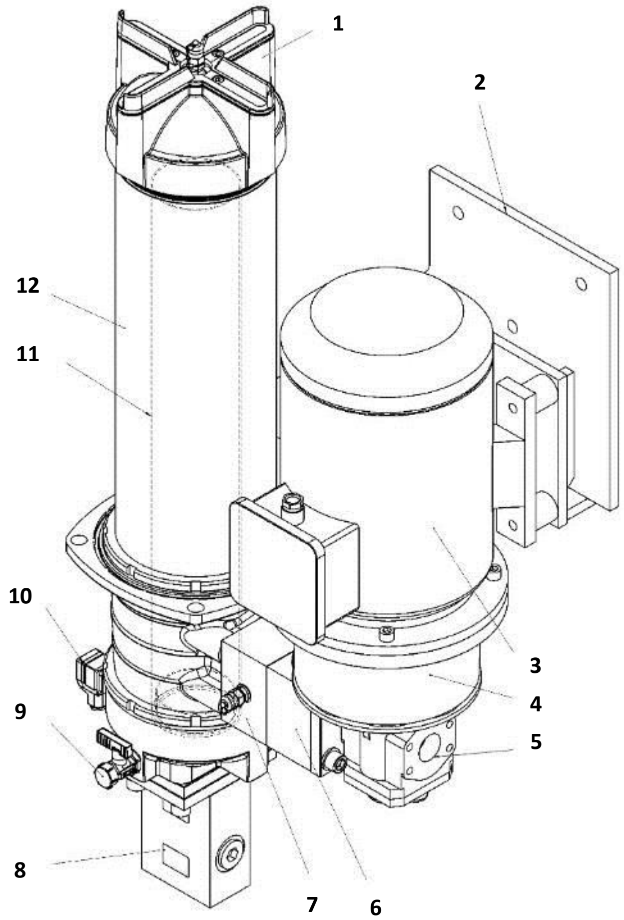
The oil filter absorbs contaminants in the gear oil, to protect the gearbox. These contaminant particles arise through abrasion/wear, contaminated oil and dust from the ambient air. Before the oil reaches the points concerned in the interior of the gearbox, it is pumped through an oil filter installation with a combination filter and cleaned in two stages.

Ideally, the filtration system should allow both particle and moisture removal, and have good particle capture efficiency to optimize the time between necessary filter changes.

There is an internal bypass valve protects the filter housing from excessive pressure, which could be caused e.g. by a clogged filter. At a pressure of 3-4 bar, depending on the WTG model, it conducts the oil directly into the gearbox.

The filter system is also equipped with a clogging indicator. The degree of clogging is determined via differential pressure and indicated by means of a visual indicator (red pin or lamp, depending on the configuration) and sensor (signaling to plc).





1	Cover	7	Pressure relief block
2	Bracket	8	Thermo-bypass block
3	Motor	9	Drain cock
4	Coupling	10	Clogging indicator sensor
5	Gear pump	11	Combination filter element 10/50 µm
6	Inlet block of the mechanical pump	12	Combination filter housing

Figure 30. Oil particle filter system

Secondary Brake

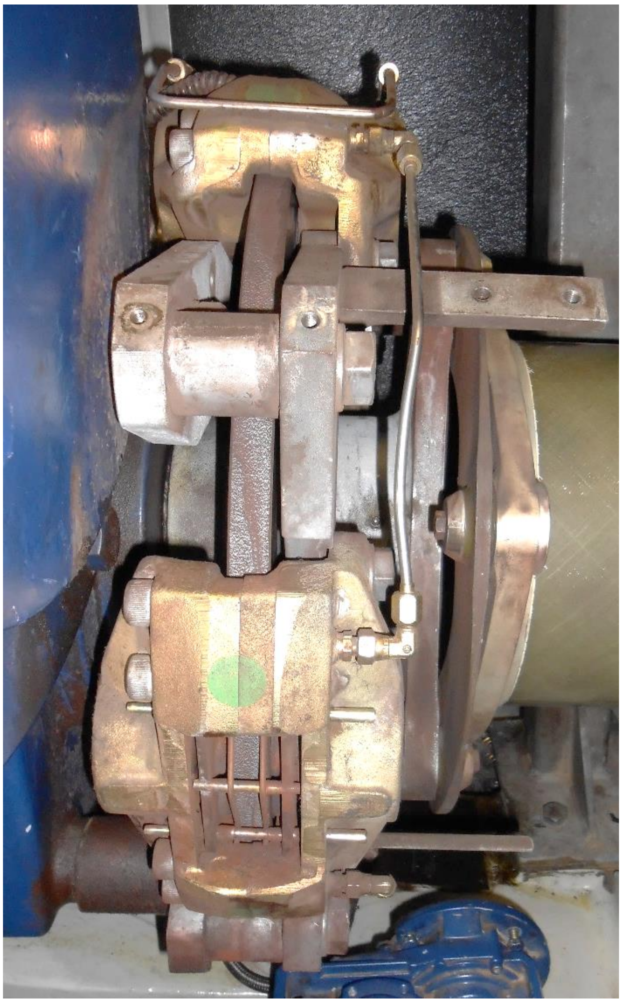


Figure 31. WTG Secondary Brake

The secondary brake of the WTG consists of an active hydraulic disk brake with an active hydraulic brake caliper. It is integrated in the mechanical drive train and the hydraulic power unit supplies the hydraulic pressure.

Figure 32. Primary brake system

The primary brake consists of pitching the rotor blades in the 90° direction, to stop aerodynamically the rotor. In normal braking procedures, the machine starts the braking process by means of the primary brake.

If the WTG must be stopped completely, the secondary brake is also applied after a specified speed has been reached.

The brake disk is mounted on the high-speed shaft of the gearbox, and the brake caliper is flange-mounted directly on the gear housing.

Figure 33. Coupling

Coupling

The coupling, installed between the gearbox and the generator, transmit torque with zero backlash while compensating for angular and parallel misalignment between the two connected shafts.

There are some kinds of couplings depending on their manufacturing materials and their forces distribution principles:

Flexible steel laminate coupling.

Figure 34. Coupling between the gearbox and the generator

Drawing of the coupling RADEX® of KTR & Co.

- Locking assembly
- Brake disc with plate assembly (gearbox side)
- Middle section with slipping unit and glass-fiber reinforced plastic tube
- Tensioning nut
- Flange (generator side)

Figure 35. Rigid coupling

It consists of two hubs, a spacer and two high strength carbon steel flexible discs, to meet the application requirements. It features a splicer type slip spine which allows the coupling to be collapsed for easy installation. It does not require no lubrication or maintenance

The alignment of the generator must be checked at each maintenance interval and corrected if required.

The coupling is provided with a slipping unit and acts as an overload protection system. The coupling slips after approx. 2.5 times the torque has been reached. The gearbox is thus protected from overloading. However, this case can only occur regarding severe damage to the generator (generator short circuit) and is excluded in normal operation of the turbine.

A further feature of the coupling is the electrical isolation of the generator.

GENERATOR

Figure 36. Generator

The generator is typically a double-fed machine with 3 or 4 poles, depending on its nominal speed, coiled rotor and slip rings. The converter control enables work at variable speeds (within a limited range) using the frequency control of the rotor currents.

Torque is transmitted to the rotor from the gearbox through a flexible coupling which absorbs the minor axial and radial misalignments which may arise while the generator is operating. This zone is called the “Drive End (DE.)” or front section. The opposite side, where the slip ring chamber is located (1), is called the “Non-drive end (NDE)” or rear section.

The torsion stresses transmitted from the flexible coupling are dampened by the generator supports.

Cooling is through an air cooler mounted on top of the generator body (3). Air is expelled through the rear of the coolant box and a duct carries it to the exterior.

The generator is protected against short-circuits and overloads. The temperature is also monitored continuously by probes mounted on the stator windings, bearings and the slip ring chamber.

The converter is connected to the generator rotor terminals at one end and to the electrical grid (through the transformer) at the other end.

Description of the components of the Generator:

Cover

The generator cover is made of grey cast iron, which offers greater protection against strain, in addition to supporting the rotor and centering the magnetic core of the stator. Lastly, it is an essential component of the machine's coolant system.

The stator terminal boxes and the auxiliary connection boxes are also placed on top of the cover and are cooled from the inside through one of the above-mentioned channels. The inside of the generator body is sealed to prevent the entry of damp or dust which lead to rust or short circuits between the coils.

Stator

The magnetic core of the stator is formed of a stack of plates compressed together by rings or pressure plates and longitudinal braces. The winding is constructed from concentric coils. The winding is double layer, that is, there are two different coils within the same groove, and is short pitch, to reduce the harmonic content of the wave generated.

The winding conductors are insulated from each other with a polyester amide type varnish, and are attached to the grooves of the stator using glass wedges.

The beginnings and ends of the windings are taken to the stator terminal box.

Rotor

The shaft supports the winding. It is made of steel, machined along the whole length and ground on the rolling surfaces.

The magnetic core of the rotor is formed of a stack of steel plates, forming the rotor "cylinder". The grooves, into which the rotor winding is placed, are on the outer periphery. The whole stack is compressed and secured to the rotor shaft with cotter pins. The rotor winding uses complete coils, laid in double layer and short pitch, made of rectangular copper plate insulated with enamel and glass.

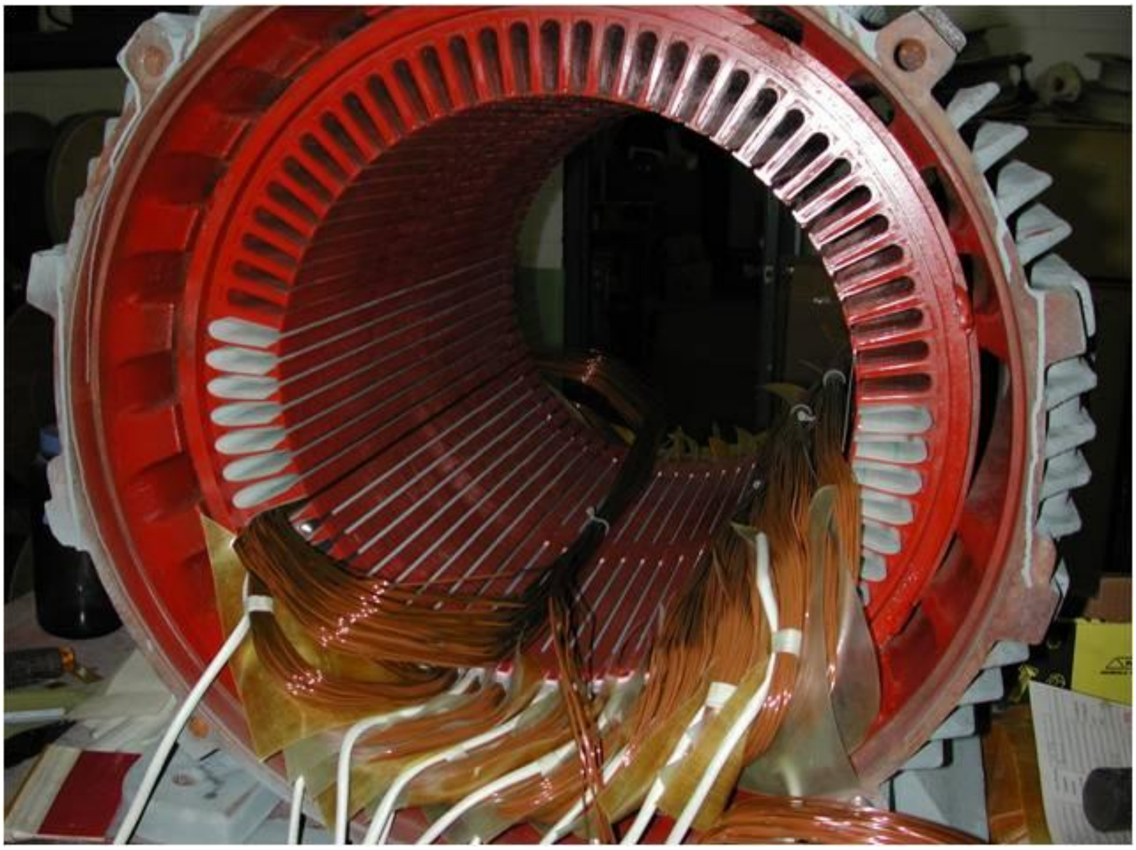


Figure 37. Rotor winding

The coils are secured to the rotor grooves with wedges, and the unit is varnished with polyester amide resin.

When the unit is coiled, the heads of the coil, that is, the parts of the coil which protrude over the lateral surface of the core cylinder, are banded to the base of the cylinder using hot polymerized glass bands. This helps to reinforce the unit against centrifugal forces.

Ring Body

On the non-drive end (NDE) there is a body of slip rings, in a housing separated from the rest of the machine. The rings are integral to the rotor and turn with it, while the brushes remain fixed. The structure is formed of four rings, three for the connection of each of the winding phases and the fourth for grounding the generator rotor, by connecting the corresponding brush of the ring to the machine cover. When the shaft rotates, the slip rings (secured to the rotor) and the brushes (secured to the cover) are continuously in contact ensuring the current connection between the rotating element and the fixed element.

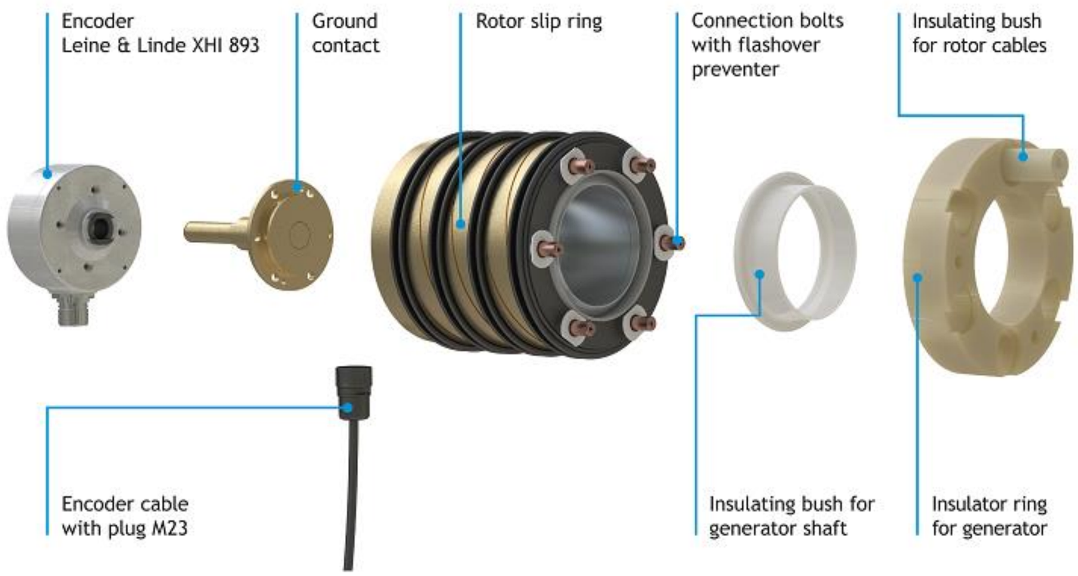


Figure 38. Ring body components

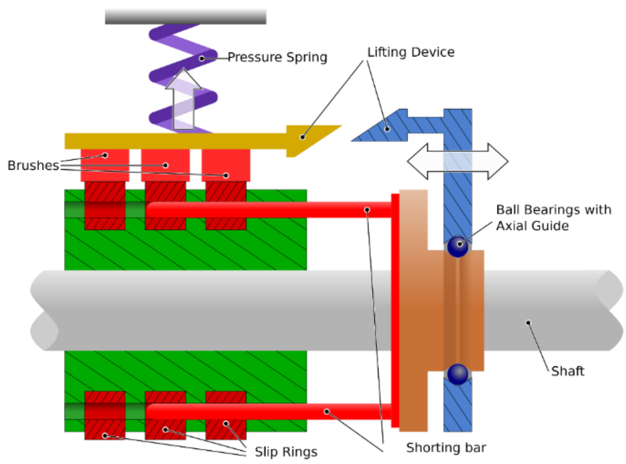


Figure 39. Slip ring body connection to the shaft

Cooling:

The generator is air cooled. There is a hot air cooler which cools the interior air. This cooler is fitted on the cover and has a fan (on the DE) to circulate the air towards the rear of the generator.

The “hot” air inside the generator circulates without escape and is driven by two fans located on the cover at the NDE.

The slip ring chamber also has an additional fan. Depending upon the model of generator, this may be an electric fan or a mechanical fan (connected to the rotor shaft).

The generator has a generator cooling system which consists of an internal circuit where the air circulates and an external circuit which takes air from outside and cools the air in the internal circuit. The fans of these circuits may operate at low or high speed depending upon the temperature of the windings.

Auxiliary measuring instruments:

There are different auxiliary components to monitor the generator operation. These are as follows;

- Temperature control of stator windings which is done with the help of Pt100 probes mounted on the groves (1 or 2 per coil).
- Temperature control of bearings with the help of Pt100 probes one on each bearing.
- Temperature control in the slip ring chamber with the help of one Pt100 probe.
- Heating of the slip ring chamber with the help of resistances.
- Encoder, mounted on the NDE, on the front section of the slip ring chamber which provides information about the angle of the shaft and the speed of the generator.
- Inductive sensor to measure the speed of the generator. (It is redundant)

Electrical Connections:

- a) Stator connection box: The stator power connection box is located on the left side of the generator. It has 6 plates with 2 connection points per phase, U1, V1, W1, U2, V2 and W2.
- b) Rotor connection box: Located in the slip ring chamber. There are 3 plates with 4 connection points per phase, K, L and M.

1.2.4.2. Service hoist / Service crane

Electric chain hoists are used to carry out maintenance work on windmill machinery and for lifting spare parts. The hoist can be mounted to a jib crane within the nacelle of the turbine. Using the hoist for service allows maintenance staff to safely raise and lower turbine appliances for repair or replacement through the hub, as opposed to accessing the nacelle through the hatch or along the tower.

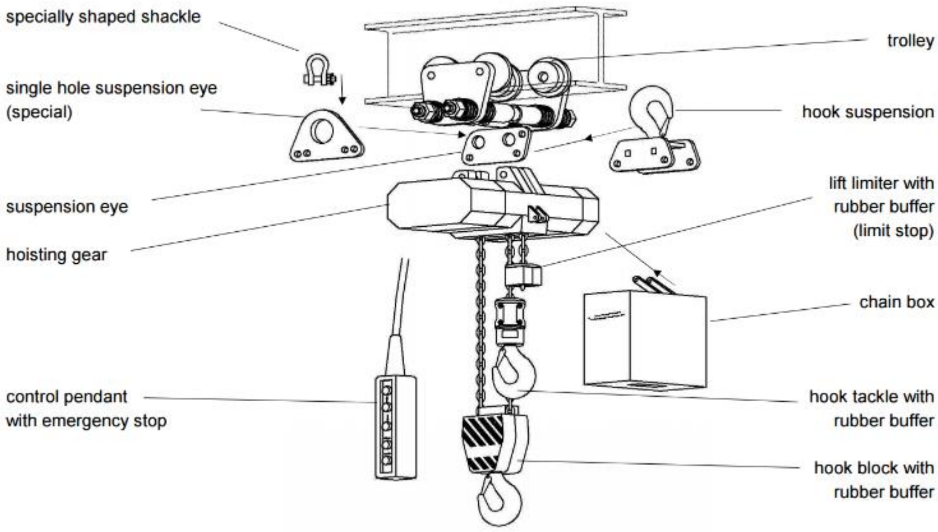


Figure 40. Hoist crane

1.2.4.3. Yaw system

The WTG uses an active yawing wind-directing method. Based on the data collected by wind vane, the main controller calculates the deviation between wind turbine and wind direction and then starts the yaw motor to turn the wind turbine up to be oriented to the wind. After of that, the yaw system brakes act, to fix it into the wind.

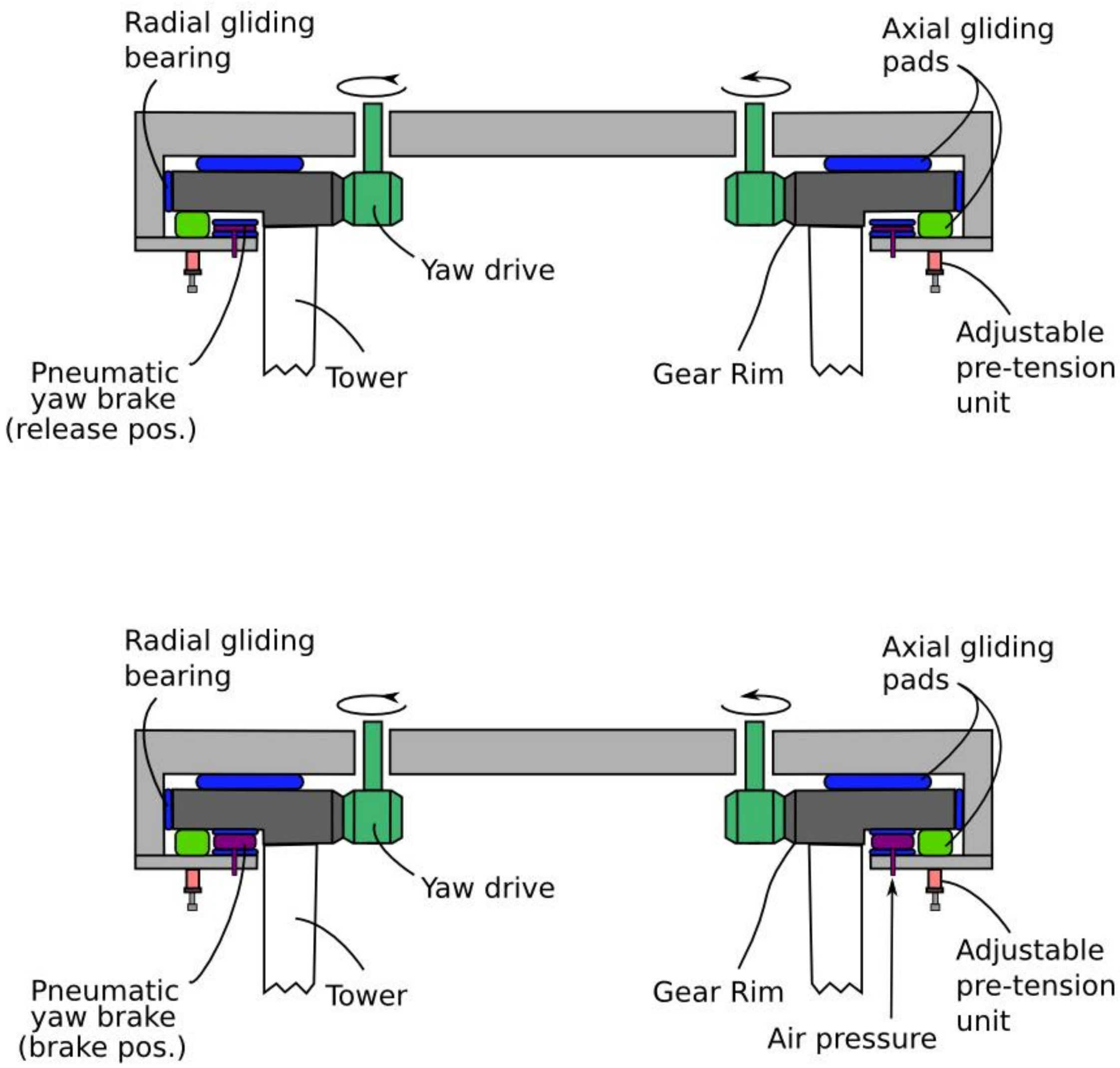


Figure 41. Yaw system location and operation

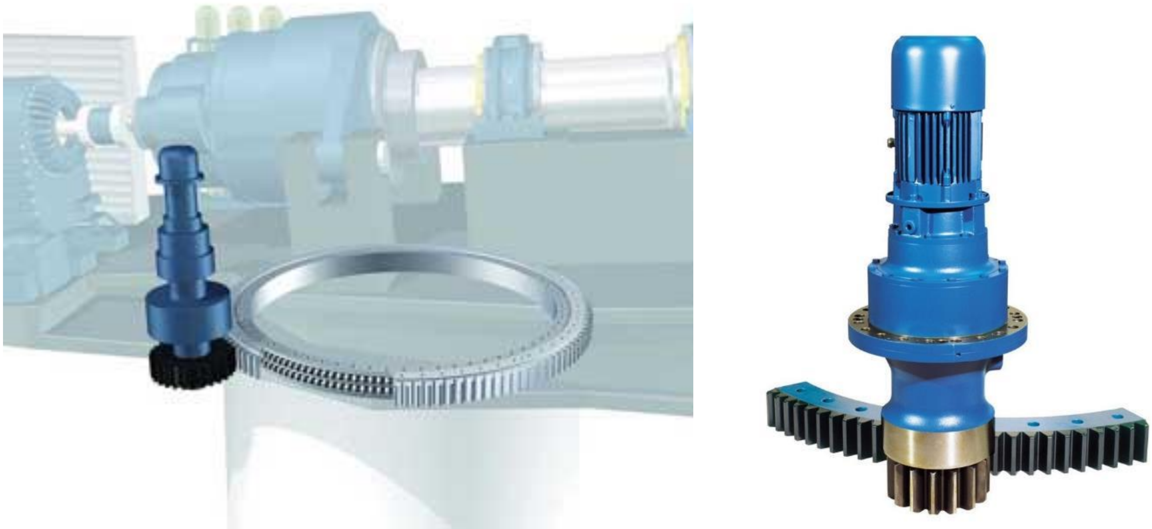


Figure 42. Yaw gear and yaw motor

The yaw system is composed by yaw motor, reducer, position sensor, yaw system grease refilling device, felt tooth lubricator, shaft, brake, disk ball bearing and yaw gear.

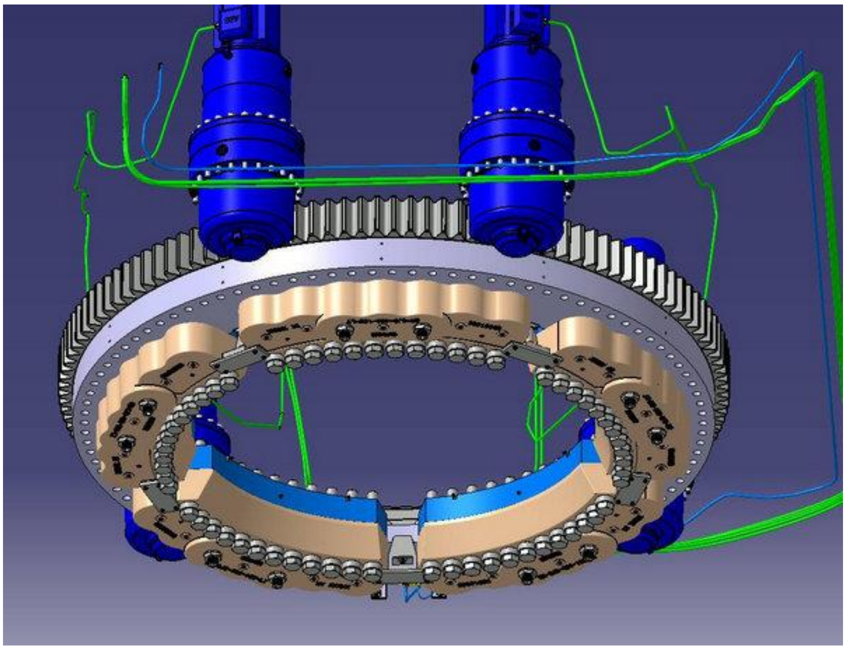


Figure 43. Yaw system

It also has a turn counter which is a ring resistor. The wind turbine gets the data of yaw speed and yaw position by measuring the value of the resistor.

Figure 44. Ring resistor for counting turns

The system has the following features:

- The yaw brake is a hydraulic-drive brake. In idle state, the groups of yaw brakes stabilize the nacelle under a certain pressure; when yawing, the brake still keeps a remaining pressure, so that there is always constant damping in yawing process to make sure that the yawing process is more stable.
- The yaw motor is a multi-polar one, whose voltage class is 400V. It has an electromagnetic brake on the driving shaft, as a failure protection. In case of external failure, the electromagnetic braking system can make the yaw system still under stable and reliable braking condition.
- The yaw system mainly includes several yaw driving mechanism, a specially designed four-point contact ball bearing with external gear ring, yaw protection and a set of yaw brake mechanism. The four-point contact ball bearing designed with “zero clearance” is used for the yaw bearing to increase the smoothness of operation of the complete machine and enhance the resistance to impact load

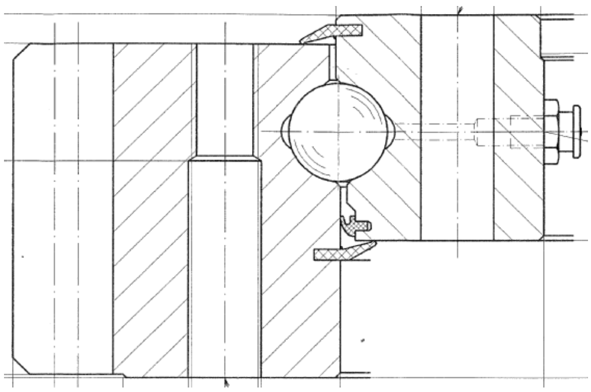


Figure 45. Yaw gear section view

1.2.4.4. Blades

The primary objective in blades design is to maximize the aerodynamic efficiency.

Effect of Number of Blades

As the number of blades in the wind turbine increases aerodynamic efficiency increases, but in a diminishing manner. When we move from 2 blades to 3 blades design efficiency gain is about 3%. But as we move from 3 blades to 4 blades design, efficiency gain is marginal, about 0,5%.

As we increase number of blades, cost of the system increases drastically. Along with that mechanical design of blades also becomes a difficult affair. With more number of blades, blades should be thinner to be aerodynamically efficient. But blades with thinner portion at the root may not withstand bending stress induced due to axial wind load. So generally, wind turbines with 3 blades which can accommodate a thicker root cross-section are used.

Blade Design

The next big factor which is affecting performance of wind turbine is shape and orientation of blade cross section.

A close look at wind turbine blade will reveal that, it is having airfoil cross sections from root to tip. The driving force of wind turbine is, lift force generated, when wind flows over such airfoils. Lift force will be perpendicular to apparent velocity. Generally, lift force increases with angle of attack. Along with that undesirable drag force also increases. While tangential component of lift force supports blade rotation, drag force opposes it. So, a wind turbine can give maximum performance, when lift to drag ratio is maximum. This is called as, optimum angle of attack. Airfoil cross sections are aligned in a way to operate at this optimum angle of attack.

Even though flow velocity is uniform along the length of the blade, blade velocity increases linearly as we move to the tip. So, angle and magnitude of relative velocity (apparent velocity) of wind varies along the length of the blade. Apparent velocity becomes more aligned to chord direction as we move to the tip.

So, there should be a continuous twist in the blade, so that at every airfoil cross section angle of attack is optimum.

Pitching of Blades

Wind condition can change at any time. So, it is also possible to rotate wind turbine blades in its own axis, to achieve optimum angle of attack with varying wind condition. This is known as pitching of blades.

Blade Length

Next big factor affecting performance of wind turbine is length of the blade. So, it is clear that, a longer blade will favor the power extraction. But, with increase in blade length, deflection of blade tip due to axial wind force also increases. So blind increase in length of the blade may lead to dangerous situation of collision of blade and tower.

With increase in blade length tip velocity increases. Noise produced by the turbine is a strong function of tip velocity. So, it is not permissible to increase blade length after a limit. Other factor which goes against long blades is requirement of huge mechanical structures which leads to heavy investment.

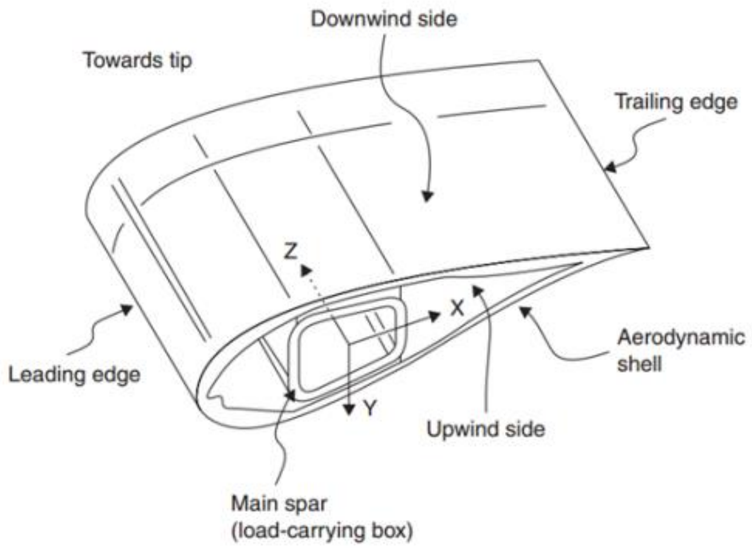


Figure 46. Rotor blade section

The blade is built mainly with a central spar whose main function is the structural resistance, assembled in two shells that give the aerodynamic shape to the group. A damage not controlled in the beam will affect mainly to the resistance of the blade while a damage in the shells will affect first to the aerodynamic efficiency but can also affect to the structural resistance because of propagation. So, it is very important to control damages in blades taken place by normal operation of the wind turbine.

Each blade is built with a lightning conductor system that is able to drive the energy of a lightning stroke from the tip (receptor) to the root where through the structure it is discharged to earth. The correct operation of this system is vital for the integrity of the blade.

Drainages are also installed to evacuate the inside water taken place mainly by condensation or in wind turbine pauses.

Blade coat protects the laminate from the environmental agents specially against humidity and UV.

Materials that are commonly used in a blade are:

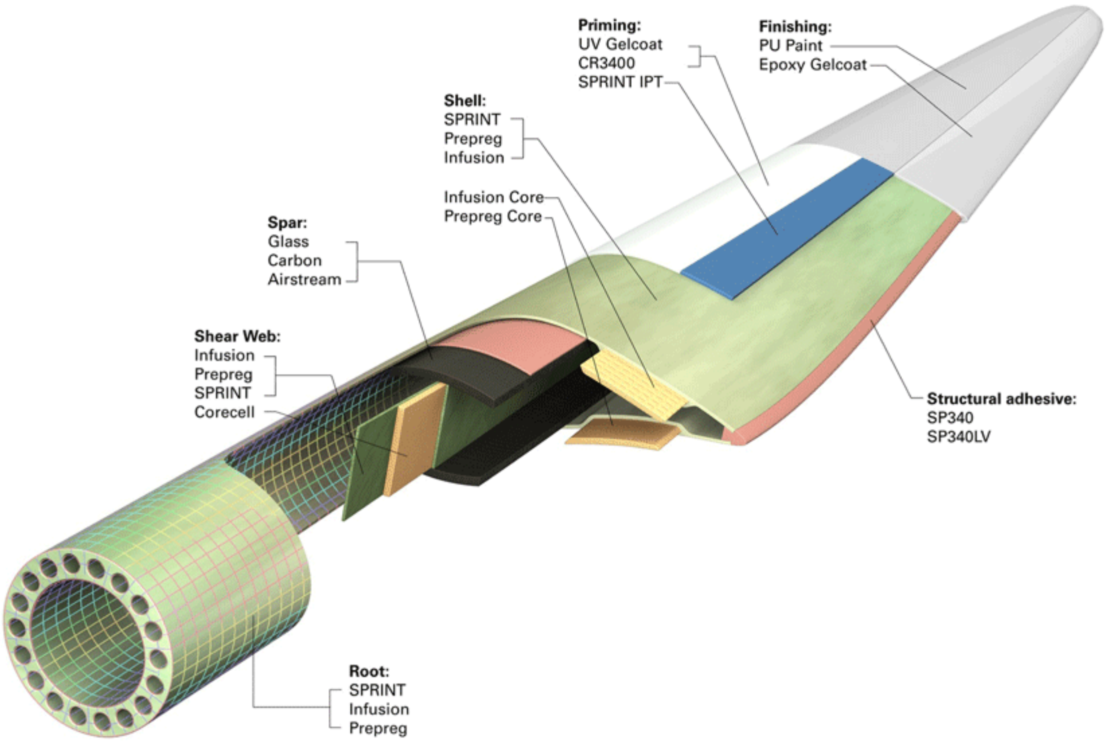


Figure 47. Rotor blade layers

1.2.4.5. Pitch system

Hydraulic pitch system

The turbine is equipped with a pitch system for each blade and a corresponding distributor manifold block facilitating oil supply to the hydraulic cylinders.

The general overview of a typical hydraulic pitch system is:

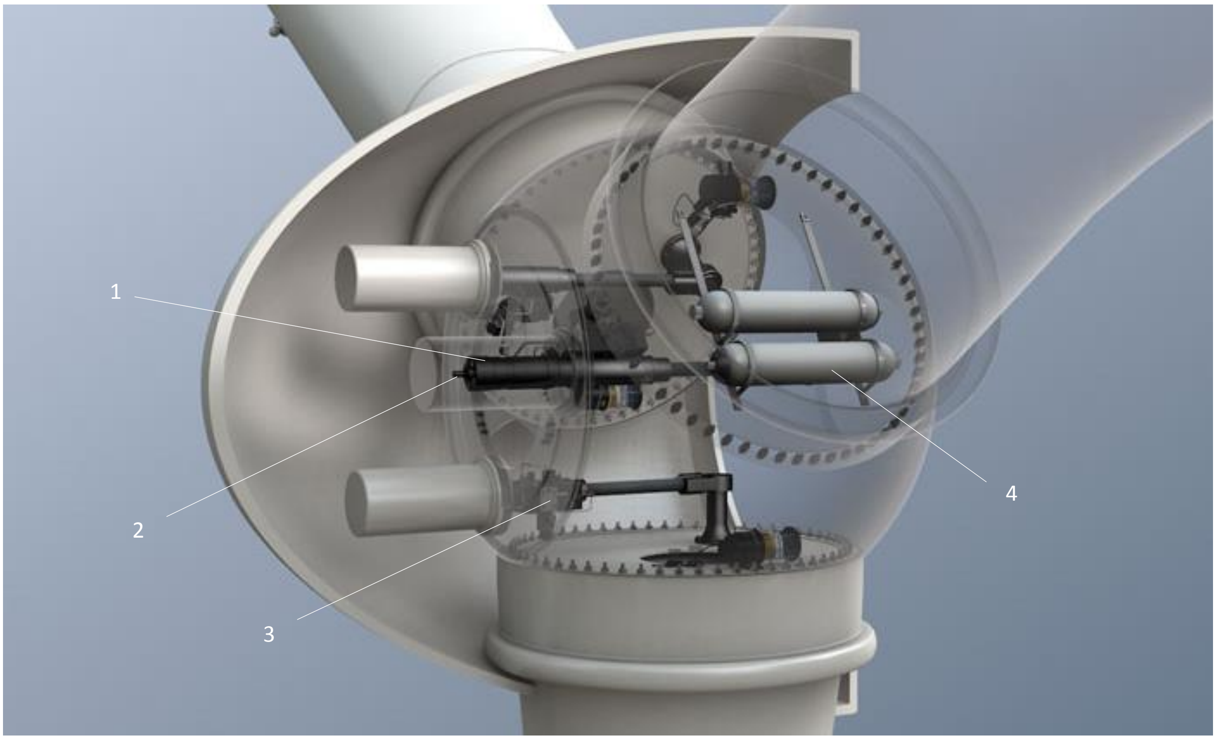


Figure 48. Hydraulic pitch system

- Blade cylinder
- Blade cylinder position transducer
- Cylinder hydraulic manifold
- Accumulator

The hydraulic cylinder acts eccentrically on a plate that is joined to the blade bearing. The eccentricity of the force applied by the piston makes the blade rotating.

Figure 49. Hydraulic pitch cylinder and bearing

Figure 50. Pitch systems and distributor manifold

Pitch systems and distributor manifold are located in the hub. The distributor manifold block is equipped with a filter with by-pass valve and visual and electrical contamination indicator.

Via two hoses (pressure line and return line) in the main shaft cavity, the distributor manifold is connected to the rotating union on the gearbox backside.

Each pitch system is composed of a cylinder linked to the hub and with piston rod connected to a crank pin on the blade root. Valves facilitating operation of the pitch cylinder are installed on a manifold block bolted directly onto the cylinder.

Each pitch system is able to pitch the corresponding blade to any position in the range -5° to +90°. In SERVICE mode it is possible to operate the pitch systems individually. When in NORMAL OPERATION, the systems are working as individual systems making attempt to respond synchronously the common pitch reference angle.

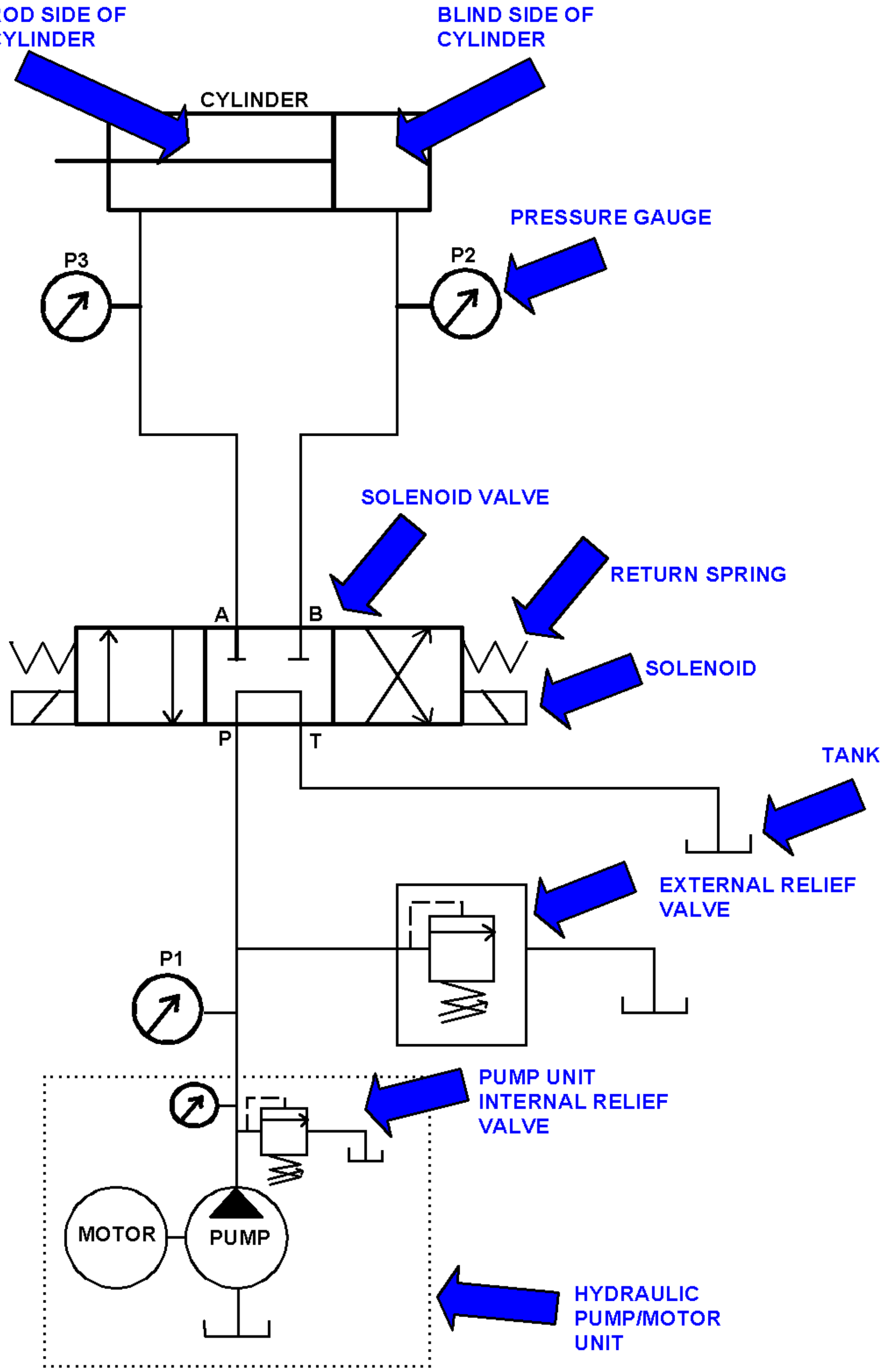

ROD SIDE OF CYLINDER
BLIND SIDE OF CYLINDER
CYLINDER
PRESSURE GAUGE
P3
P2
SOLENOID VALVE
RETURN SPRING
A
B
SOLENOID
P
T
TANK
EXTERNAL RELIEF VALVE
P1
PUMP UNIT INTERNAL RELIEF VALVE
MOTOR
PUMP
HYDRAULIC PUMP/MOTOR UNIT

Figure 51. Hydraulic pitch system circuit

The operation of the pitch system is:

Run Pitch Towards -5º

In RUN mode and PAUSE mode each pitch system is working as below:

Solenoid valves are energized, and the proportional valve is pressurized from the power unit via rotating union and distributor manifold.

Energizing proportional valve to “cross connection”, oil is sent through check valve to the B-port of the cylinder. The piston moves to the right to pitching the blades in direction -5 deg. Oil from right hand end of the cylinder is returned to tank through the solenoid valve and the proportional valve.

Run pitch towards +90º

Solenoid valves are energized, and the proportional valve is pressurized from the power unit via rotating union and distributor manifold.

Energizing proportional valve “straight connection”, oil is sent through solenoid valve and into the right-hand end of the cylinder. The piston moves to the left equivalent to pitching the blades in direction +90 deg. Oil from left hand end of the cylinder is returned to the pressure line through check valve and solenoid valve. The different left and right-hand piston area is the reason to the piston is moving to the left.

Stop and Emergency Stop

In STOP mode and EMERGENCY STOP mode each pitch system is working as below:

Solenoid valves are de-energized, and oil thus sent from accumulator through the flow control solenoid valve and check valve to A-port of the cylinder. Cylinder B-port is drained to tank through solenoid valve and overcentre valve.

The overcentre valve is kept in open position by pilot pressure from the cylinder in the A-port. In case of external forces pulling the piston rod while emergency feathering, the cylinder A-port pressure will drop. Thus, also the pilot line pressure drops and thereby makes the overcentre valve gradually closing. That prevents too high pitch velocity.

The pilot line is equipped with a diaphragm accumulator to reduce pulsations. On the tank line from overcentre valve the accumulator is mounted to absorb pressure peaks. The blades are pitched to mechanical end position in +90 deg. Without influence from the proportional valve at all. Check valve only allows oil flow into the pitch cylinder. Pitch forces from the wind will not be able to return oil from the A- port end of the cylinder into accumulator and thus pitch the blades in direction of -5 deg.

In STOP the pump continues to run on/off automatically. Emergency feathering is therefore performed by oil partly from accumulators, partly from accumulators and partly directly from the pump.

In case of EMERGENCY STOP, the pump is switched off immediately, and emergency feathering is performed only by oil from accumulators. The oil accumulated in accumulator is sufficient for a full stroke.

Emergency feathering velocity is controlled by the two valves and is limited to approx. 10 deg./sec.

Rotating Union

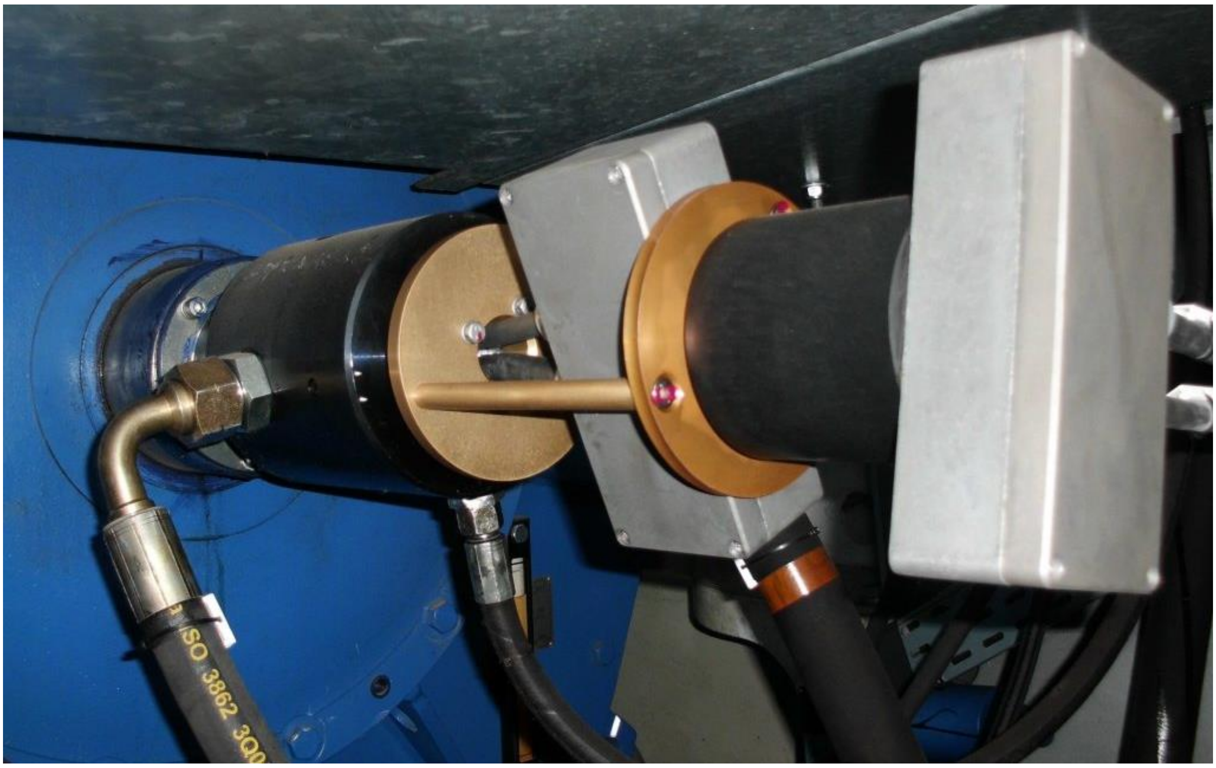


Figure 52. Pitch rotation system

Oil for the pitch system is supplied from the power unit via a dual channel rotating union behind the gearbox, through hoses in the gearbox and the main shaft to the pitch systems in the hub.

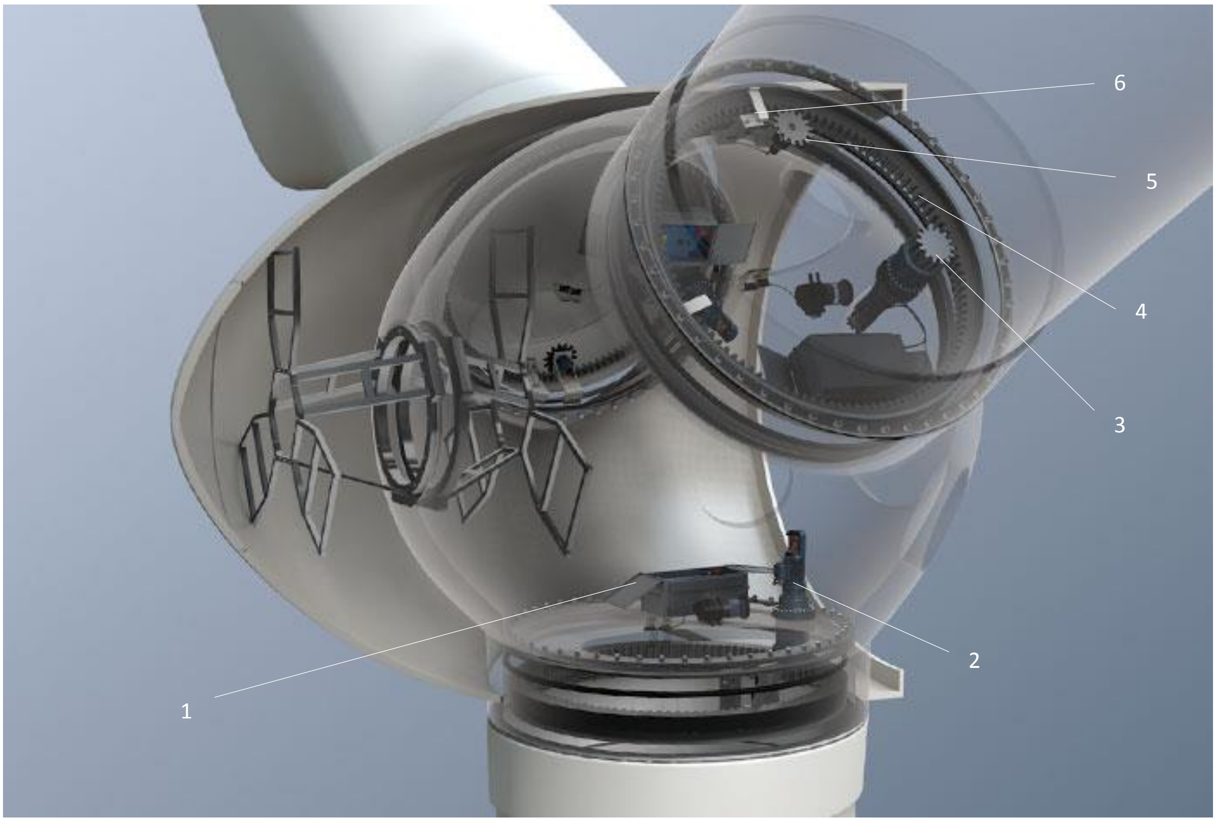
The rotating union is a dual channel type with pressure line and return line. The rotating union is equipped with hydrostatic bearings in both channels to provide sufficient oil supply for the bearings. A spring-loaded check valve ensures a minimum pressure in the return line.

Drain oil from the hydrostatic bearings will continuously be returned to the reservoir through the drain line.

When the rotating union is blocked a circuit has been foreseen upstream from the rotating union to the tank. The circuit is equipped with a bursting disc which bursts when the pressure arrives to 140 bars and allows the oil to pass to the tank. The system composed by the accumulator, spring loaded valve and safety valve, stabilizes the pressure to avoid a fatigue fracture of the bursting disc.

Electric pitch system

The general overview of a typical electrical pitch system is:



1. Battery/control box (one per blade)
2. Electric drive with gearbox
3. Pinion
4. Gear
5. Turning Speed and position Redundant-control
6. Limit switch

Figure 53. Pitch electric system components

The system sets the blade angle through pitch motor control, responding to pitch speed commands from the turbine controller programmable logic controller (PLC).

The system returns the calculated angular position of the blades back to the turbine controller, allowing it to regulate rotor speed and torque. For the turbine to be operational, all three blades must be actively controlled. It features a high-speed networked Ethernet diagnostic input/output (I/O) and CAN bus connection for control and diagnostics. Diagnostic fault messages and predetermined feedback signals are available to the communications networks for control, trending, and diagnostics. Power and hard-wired interlocks are wired from the Top box through the slip rings to the Pitch box controller.

The PLC Controller sets the axis speed reference, enables the Pitch to go to speed command, and controls the Pitch brake in software. With the commands and reference from the PLC controller, the Pitch system regulates motor speed and torque. The motors have integral brake and incremental encoder.

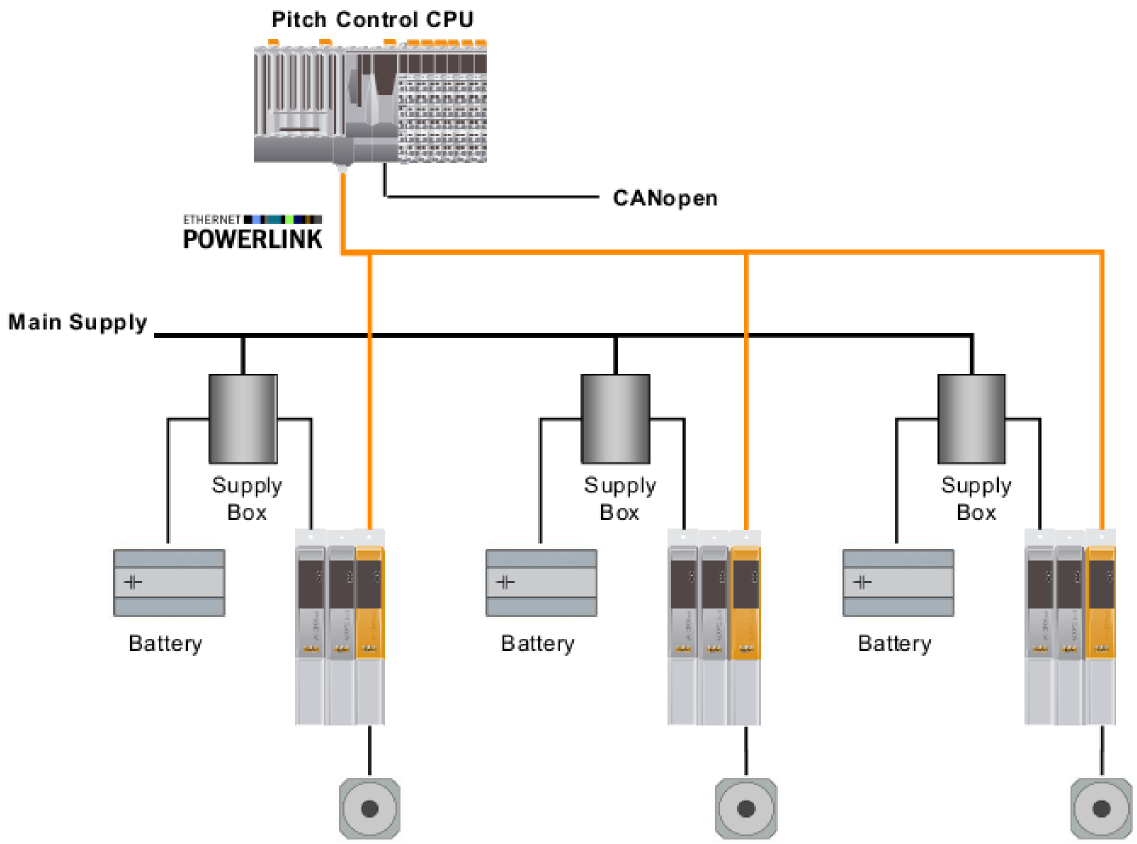


Figure 54. Pitch control diagram

The system provides emergency feathering from a grid or battery supply. A hard-wired control signal or CAN bus signal over the slip rings from the Top box activates the emergency feather system. If at least two of the three blades feather to the 90° position, the turbine slows to a safe speed. The pitch system will have three modes of operation. Each of these modes is capable of feathering the blades and bringing the turbine to a stop or safe speed.

- The first mode is normal operation. In this mode the turbine controller supplies each of the three blade controllers with speed references via the CAN Bus. The turbine generally shuts down gracefully with minimum stress on the tower. This is the preferred mode of shutting down the turbine and is generally used when there are no failures in the pitch system, turbine controller, and CAN communications.

- The second mode is controlled profile feathering operation. In this mode each axis controller follows a predefined speed profile until the 90 or 95 degree limit switches are reached. This mode is initiated by the loss of the safety loop or the turbine controller via CAN bus. This mode is normally powered by the grid. If the grid supply is lost, it operates on battery power by connecting batteries to the DC Link via diodes. Grid power usage immediately resumes if the grid power returns.

- The third mode is direct battery drive operation. This is a redundant safety system and feathers the blades automatically when other modes fail. This mode directly connects the batteries to the motor with contactors until either the 90 or 95 degree limit switch activates. This mode is initiated if the controller detects an internal failure. The turbine controller can force a transition to a direct battery drive over CAN bus if the minimum profiles performance is not met. Also, turbine controller initiates this mode over CAN bus during battery test.

The turbine has a brake on the rotor that is capable of holding a stopped rotor (secondary brake). Emergency feathering protects the turbine during high winds.

1.2.4.6. Evaluation test

Blades and pitch system

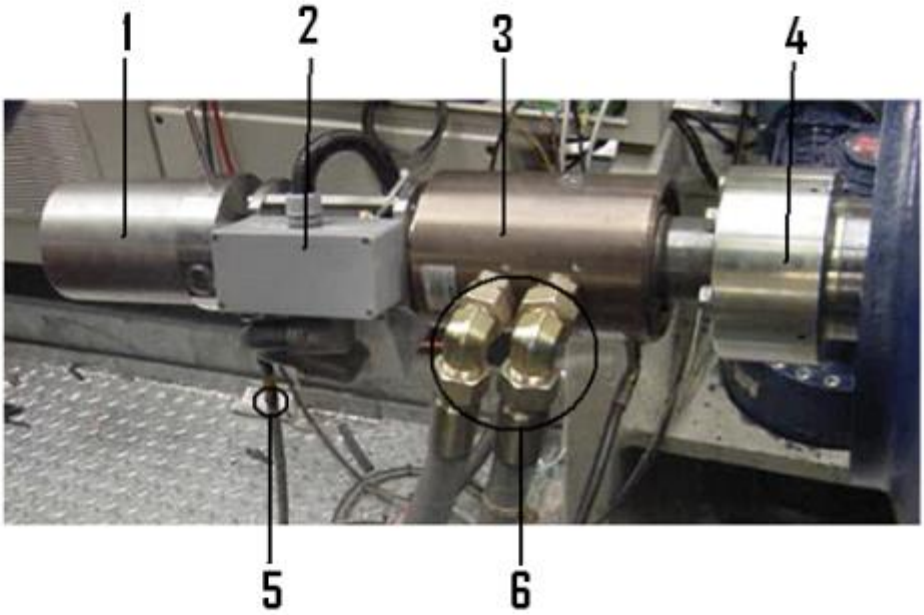
Balluf

In a balluf change is necessary some settings for a proper operation.

Indicate which of the following questions relating with the setting are true or false

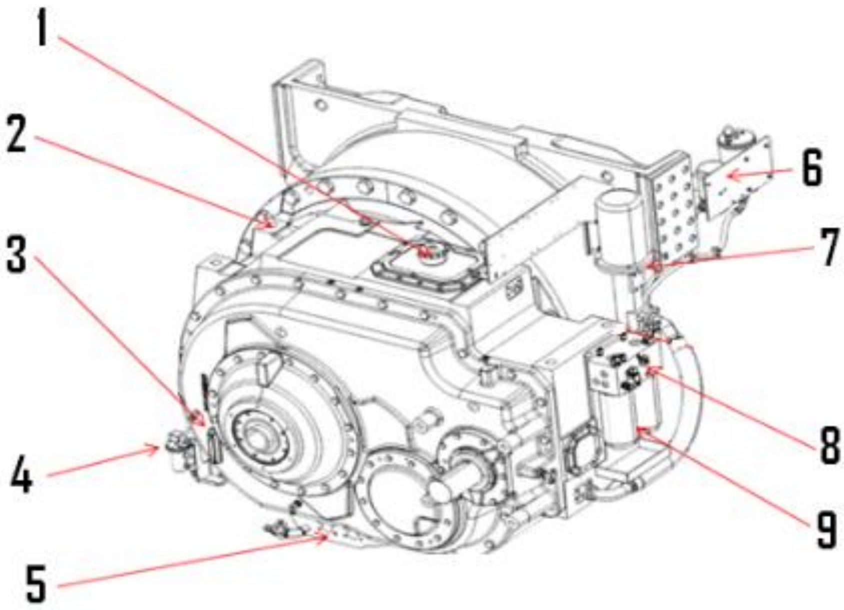
- Is regulated; by positive and negative limits independently of incorporate the blade angle of 87º or not.
- Is regulated adjusting the TC of the blade, screwing or unscrewing the cylinder on the connecting rod.
- Both positive and negative limits are regulated.
  Positive limit: We press the grey button for 4 seconds and without press we press the blue button during other 4 seconds then we no press and now this is unlocked, adjust it according to the needs (blue button up, grey button down)
  Negative limit: We press the blue button for 4 seconds and without press we press the grey button during other 4 seconds, then we no press and this is now unlocked, adjust it according to the needs (blue button up, grey button down)
- All the previous answers are true.

1) Match components with their description in the following image



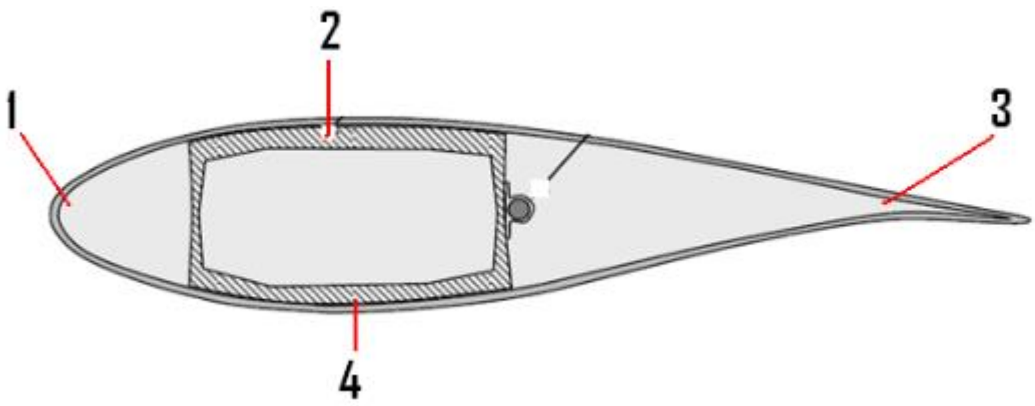
6	a)	Pressure and return hoses
4	b)	Rotative joint adapter
3	c)	Hydraulic rotative joint
5	d)	WA-78 cable
2	e)	Electrical connections box
1	f)	Electrical rotative joint (also called slip rings)

2) Match components with their description in the following image



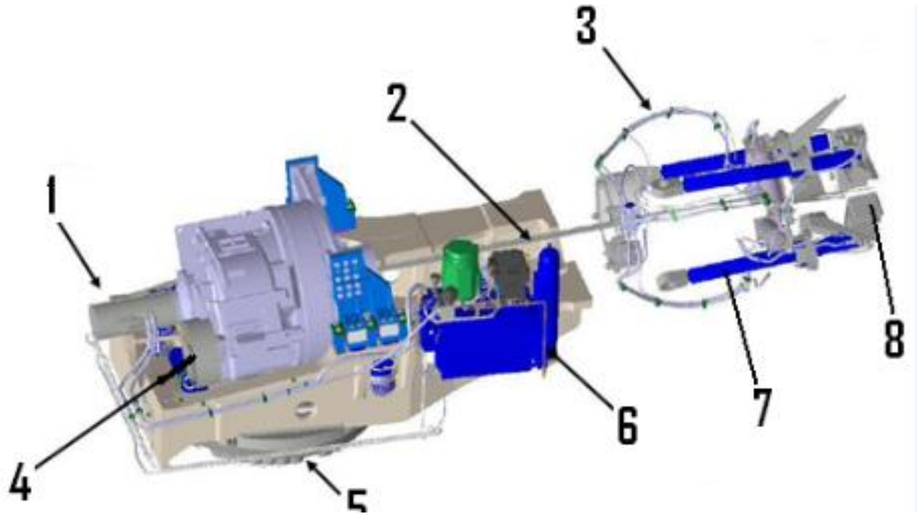
1	a)	Air filter
7	b)	Electric pump
8	c)	Manifold block
2	d)	Magnet
3	e)	Oil level indicator
5	f)	Heating resistor
4	g)	Low oil level sensor
6	h)	Offline filtering system
9	i)	Oil filter (online)

3) Match components with their description in the following image



1	a)	Leading edge
2	b)	Suction Shell
3	c)	Trailing edge
4	d)	Pressure Shell

4) Match components with their description in the following image



4	a)	Brake
5	b)	YAW system hydraulic circuit
1	c)	Rotative joint
8	d)	Blade valve block
7	e)	Pitch cylinder
2	f)	Electric and hydraulic connections through main shaft
6	g)	Hydraulic unit
3	h)	Pitch system hydraulic circuit

1.2.5. Lesson 5 - Hydraulic systems (WTG specific)

The objective of this lesson is to familiarize with the WTG hydraulic systems

During this lesson, the trainee will learn:

(1) To identify and to understand the functionality of the different hydraulic systems

(2) To interpret the hydraulic schematics

(3) How the hydraulic systems work

It is very particular of each manufacturer in the following diagrams are presented general schemes

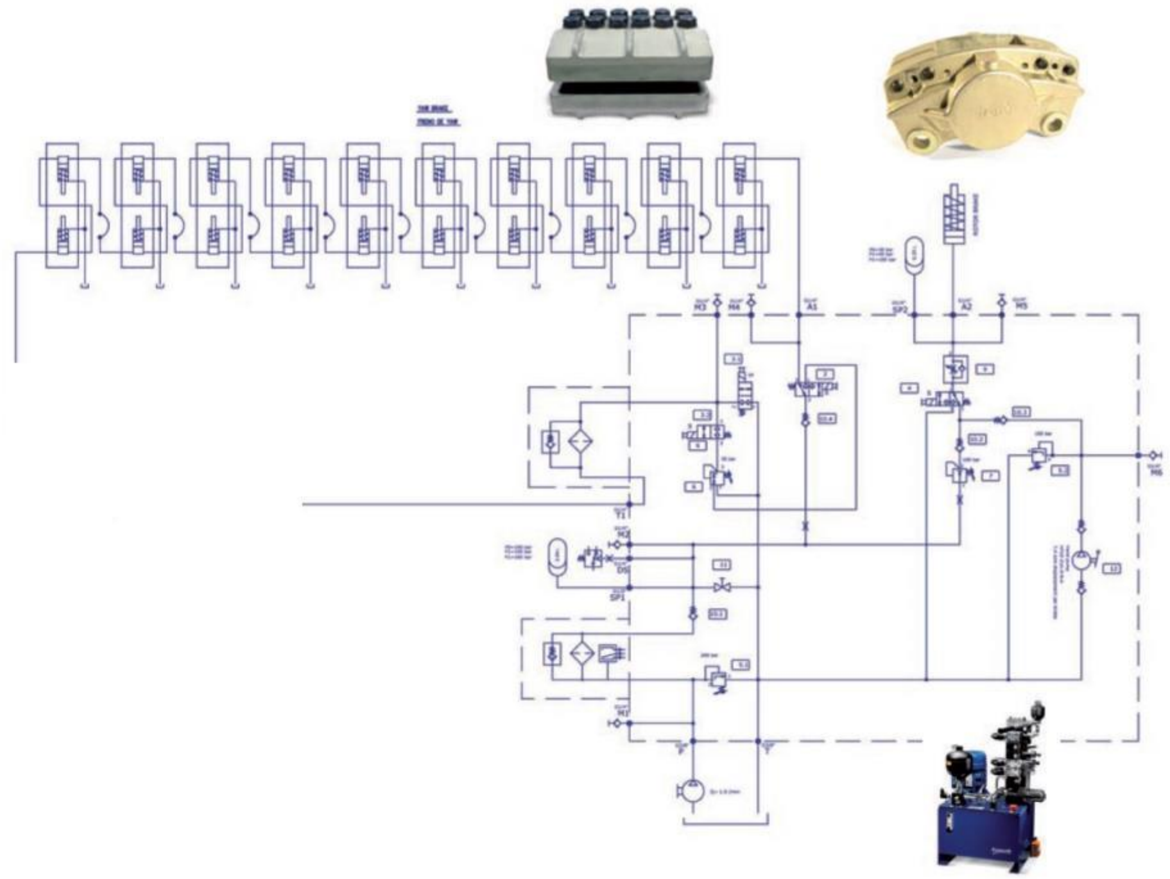


Figure 55: General scheme of the hydraulic system

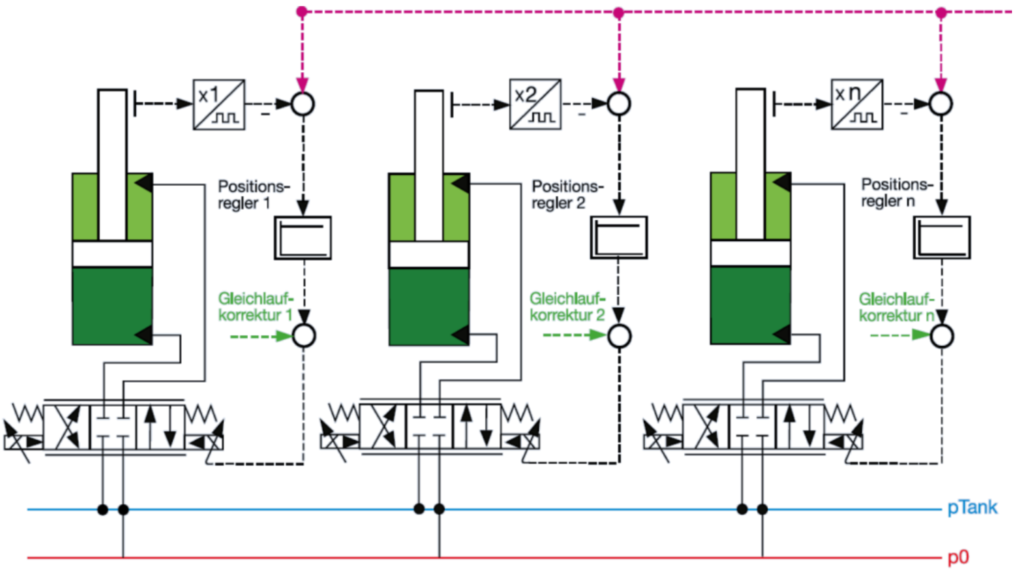


Figure 56: Hydraulic pitch actuators

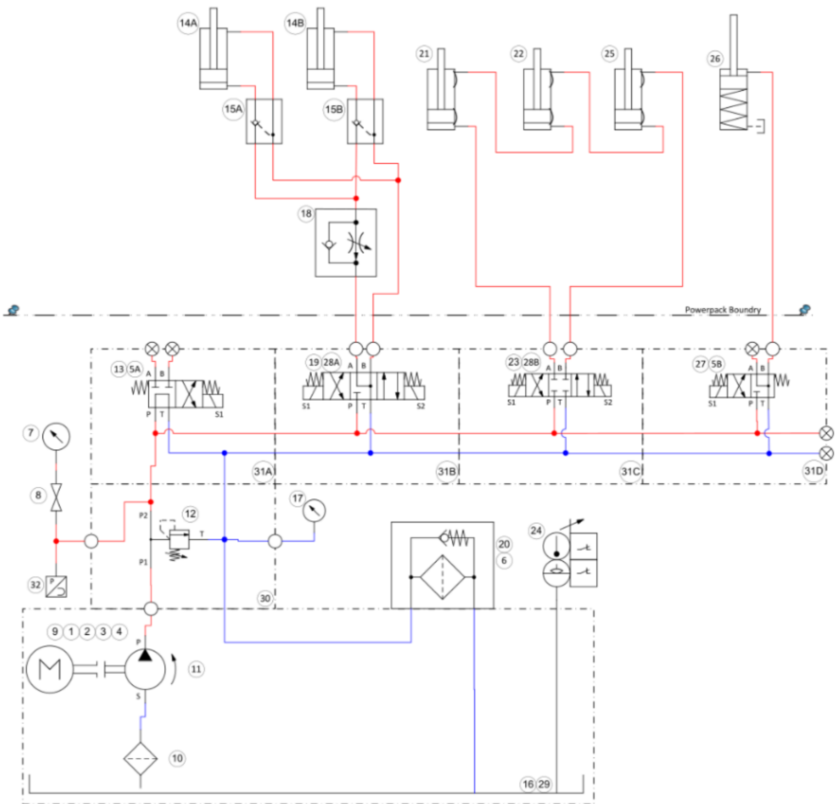


Figure 57. General overview of the hydraulic system

1.2.6. Lesson 6 - Electrical systems (WTG specific)

The objective of this lesson is to familiarize with the WTG electrical systems During this lesson, the trainee will learn: (1) The different electric systems on the turbine, their functions and location (2) The types of transformers and Switchgears (3) The different sensors on the turbine and their functions (4) The importance of the safety line circuit. (5) The generator types and basics

Wind turbine converters are typically designed for use with induction generators with wound rotor and slip rings following this drawing:

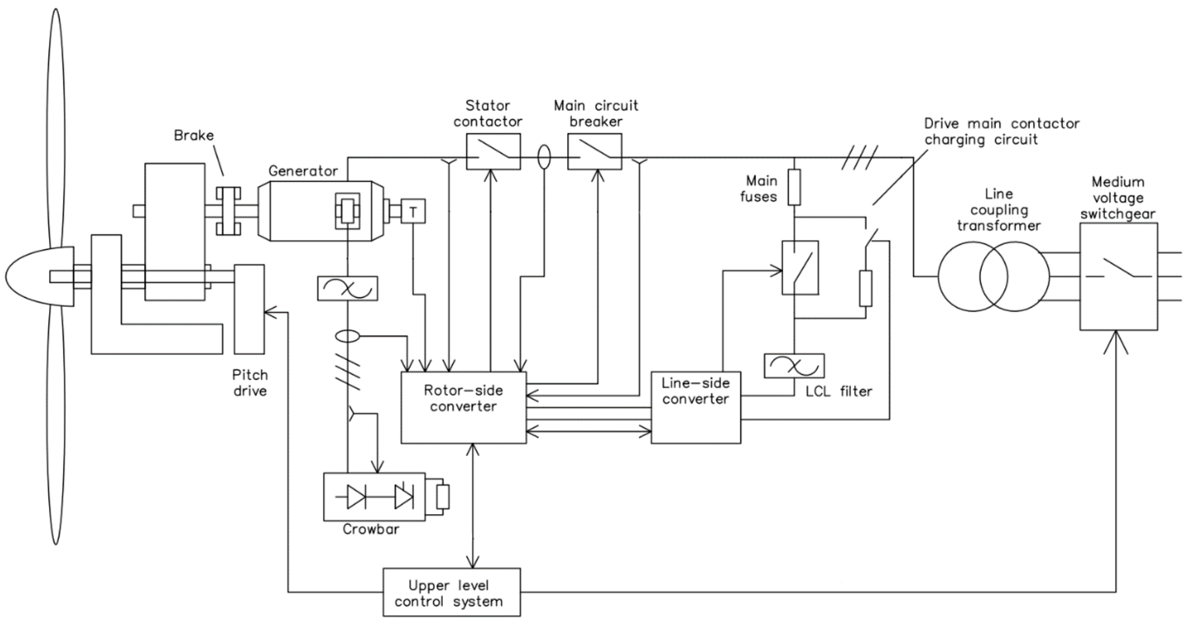


Figure 58. Wind turbine electrical diagram

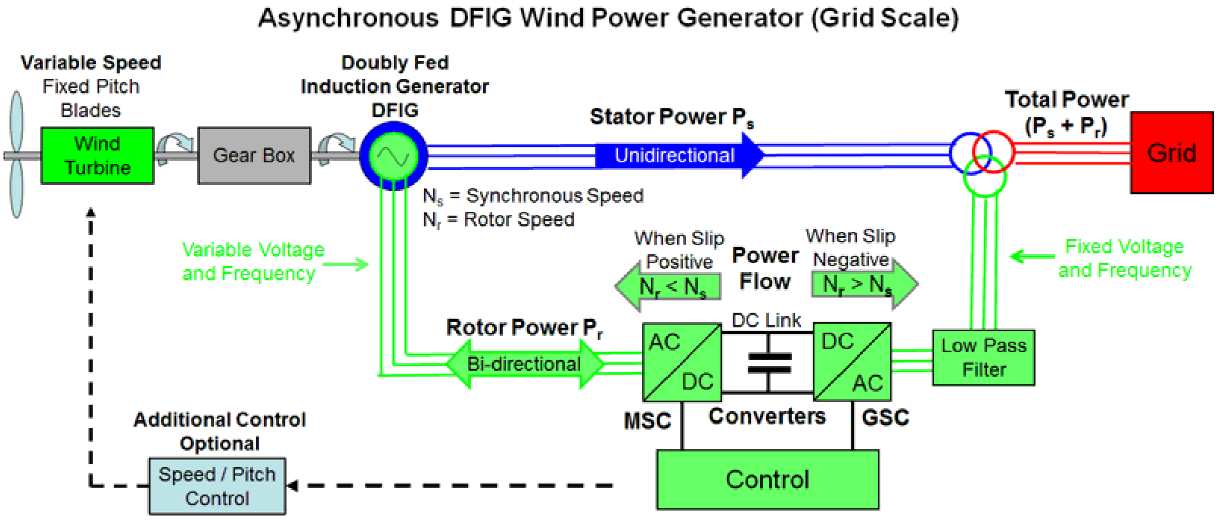


Figure 59. Asynchronous DFIG Wind Turbine Generator electrical diagram

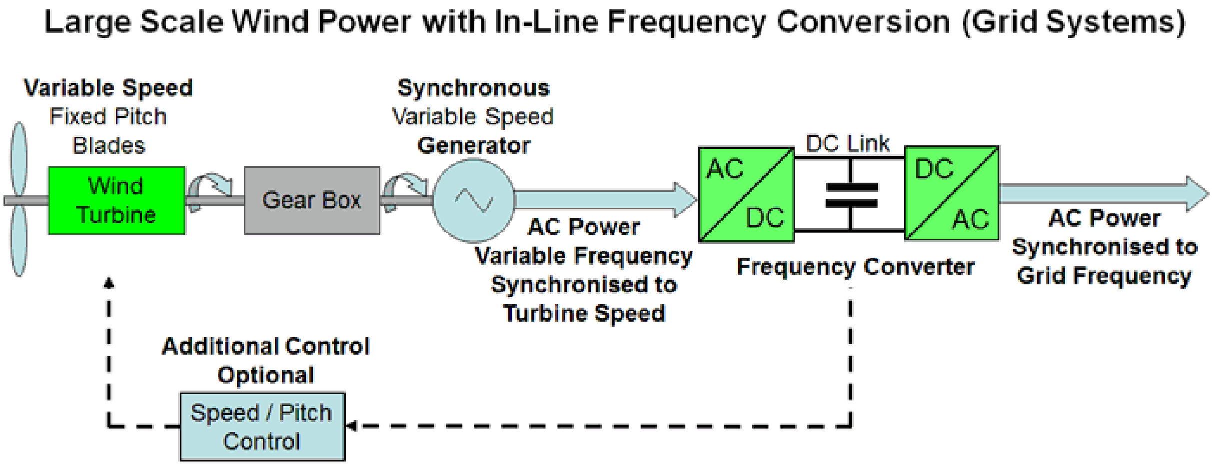


Figure 60. In-Line Frequency Conversion

The converter is connected between the generator rotor and the supply network and it can be installed in the tower base or in the nacelle.

In order to keep the speed optimal (i.e. somewhat higher than the synchronous speed of the generator), the angle of the rotor blades is adjustable by means of a pitch drive. However, adjusting the pitch is fairly slow. To compensate for faster changes in rotor speed, the converter accelerates or decelerates the rotation speed of the magnetic field in the rotor in order to retain the optimal slip. When the wind decreases, the converter takes energy from the supply and accelerates the rotation of the rotor field so that the stator remains capable of feeding energy to the grid. Likewise, the rotation of the rotor field is decelerated at increasing wind speeds. The energy generated in the rotor above the synchronous speed can also be exported to the grid. The converter is also used for synchronizing the stator output with the grid before the actual grid connection. On disconnection, the converter adjusts the torque to zero. This also decreases the stator current to zero so that the generator can be disconnected.

Grid-side and rotor-side converters

The line-side converter is an IGBT based module equipped with AC and DC fuses and optional devices. It has a control unit with IGBT Supply Control

Program. The converter is controlled by the rotor-side converter control unit via a fiber optic link. The line-side converter rectifies three phase AC current to direct current for the intermediate DC link of the converter. The intermediate DC link supplies the rotor side converter. The line filter suppresses the AC voltage and current harmonics.

Typically, the control of the IGBT power semiconductors is based on the Direct Torque Control (DTC) method typically used in motor control of the converter. Two-line currents and DC link voltage are measured and used for the control.

The functions of the other modules can be briefly described as follows:

The generator reactor (du/dt filter) is a combination of an inductor and capacitors and resistors. It reduces the high voltage increase speeds at the output of the generator converter, which can amount to 2 … 3 kV/µs. The arising overvoltage could otherwise cause damage to the insulation of the generator winding.

The line reactor and grid filter ensure that the voltage and current fed into the power supply grid by the grid converter have the required quality, and that the limits for harmonics are complied with.

The so-called Dynamic Brake converts excess energy into heat, thereby protecting the DC link from overvoltage. Excess energy can arise for a short time e.g. after sudden switch-off of the generator contactor or grid contactor.

A main switch is also used. However, this switch functions purely as a protective device against over current; it does not assume any switching function except in case of faults.

Control of the Frequency Converter System

The overriding control system of the WTG specifies the speed and torque of the generator depending on wind conditions. The control electronics of the frequency converter compare these specifications with the measured operating data. As a result, they generate the trigger signals for the IGBTs in the grid converter and generator converter, by means of which the output power is converted, so that the voltage and frequency are in line with the grid, and power can be fed into the grid.

The converter communicates with the PLC via CAN Open and continuously exchanges set values and actual values.

The PLC receives information about the wind direction and speed from the anemometer station. Information about the grid is also processed, in order to be able to optimally integrate the WTG in the grid electrical system.

The so-called warm-up sequence may occur after a grid outage or a restart of the frequency converter if the ambient temperature is too low. The DC links are pre-charged and the control electronics (MACC card, amongst other things) are supplied with voltage only after this warm-up phase, which lasts at least two hours.

In standstill and fault free status the grid side breaker and the generator side breakers are closed, then the converter is in pulse interlock. The capacitor DC-link is charged with open grid side breaker (fault in the CCU) via the pre-resistances and the anti-parallel diodes of the IGBT.

Is the frequency converter fault free and the grid and generator breakers are closed, then the DC-link is charged to around 1020 VDC.

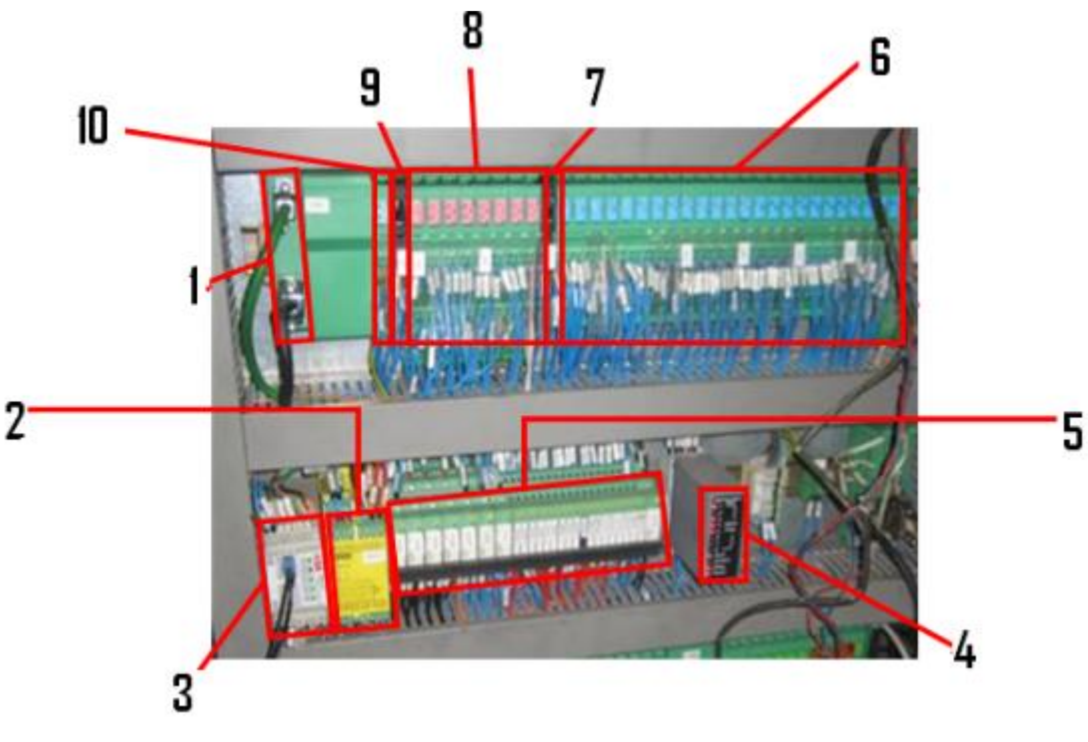
As soon as the wind speed, turbine condition and grid conditions permit start-up of the WTG, the rotor blades are pitched and the WTG starts up. When the generator speed reaches 600 rpm and the enable signal of the controller has been output, the frequency converter is started.

For the start of the system, the frequency converter turns the IGBT from pulse interlock into operation. The grid side converter charges now the DC-link to a voltage level from about around 1070VDC, then the generator side converter starts and fed the generator voltage into the capacitor DC-link. The grid side converter takes away the surplus voltage and fed that into the grid. If during the operation a fault occurs, the control system of the converter shuts the unit down.

During stand still (pulse interlock) the capacitor DC-link almost consumes no energy, no energy consumption or delivery, only exception is the leakage current via the electrolyte capacitors, this is very low.

Additionally, to SKILLWIND game those are a list of questions which can be used to evaluate the level of knowledge of the trainee:

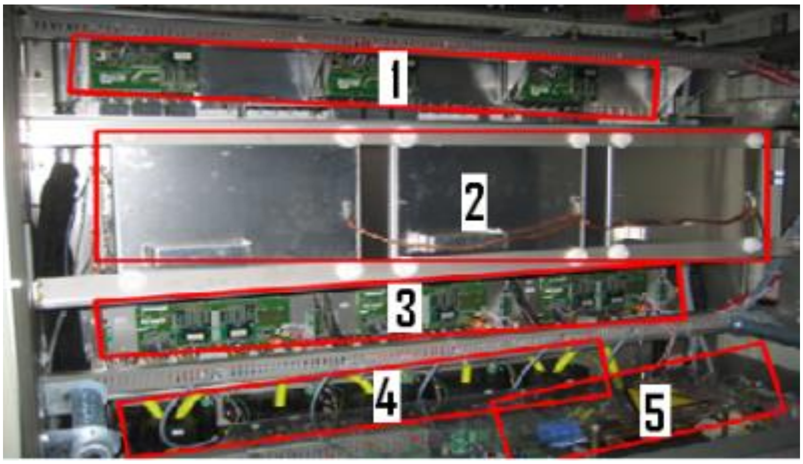
Match components with their description in the following image



3	a) NIBA (connection between bus coupler 2 and 5)
6	b) Digital inputs
4	c) VOG card
5	d) Relays
8	e) Digital outputs
7	f) Electronic fuse
1	g) Bus coupler 5 (communications between TOP and HUB)
2	h) KR919 Emergency series relay

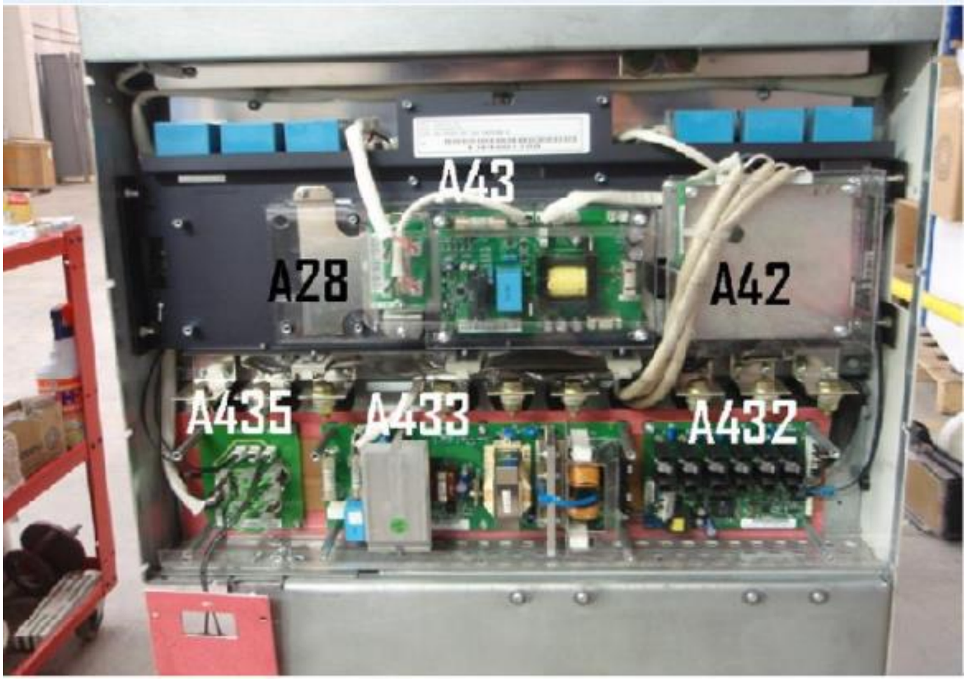
10	i)	Bus coupler power
9	j)	Power in

Match components with their description in the following image



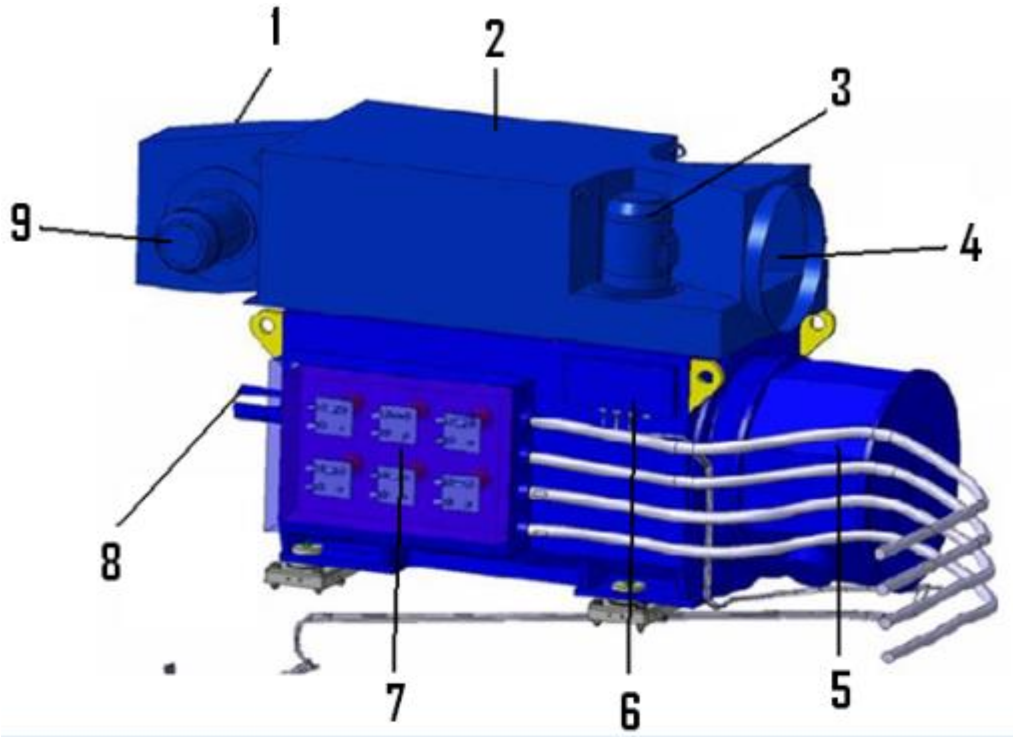
4	a)	Current transformers (TC's)
5	b)	Passive crowbar
1	c)	Inverter
3	d)	Rectifier
2	e)	Capacitors BUS

Match components with their description in the following image



A432	a)	AFIN: Cooling control board
A435	b)	AHCB-01C: heating control board
A28	c)	NRED: safety fuse
A433	d)	AFPS: Power supply for cooling
A43	e)	APOW: Power supply for IGBTs control board
A42	f)	AINT: converter control board

Match components with their description in the following image



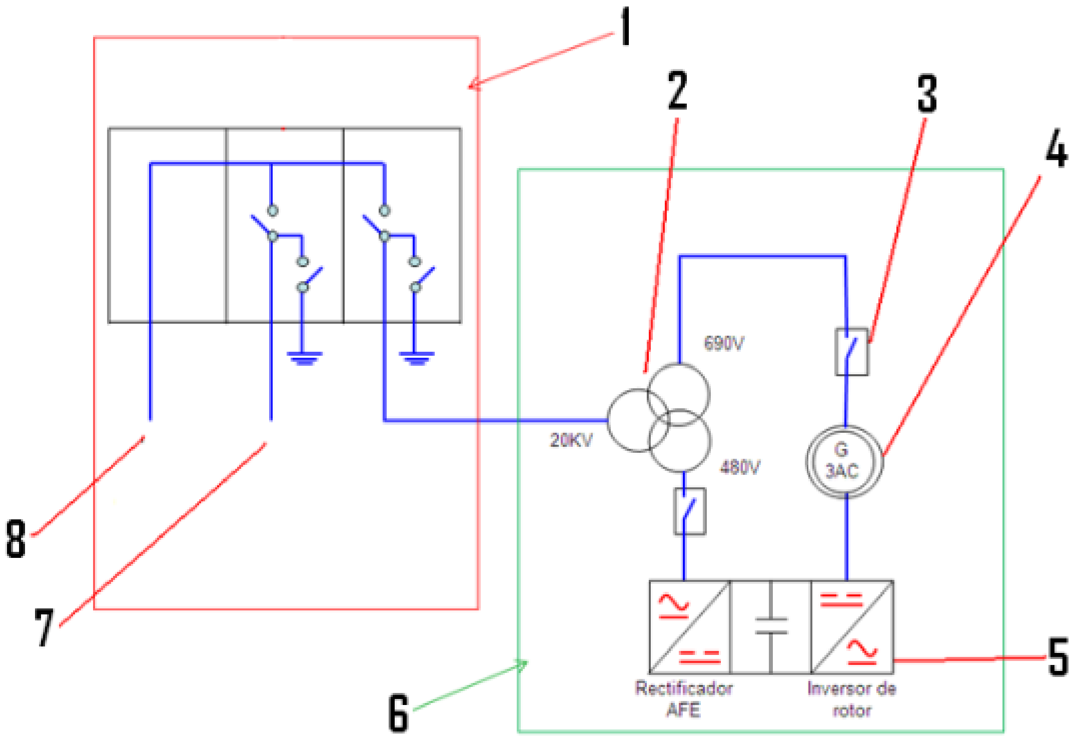
6	a)	Auxiliary connection box
9	b)	External cooling circuit fan
2	c)	Cooling unit
1	d)	Air inlet
3	e)	Internal cooling circuit fan
7	f)	Stator terminal box
4	g)	Exterior air outlet
8	h)	High speed shaft coupling
5	i)	Slip ring box

Brake chopper

Indicate if the next answers about Brake Chopper are true or false.

a) Short-circuit the rotor when the machine raisin to emergency state
b) Support to system smart crowbar
c) Dissipate the power in bus through a resistance
d) Operates independently of the CCU

5) Match components with their description in the following image



1	a)	MW Switchgear
4	b)	Generator
2	c)	Transformer
6	d)	Nacelle
5	e)	Frequency converter
3	f)	FG008 contactor breaker
8	g)	20kV line switchgear module (0P)
7	h)	20kV rise switchgear module (1L)

6) Match the function of each of the following components shown in the pictures

1.

2.

3.

4.

5.

6.

7.

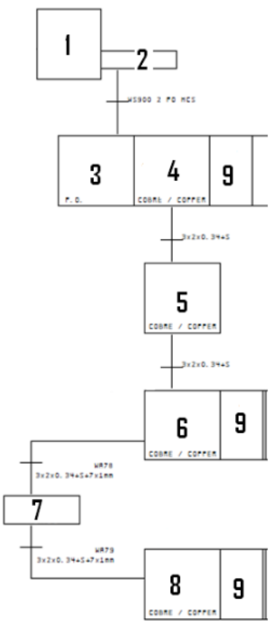
8.

9.

10.

8	a)	Measures windspeed, direction and temperature
7	b)	Measures windspeed and sends the information to a pulse counter module.
1	c)	Detects twisting turns of the nacelle.
6	d)	Detects wind direction.
2	e)	Detects current flow through neutral cable
5	f)	Measures rotor position and generator rpm's
9	g)	Resistor varying as temperature changes
10	h)	Arc detecting system by using a photovoltaic sensor.
3	i)	Linear position sensor that indicates cylinder movement.
4	j)	Devices that prevent wind turbine problems due to overcurrent and overvoltage

7) Match components with their description in the following diagram



5	a)	Headboard 4 (communication converter)
8	b)	Headboard 6
3	c)	Bus coupler 2
2	d)	OPC
1	e)	CPU
6	f)	Headboard 5
4	g)	Headboard 3
9	h)	Power-in
7	i)	Rotative joint

8) Indicate if the following sentences are true or false (T or F)

T	a)	Main task of the emergency electro valves is to turn back blade from 0º to 90º in case of power loss
T	b)	Pressure switches are set to a certain pressure. In case of pressure drop below this value, state changes into emergency and normal function cannot be achieved unless pressure rises this value.
F	c)	Every manifold block of the blade contains 4 Normally Open (NO) electro valves.
T	d)	Every manifold block of the blade contains 2 Normally Open (NO) and 2 Normally close (NC) electro valves.

1.2.7. Lesson 7 - Communications and control

The objective of this lesson is to realize the different aspects of control and communications.

During this lesson, the trainee will learn:

(1) The WTG control system

(2) The Scada System and its features

(3) Get familiar with the WF internal and external communications systems

1.2.7.1. The SCADA system and its features

It is a software for computers that allows to control and supervise industrial procedures from a distance. It provides feedback in real time of field devices (sensors and actuators) and controls the procedure automatically. It supplies all the information that is generated during the generation procedure (supervising, quality control, manufacturing control, data storage, etc.) and allows its management and intervention.

The SCADA stores information in real time of the following field devices:

- Wind turbine generators
- Met towers
- Electrical substation
- Meter boxes

The refreshing period depends on the architecture and device technology and the field connection net.

Wind turbine acquired data:

- Generation data
- Temperature data
- Electrical data
- Atmospheric data
- Events
    - Alarms
    - Errors
    - States

Data sent to Wind Turbines:

- Orders and instructions

Substations acquired data (UCS):

- Electrical data
- Switches and cell states
- Events:
    - Alarms
    - States

Data sent to Substations:

- Orders

Data acquired in Met stations:

- Atmospheric data

Data acquired in Meter boxes:

- Generation data
- Consumption data
- Closing invoices

In base of all the received information, the storage and erasement information politics must be defined, in addition to the definition of all the Key Performance Indicators (KPI). Therefore, in the SCADA data base will be stored not only brute information (generation, meteorological data, voltages, intensities, temperatures, states...), but also calculated information (ten minutes averages, disponibilities, equivalent hours…). Based on this information, the technical reports will be elaborated.

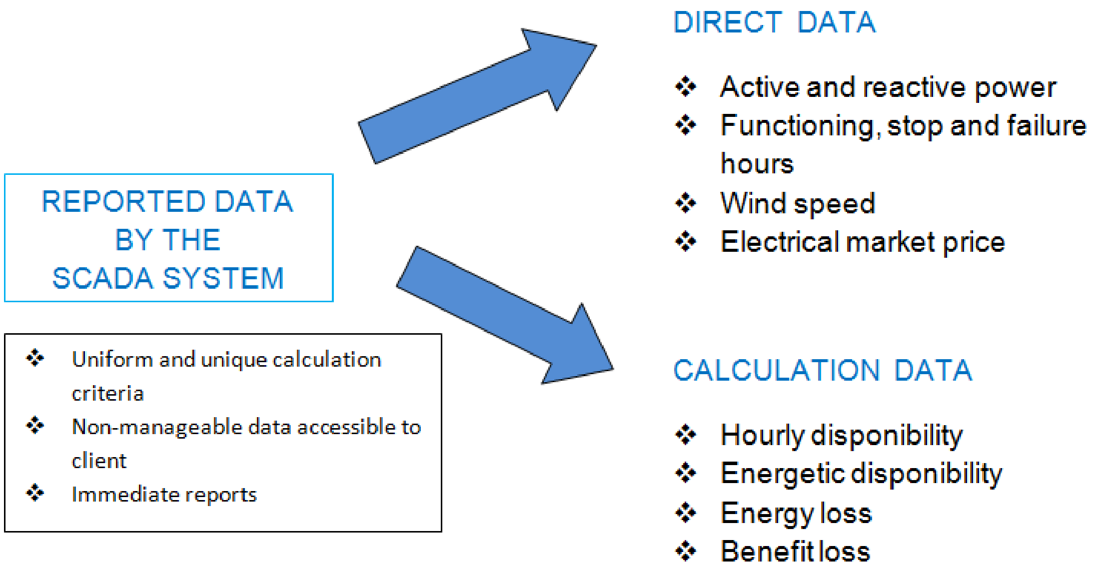


Figure 61. SCADA System functioning summary

Store data devices and local control. SCADA

- Server: Computer that contains SCADA and usually the Data Base. It oversees collecting all the information from the field, processing it, storing it and providing not only the Human Machine Interface but also managing the connections with the Control Centers or Delegate Offices.

Figure 62. SCADA Server

- Firewall: Hardware (or software) that controls, manages and filters the connections and traffic to or from a net. It is a critical security element that prevents non-desirable accesses. All the traffic goes through the Firewall.

Figure 63. SCADA Firewall

- Switch: digital logical device of interconnection of all the equipment in the same net.

Figure 64. SCADA Switch

- Router: Logical device that interconnects nets.

Figure 65. SCADA Router

- UPS (Uninterruptible power supply): this device thanks to its batteries, supplies with electrical energy for a limited period of time. Furthermore, it filters voltage ups and downs, eliminating harmonics.

Figure 66. Uninterruptible power supply (USP)

- Signal converter: it is a device that allows the communication between two different physical means.

Figure 67. SCADA Signal converter

- Viewer equipment: It is the computer that runs the desktop application or web browser that access to the SCADA lodged in the Server

Figure 68. SCADA viewer equipment

The main components of the SCADA and the relationship between them are presented in the pictures below:

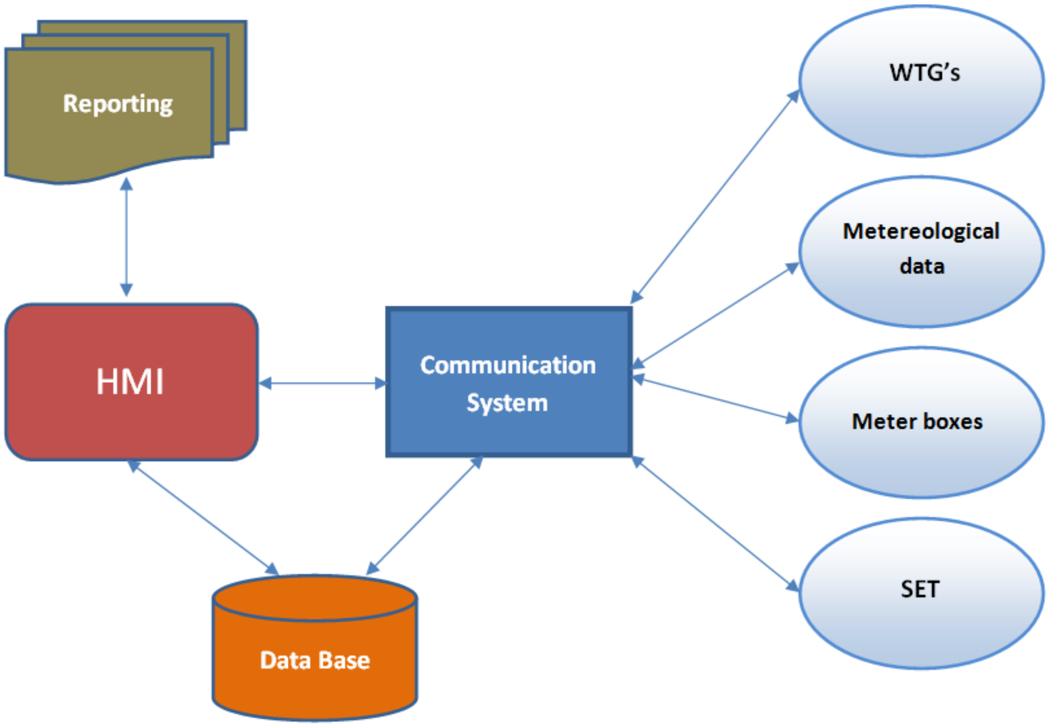


Figure 69. SCADA components

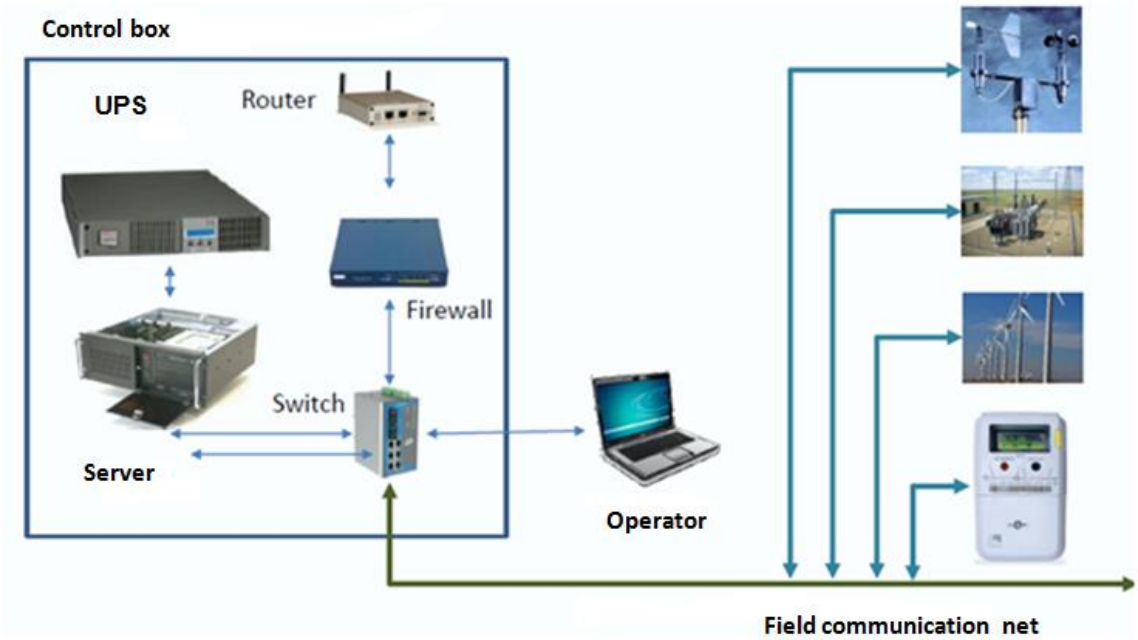


Figure 70. SCADA components communication

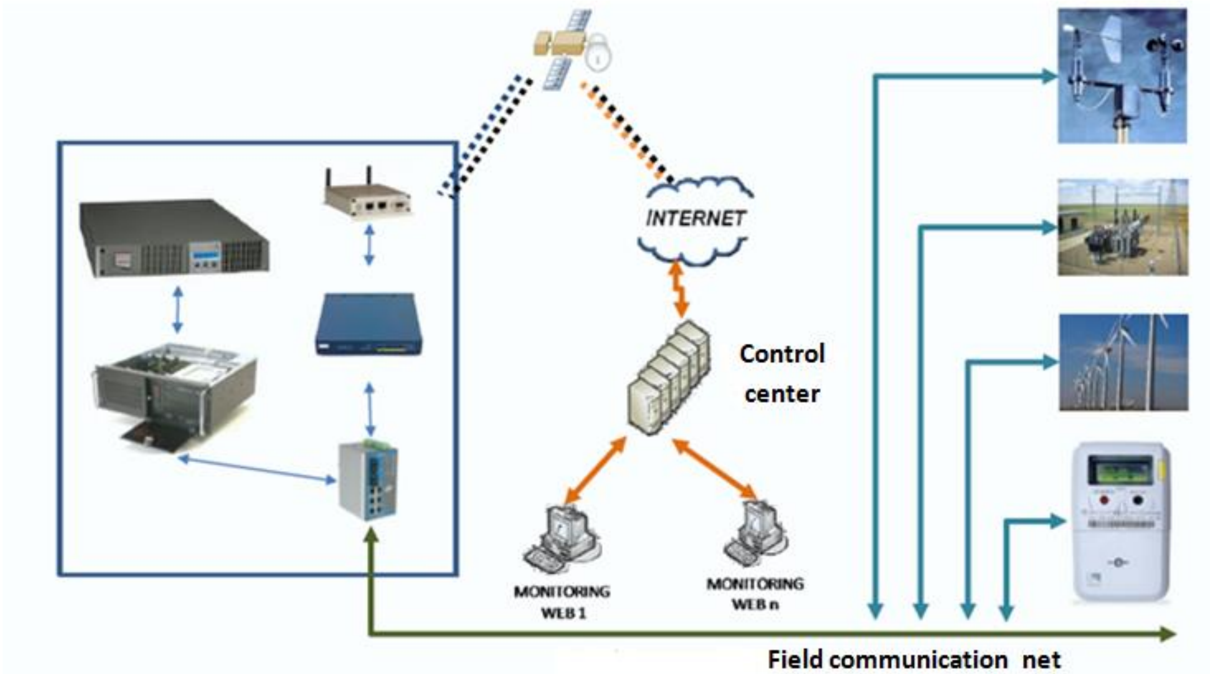


Figure 71. SCADA information storage

Equipment	Usual Location
Server	Control room
Server Backup	Control room
Firewall	Control room
Switch	Control room
Router	Control room
UPS	Control room
Viewer equipment	Control room
Signal converter	Control room or field
Metereological data logger	Met tower
Meter boxes	Electrical substation
UCS	Electrical substation
Control PLCs	Wind turbine Generator

Chart 3. SCADA component location

1.2.8. Lesson 8 - Documentation and schematics

The objective of this lesson is show the documentation and schematics necessary to make the O&M works properly.
During this lesson, the trainee will learn:

(1) The maintenance manuals and the work instructions structure

(2) Understand the periodical preventive activities

(3) Find out how to read and apply troubleshooting

1.2.9. Lesson 9 – Reporting

The objective of this lesson is to define the proper way to fill in the Work orders, Incident communication forms and to use the Computerized maintenance management system (CMMS).
During this lesson, the trainee will learn:

- How to report his maintenance tasks

Reporting
IEC 61400-25 is a subset of IEC 61400; a combination of regulations for wind turbines design, (communications to track and control the wind power plants, TC 88), which provides the exchange of uniform surveillance information and wind power control system. This, tackles the problem of patented communications systems that uses a variety of protocols, labels, semantics, etc., which permits an information exchange between different wind power plants independently of a supplier.
The IEC 61400-25 norm is the basis for the simplification of wind turbines functions and SCADA system executions. The crucial part of the information of the wind power plant, information exchange methods, and communication stacks are standardized.
In terms of SCADA mentioned before, the principal reports are:

- Production report
  As it can be observed in the figure below the production report produces a chart and a plot where the hourly information of the generation is available. The values of

energy production, capacity factor, wind speed, real availability and technical availability are shown in the chart.

	Enr. Prod. (kWh)	Factor de cap. (%)	Vel. Viento	Disp. Real (%)	Disp. Tecn. (%)
03/10/2013 0:00	231	0,38	3,04	95,46	97,50
03/10/2013 1:00	1.003	1,67	3,48	97,50	97,50
03/10/2013 2:00	58	0,10	2,66	96,81	97,50
03/10/2013 3:00	6	0,01	2,32	96,22	95,00
03/10/2013 4:00	30	0,05	2,87	94,85	95,00
03/10/2013 5:00	56	0,09	2,76	93,75	95,00
03/10/2013 6:00	776	1,29	3,65	94,65	99,36
03/10/2013 7:00	2.740	4,57	4,16	100,00	100,00
03/10/2013 8:00	3.255	5,42	4,64	97,47	98,04
03/10/2013 9:00	1.716	2,86	3,87	97,32	97,41
03/10/2013 10:00	3.070	5,12	4,29	98,66	98,66
03/10/2013 11:00	13.431	22,38	6,11	97,93	97,93
03/10/2013 12:00	22.976	38,29	7,18	87,55	97,77
03/10/2013 13:00	37.726	62,88	8,33	100,00	100,00
03/10/2013 14:00	29.205	48,68	7,48	100,00	100,00
03/10/2013 15:00	46.237	77,06	8,73	100,00	100,00
03/10/2013 16:00	50.528	84,21	9,35	100,00	100,00
03/10/2013 17:00	48.977	81,63	9,17	100,00	100,00
03/10/2013 18:00	60.067	100,11	10,47	100,00	100,00
03/10/2013 19:00	61.143	101,90	11,39	100,00	100,00
03/10/2013 20:00	61.206	102,01	12,31	100,00	100,00
03/10/2013 21:00	61.213	102,02	13,87	100,00	100,00
03/10/2013 22:00	61.191	101,98	13,57	100,00	100,00
03/10/2013 23:00	61.216	102,03	13,33	100,00	100,00

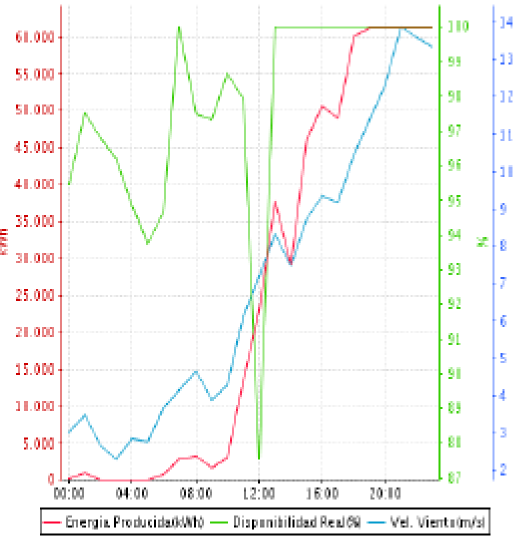


Figure 72. Energy production report

- Meteorology report

The meteorology report consists a chart and a plot where the wind speed and temperature are displayed hourly at hub, blade extreme and medium height as well as general humidity and pressure information.

	Altura Buje		Altura Ext. Pala		Altura Med.			
	Vel. V. (m/s)	Temp. (ºF)	Vel. V. (m/s)	Temp. (ºC)	Vel. V. (m/s)	Temp. (ºC)	Presión (mb)	Hum. (%)
01/02/2013 00:00	0,15	-79,53	6,94		6,63		985,63	0,33
01/02/2013 01:00	0,15	-79,53	6,80		5,77		985,53	0,32
01/02/2013 02:00	0,15	-79,53	5,03		4,82		984,69	0,33
01/02/2013 03:00	0,15	-79,53	6,34		6,02		984,46	0,32
01/02/2013 04:00	0,15	-79,53	5,11		4,77		984,30	0,33
01/02/2013 05:00	0,15	-79,53	3,71		3,69		983,78	0,32
01/02/2013 06:00	0,15	-79,53	2,54		2,91		983,82	0,32
01/02/2013 07:00	0,15	-79,53	3,26		2,77		983,56	0,32
01/02/2013 08:00	0,15	-79,53	2,19		2,00		983,72	0,32
01/02/2013 09:00	0,15	-79,53	2,07		1,95		983,94	0,32
01/02/2013 10:00	0,15	-79,53	3,29		3,25		983,77	0,32
01/02/2013 11:00	0,15	-79,53	4,93		4,87		983,05	0,33
01/02/2013 12:00	0,15	-79,53	4,84		4,72		982,38	0,32
01/02/2013 13:00	0,15	-79,52	5,85		5,74		981,09	0,33
01/02/2013 14:00	0,15	-79,52	6,14		6,00		979,66	0,33
01/02/2013 15:00	0,15	-79,52	6,82		6,72		978,17	0,33
01/02/2013 16:00	0,15	-79,53	7,00		6,86		977,48	0,34
01/02/2013 17:00	0,15	-79,54	7,79		7,74		976,99	0,34
01/02/2013 18:00	0,15	-79,54	7,82		7,78		977,00	0,34
01/02/2013 19:00	0,15	-79,54	7,82		7,65		976,60	0,34
01/02/2013 20:00	0,15	-79,52	8,60		7,99		975,33	0,33
01/02/2013 21:00	0,15	-79,52	8,66		8,05		975,18	0,32
01/02/2013 22:00	0,15	-79,52	7,91		7,29		974,78	0,33
01/02/2013 23:00	0,15	-79,52	5,90		5,26		974,30	0,33

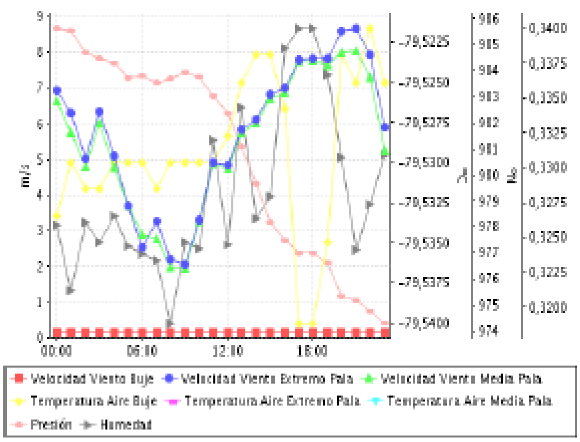


Figure 73. Meteorology report

- States report
  It is a report where all the states in which the wind turbine generator has been for a day are registered.

- Power curve report

  In this report the power curve of a generator is plotted versus the wind speed as well as the wind distribution curve.

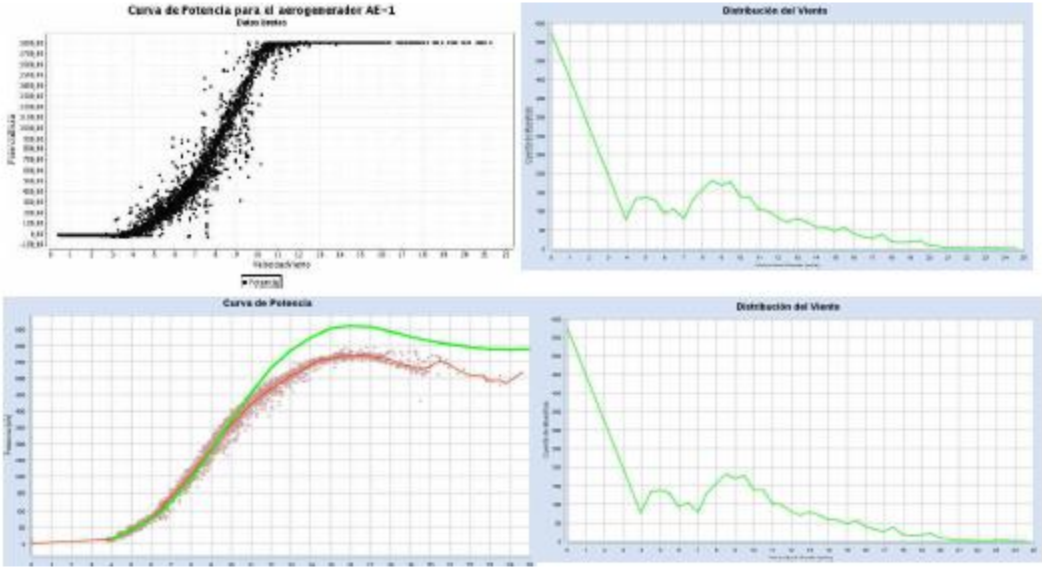


Figure 74. Power curve report

- Regulation report
- User report

SCADA requires of maintenance tasks that guarantees its proper work and efficiency, just as much as for hardware and software level. The maintenance on both levels is divided into two types:

- Corrective maintenance
- Predictive maintenance

Obviously, a proper preventive maintenance will minimize the incidences, and therefore, the corrective maintenance tasks that are not schedulable.

To optimize the task, it's necessary to make a Preventive Maintenance Plan to determine the actions and the periodicities to carry out. A "checklists" must be composed, that operators must fill in a simple way, to track the activities as well as to define the following informs, where the date of the next maintenance action must be established. The maintenance must be done in three ways:

- Face-to-face maintenances
- Remote maintenances
- IT infrastructure maintenance. Monitoring system.

HARDWARE	SOFTWARE
To register photos before and after an specific action	Cleaning the temporally files
To register equipment serial numbers	Checking space disk and free CPU memory
To review the sell-box and fan state	Defragmentation of hard disk (Windows)
To check the adequate performance of the printers	Cleaning log files
To check the adequate performance of the SAI (Uninterrupted Feeding System)	Updating antivirus
Physical cleanliness of the hardware	Synchronization trough NTP servers
Fans cleanliness	Scanning the computer against virus
	Software backup
	Firewall backup
	Registration of static IPs
	Registration of access and administrator keys
	Systematic tests of all SCADA and reports
	Others pending of technical solution

Chart 4. Software and hardware maintenance

Control, optimization and Wind Farm operation. Control centers.

To control efficiently the proper work of a wind parks group, it's required:

- A control system.
- Trained operators.
- Clear and effective procedures.