Maintenance

Version 1.0

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

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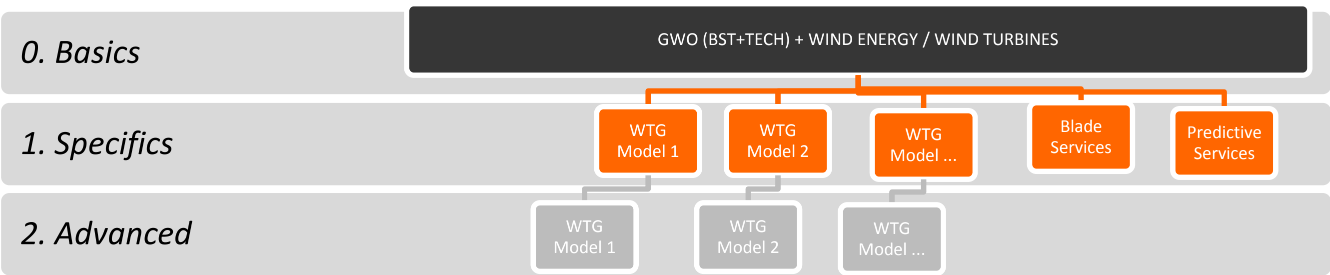
TRAINING PATHS

The general scheme of the paths are presented in the following scheme similar to the used in the previous chapters.

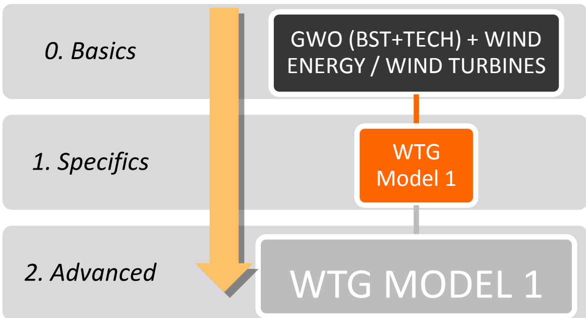
- Basics, present the main items included:
    - HSE based in the GWO BST structure (there is an agreement to use this reference that it is becoming the standard in the sector).
    - Necessary taks to promote and to develop wind farms.
    - General WTG chacteristics.
    - General actvitities related to the Engineering Procurement and commissioning of the wind Farm.
- Specifics, the experiences shows that it is necessary to teach about specific Wind Turbine.
- Advanced, training on detailed components of the WTGs.

Taking into consideration the limited scope of the SKILLWIND project the following contents reach up to the specifics level.



PATH #1. WIND FARM O&M TECHNICIAN

Following the above general scheme the path 1 starts with the basics to reach the specifics and finally the advanced level. Another path has to be developed for a different WTG model. We are concentrated in the a generic DFIG model no related to a specific manufacturer for being the most common technology in the market.



The contents included in this path are the present in the following section.

CONTENTS INCLUDED IN PATH #1

MAIN CRITERIA OF MAINTENANCE PLANNING

Before to star specifically with the maintenance is necessary to organize the workload with the planning of the main activities.

Lesson 1: General presentation

The aim of this lesson is to give the delegates a general overview of the main characteristics of the different types of maintenance as well as some initial general concepts to properly develop the maintenance activities.

The studenst should have after the lesson a good knowledge of the general approaches of the maintenance of wind installations.

The main goal of the operation and maintenance are presented in the following figure, where it is shown the importance of increase the incomes and recudes the costs, but also the procedure to increase the useful life of the installation.

Operation is normally related to the typical activities in normal conditions to guarantee the electricity generation if wind flows following the curves presented in previous chapters. Maintenance is the set of taks to allow a correct funcitioning of the WF installations and the different components and they are organized in different levels of difficulty.

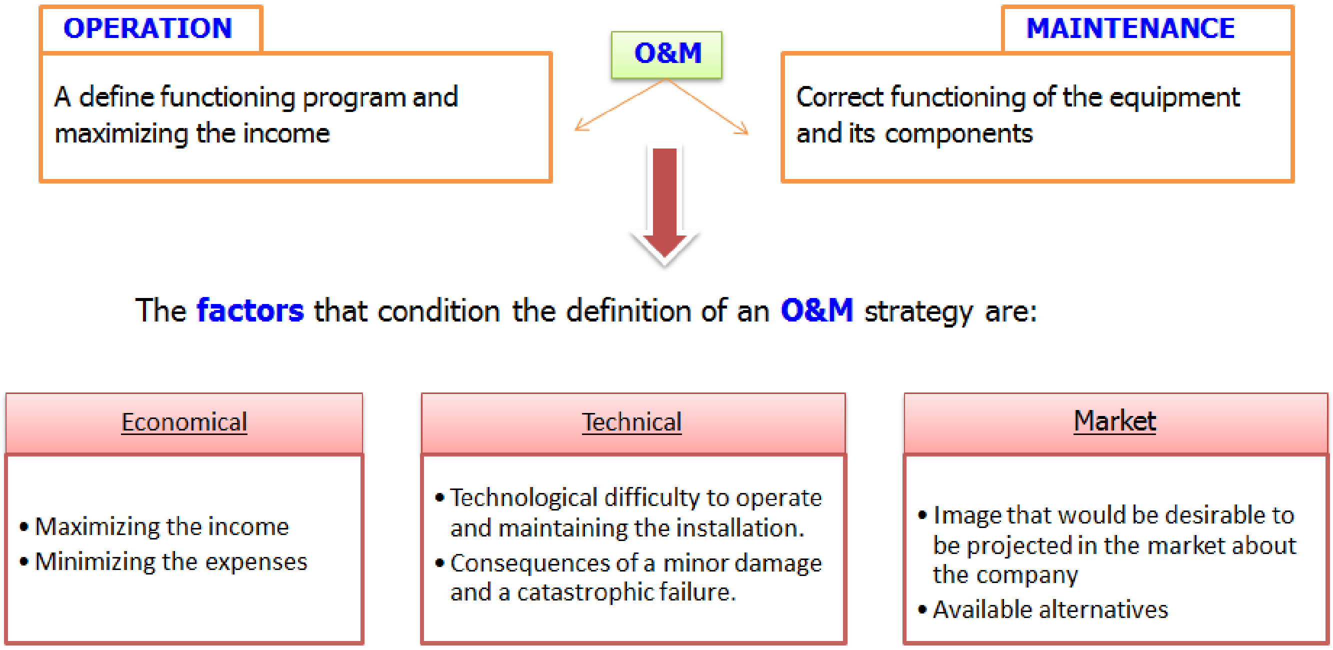


Figure 1. Operation and maintenance objectives

In relation to the specificities of the maintenance in comparison to other industrial activities in the following scheme is presented. When the maintenance of the wind farms was initiated typical tasks applied to the industry where used, nevertheless they were adapted afterwards to the characteristics of this sector.

Particularities of the wind farm maintenance

Location	Temperature variations	Vibration	Electrical works	Height works and confined spaces
• Limits the access to the wind farm	• Material wear	• It weakens the connections: hot spots	• They require special attention: hot points and highly risky	• Operative difficulty

❖ There are **other elements to be considered:**

- It is optimal if have been applied in other industrial sector and exportable to the wind sector (for example Condition Monitoring coming from the aeronautical industry).
- It is optimal and applicable by all the wind energy sector agents (for instance the use of Computer assisted for following the maintenance activities).
- Unique that are appropriate to be applied to all the wind farms of the same agent (for instance introduction of vibration sensors).

Figure 2. Particularities of wind farm maintenance

The general strategy is also presented in the following sections and it is summarised in the following figure:

❖ The O&M strategies should be compared by **value**:

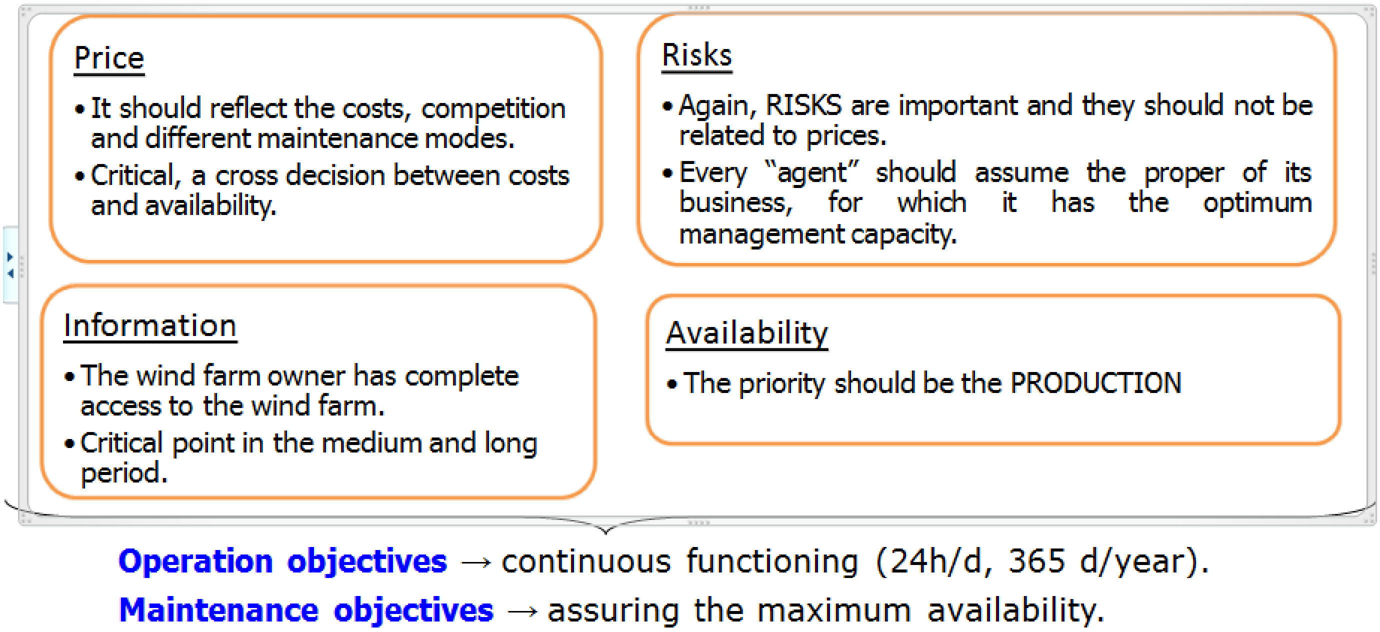


Figure 3. O&M Strategies

Maintenance is becoming crucial after the gurantee period (normal of two years and extended could reach twelve years) whre is responsabilyt of the OEM to keep the avaialbily of the WF as stated in the contract. So, in the following sections are presented typical maintenance activities:

- Each of the actions to be undertaken and when to perform them.
- Regular monitoring to observe, in relation to the techniques of each component of the wind turbine and wind turbine operation, the characteristics as a whole.

In general, for a good planning in maintenance and operation the wind forecast should be available in short and medium term, specially it is necessary to rent cranes to remove big components.

In case of repeated failures in the same wind turbine, traceability is necessary to find the fault origin, checking the whole process from wind turbine manufacturing, assembly, installation and commissioning, to correct the initial cause that causes the problem.

A monthly report of the maintenance actions, energy production and forecasts of the work to be done in the future is made. This report is transmitted to the responsible operating the park, whether it is the company that owns the park or not.

In general, it is recommended to have WTGs of the same manufacturer to facilitate the existence of stocks of spare components and to spread the experience between the different wind farms but this is not allways possible for diiferente reasons: prices of the WTGs, adequacy to the wind conditions (Tipology of Classes according to the IEC-61400 for instance) of the site or lack of available turbines, such as it happen in Spain in 2007 with a huge demand due to regulatory change the following year.

Once the useful life of the wind turbine is reached, some of the following actions could be taken:

- The diagnosis and evaluation of the wind turbine state.
- Decision of either repowering or extend the WTGs life.
- End of lease of land.
- Expiration of the administrative concession that regulates the operation of the wind farm.

Lesson 2: Maintenance program.

The aim of this lesson is to give the delegates the global overview of the different phases of the maintenance program.

After the this lesson the students should have clear concepts on how to organize the different tasks for properly maintain the turbines and the installation.

Once begins the WF operations, its maintenance starts according to:

- The technical specifications of the wind farm design
- The technical specifications of each component.

- The maintenance handbook of the all components, which is going to be an alive document to collect the experiences through the Project life.

The maintenance plan is broken down into the following phases presented in the following page:

Root cause analysis

- Indicent follow up
- Information analysis and indentifying the root causes
- Improvement proposals
- Evaluating the impact in power

Definition and improvement of procedures

- Updathe in the Maintenance manual the improvements and proposals lauchend
- Establish guidelines for their execution and monitoring

❑ Maintenance performance

Faults identification

- Location of incidents and failures
- Inmediate solving locally or remotely if possible
- Initiate the local diagnose if procedent

Work orders

- Prepare work execution orders in wind farms
- Launch preventive maintenance orders
- Control the work performance quality

Execution

- Work perfomance by emited orders
- Send the report information to the management system

❑ Logistics and storage

Stock level definition

- Defining the optimal stock of big components, small materials and consumable spare parts, as well as the location.
- Continuous update of the stock levels.

Storage management

- Locating suppliers
- Frame contracts to supply materials and components. componentes y material
- Controlling the stock leves
- Stocking spare parts and consumables.
- Service rental.
- Spare and consumable parts request

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Figure 4. Maintenance task phases

From this general scheme, each company organizes their maintenance tasks in accordance with the configuration of its WFs and the types of machines.

Before all of these activities is important to collect the operation, alarms and maintenance data to create a good base to compare the main indicators with those foreseen before starting the wind turbines operation.

In the following figure is presented the different phases of the maintenance:

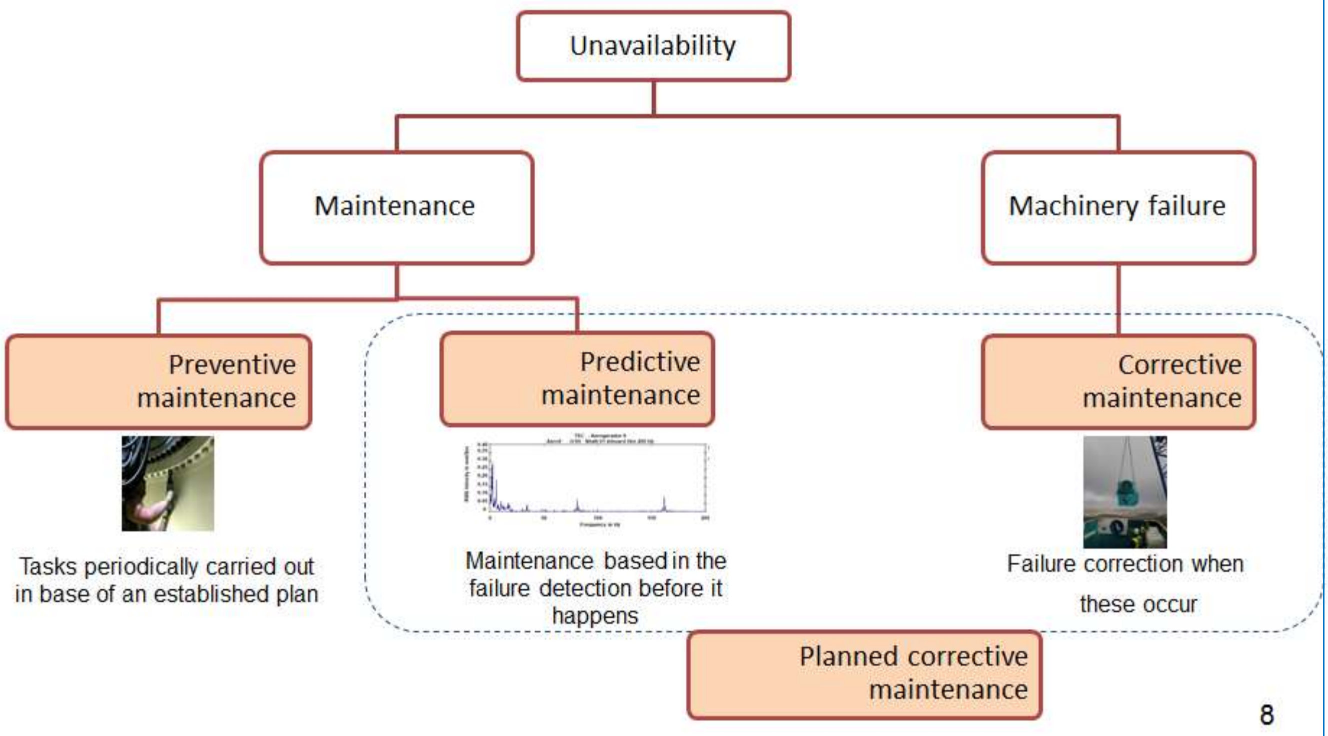


Figure 5. Preventive and predictive maintenance characteristics

The planning of maintenance is developed in three different stages:

- Predictive.
- Preventive.
- Corrective.

In the following table are presented some of the main characteristics of the different types of maintenance. It is important to carry out the two phases of predictive and preventive maintenances.

CORRECTIVE MAINTENANCE	• No special advantages, it should be avoided thorugh the use of the other phases of maintenance.	• Risk of long inactive periods of time. • Risk of big collateral damages. • Cost of cranes request an adequate working program.
PREVENTIVE MAINTENANCE	• A small investment is required to establish the model of intervention. Afterwards is simple and neither advanced resources or personal qualification is required.	• Risk of frequent interventions, with large costs. • Risk of late interventions with a complete failure development, and therefore with same disadvantages as corrective maintenance.
PREDICTIVE MAINTENANCE	• Prevent future failures in advance in order to activate the intervention program, with low costs on resources and small periods of inactivity. • Low risk of collateral damages.	• Medium-high complexity. Advanced resources and personal qualification are required, which involves costs.

Chart 1. Types of maintenance

The first three strategies studied for the separate turbine onshore gave the following results when a CMS (Condition Monitoring System base of Predictive maintenance) cost is added to the basic case; to compensate for the additional cost the preventive maintenance has to be decreased by 23 %. To compensate for the additional cost the preventive and corrective maintenance together have to be decreased by 3,5 %.

Simillarly, he question that often is discussed in maintenance consistence is the balance between preventive and corrective maintenance and the relationship between those. In practice it is difficult to find the optimal relationship between them. It is very difficult to determine which corrective maintenance cost is associated with a particular amount of preventive maintenance such as it can be seen in the following figure:

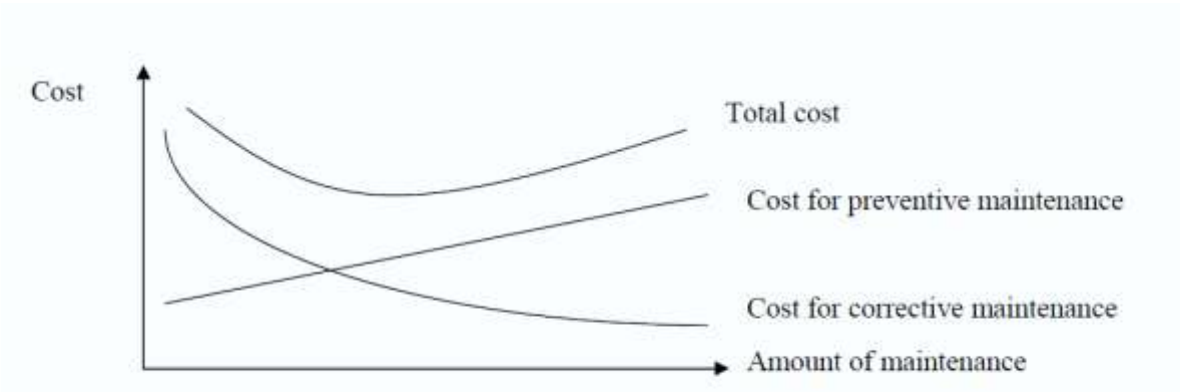


Figure 6: Balance between preventive and corrective maintenance (Source: Julia Nilsson. RIT KTH)

In the following sections are presented the different type of maintenance although predictive maintenance is always a complementary formation acitivity in the this training path.

PREDICTIVE MAINTENANCE

It is defined as the maintenance based in detecting failure before it happens, in order to have enough time to correct it neither affecting the service, nor stopping the generation and stopping in periods when the economic impact is minor.

Normally people involved in predictive maintenance is very specific and not involved in the rest of maintenance tasks that it makes teaching on this activitiy independent of those of preventive and corrective.

Lesson 1 – Introduction to Predictive maintenance

The aim of this lesson is to explain the importante of predictive maintenance .

To successfully complete this Lesson, students shall be aware of:

(1) Justifying the importance of the predictive maintenance.
(2) Main elements of the conditioning monitoring

The machines are made of several components. These are built with a number of materials that are subjected to a series of stresses in time, which modify its operation to some extent and thus, the machine itself. While this modification operation is tolerable, no fault, but reached a certain state of disrepair where the operation is outside the specified or expected arrived at fault.

It is important to apply predictive maintenance before the potential failure appears, such is is shown in the following figure and it is known as the maintenance based in the condition.

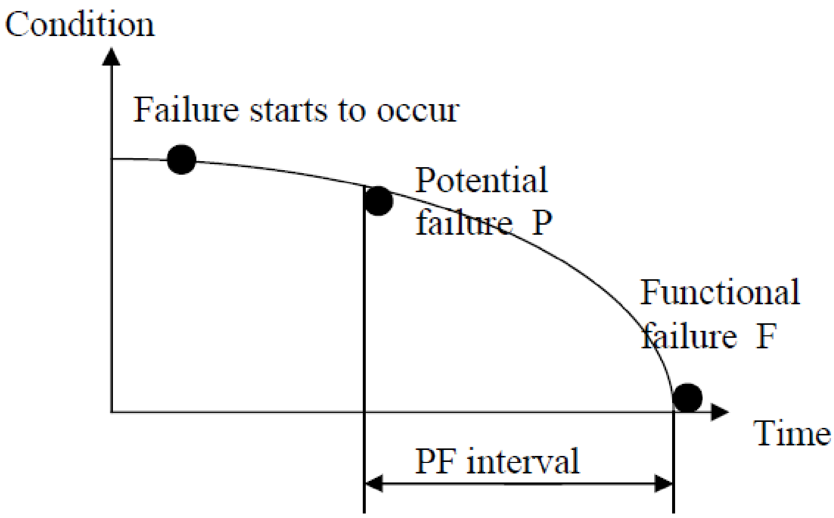


Figure 7: Potential failure (Source: Julia Nilsson. RIT KTH)

Predictive maintenance is periodically monitorized of cumulative conditions to avoid unexpected failures and summarized:

- To determine the current technical status of the wind turbine,
- To detect and specify initial damages and,
- To help to avoid secondary damages by early detection of faults.

Normally Predictive Maintenance is usuallt based, but not allways, on the Condition Monitoring System(CMS) which continuously monitors the performance of the windturbine components such as for instance: generator, gearbox and transformer and help to determine the best time for specifc maintenance work. The results of the condition monitoring is to be documented and contains necessary maintenance tasks as well as recommendations for maintenance dates for the operator.

The goal is to maximize the life of damaged predictions, which are based on damage evolution in components.

One of the methods is based on the FMEA procedure, Failure Mode and Effect Analysis, is used in reliability analysis and with this method the connection between possible failure modes for a construction and the failure effects that these give rise to can be determined . The method was introduced by the aircraft manufacturer Boeing in 1957. The method was developed during the fast technical development in 1940-1960.

The purpose of the method is to find all the ways that the product can fail. Three questions are answered, these are:

1. What failures/events could appear?
2. What are the effects of the failures/events?
3. What are the causes of the failures/events?

Then the failures probability, seriousness and possibility of discovery should be estimated. To perform this the system is being divided into several sub systems. When the three questions have been answered the frequency with which the failure can occur is indicated with a number between e.g. 1 and 10. Then a number indicates the seriousness of the consequence. Finally a number indicates the probability for discovery. These numbers are multiplied into a combined index number, for which a higher value indicates a worse failure. This number is called risk priority number. This gives a ranking list for the failures, from which using the size of the risk priority number one can make an estimation of the seriousness of the failures and then make a measurement

The predictive maintenance is thus generally implemented in the field through non-destructive testing, whose objectives are:

- To detect the presence of damage.
- To locate its position.
- To quantify its size.

Even though there are different methods, a lot of usual procedures are based on vibrations, temperature sensors and ultrasound equipment whose threshold of detection is 1 mm at least.

- Ultrasounds.
- Phased array.
- Time-of-flight diffraction (TOFD), ultrasonics method.

It is possible to make a new estimation of the remaining life of a component with the data obtained and then to make a review of inspection. Sometimes, for reasons not controlled in the design stages, some components develop damages which can reduce their life.

The predictive maintenance is very useful to deal with unexpected events allowing these to continue operating safely since the evolution of cracks is controlled at all times by this tool. To do this, the following task should be properly performed:

- To diagnose the failure process correctly.
- To determine evolution of the cracks safely.
- To control the evolution of the cracks adequately.
- In the following figure it can be observed a typical scheme of predictive maintenance supported by specific simulator software:

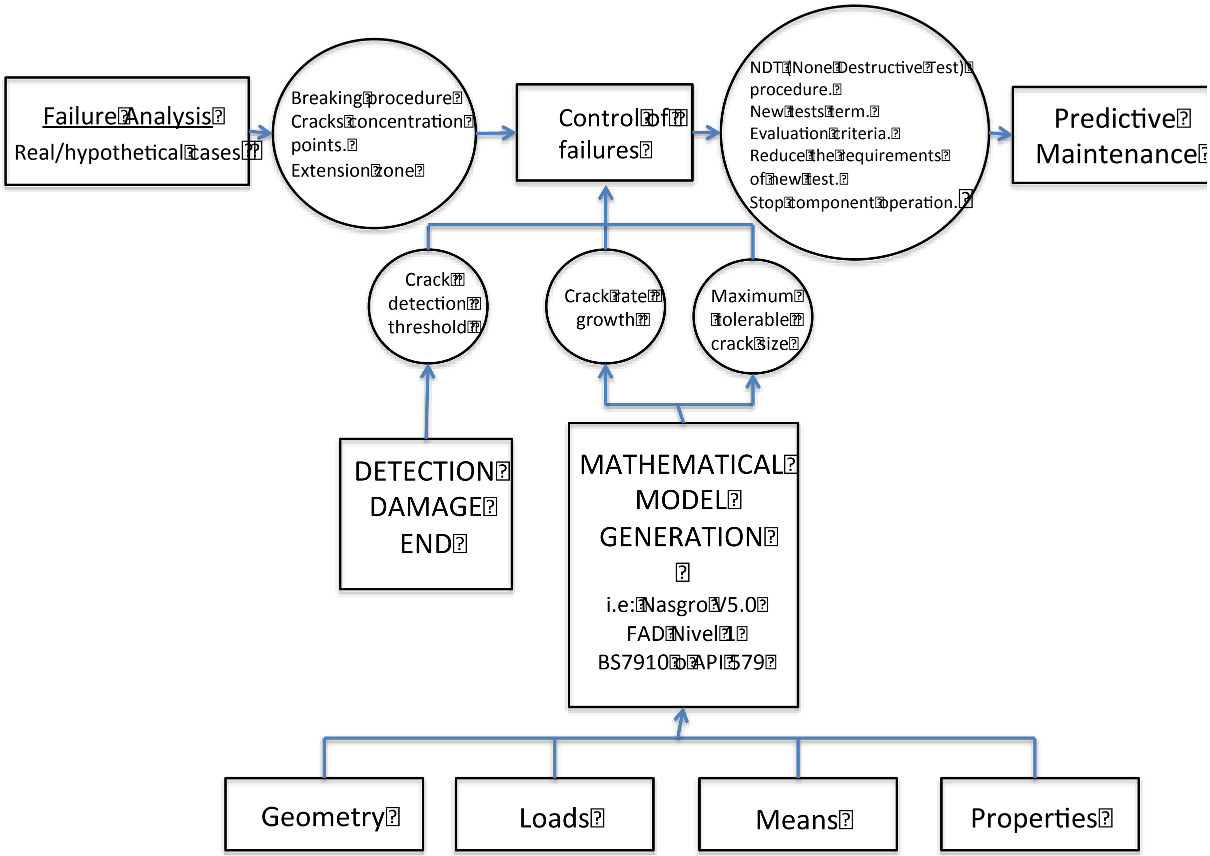


Figure 8. Typical predictive maintenance organization

There are of course different approaches in an area of activity with an important growth in the recent past thanks to the introduction of BIG DATA and Digitalisation products.

Typical predictive activities.

The aim of this lesson is to explain the activities related to predictive maintenance . *To successfully complete this Lesson, students shall be aware of:* *1) Typical predictive activities* *2) Solutions for vibration control* *3) Inside WTG noise control* *4) Oil lubricant quality control*

In the following figure is presented the typical predictive activities:

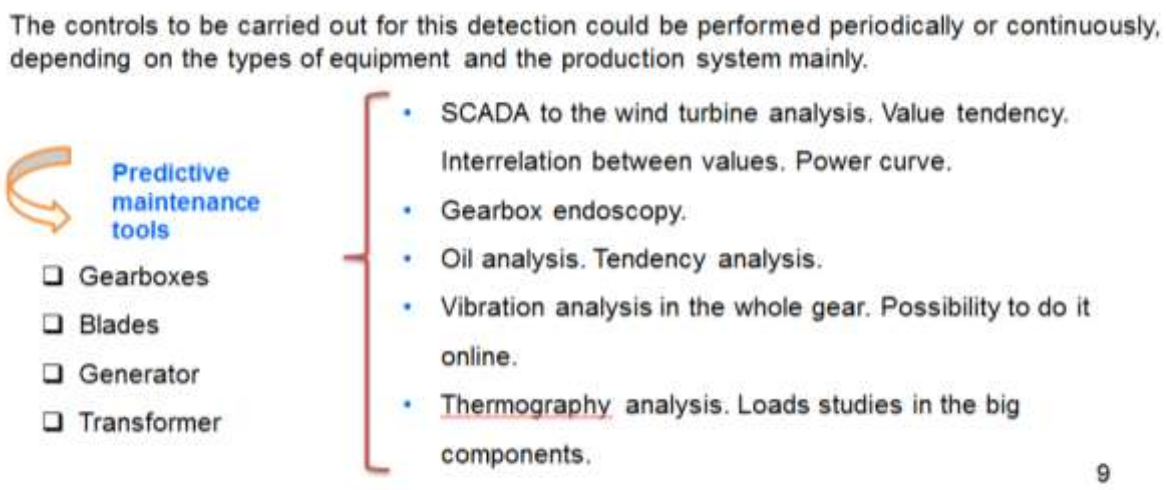


Figure 9. Predictive maintenance

More specifically in the following Figure typical tasks are presented.

➤ SCADA analysis of the Wind turbine

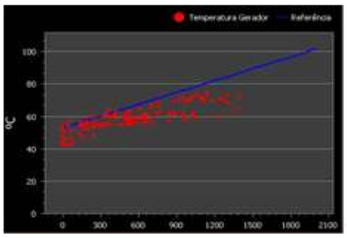
The operation profile and the standard operation parameters, their tendencies and the possible deviations.

The component temperatures,vibrations and the rest of study variables are identified, analyzed and monitorized, considering the references and data collection and storage.

Some examples of data collection points.

Main bearings | Gear boxex | Gearboxes | Generators | Generators

Component temperatures



Vibrations

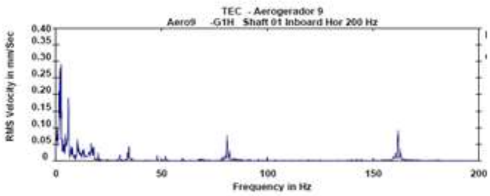


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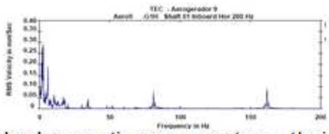
Figure 10. Predictive maintenance II

In the following figre the collection points of some of the sensors are shown.

➤ SCADA of the wind turbine analysis



The operation profile is obtained as well as the standard operation parameters, their tendency and the possible deviation as well as the different alarms to follow the wind farm operation.

➤ Oil analysis. Tendency analysis

- Samples taken from the gearboxes following the procedure every X months
- Samples send to the laboratory
- Results stored in the Data Base
- Predictive analysis

➤ Vibration analysis

Systems composed by computers, vibration and speed sensors that monitor continuously the vibrations in generators and gearboxes.

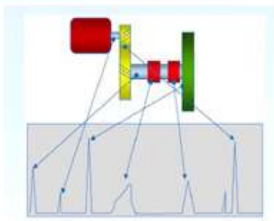


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Figure 11. Predictive maintenance sensors

Normally the typical predictive activities are linked to the Wind Farm and Wind turbines characteristics. Those minimum requirements for the WTG are:

1. An appropriate access.
2. Complete equipment concerning operator protection (stop cable lifelines, personal protective equipment).
3. The kinematics data of the drive train (as assumption to fulfill the vibration diagnostics)
4. Service manual.
5. Maintenance records and oil inspections.
6. If existent: technical background file of the rotor blades.
7. Operating manual.
8. Building permission, type approval or individual approval.
9. Declaration of conformity.
10. Installation and assembling records.
11. Records of commissioning.
12. Duplication without written approval is disallowed.
13. Contract of maintenance.

The installation of the specific equipment for Condition Monitoring is below commented in addition to the procedures to be followed to obtain specific results to feed to following phases of the maintenance, either preventive or corrective.

Predictive maintenance → Collected data analysis that takes place after their collection, obtaining the diagnose several hours/days after obtaining the information.

└ Condition-based maintenance → Information analysis and processing in real time, obtaining an immediate diagnose to the data collection.

Figure 12. Condition based maintenance

The technical expert provides an over-all report about the wind turbine's monitoring. Therein, all results are accurately documented. Irregularities and initial damages are not only to be detected but to be rated according the life-cycle of affected components if possible and reasonable.

Eventually repair necessities and references to repair dates are to be described precisely. In case the repair date cannot be fixed because of initial damages, so another inspection of the affected component is to be appointed.

a.1. Solutions for vibrations monitoring.

Vibration analysis is a technique widely used in the industry to estimate a machine condition and predict faults of specific components. These techniques dated back to the beginning of the century with the first portable vibration measurement instrument constructed by Schenk in 1925. Several standards also exist regarding the maximum allowable vibration levels that a piece of machinery should exhibit while operating (DIN ISO 10816, 7919 and 8528-9). With the advent of electronic computers giving the ability to perform Fourier transformation of the measured signal, this technique was further developed to perform analysis to the frequency domain where specific frequencies where correlated to specific faults. Although very promising, widely used and having a large number of personnel trained; it has failed to become an industry standard and it is still regarded as a very useful extra technique.

Despite its employment in the wind turbines maintenance plans, the main problems that this technique faces are that along with the machine induced vibrations, in the measured spectrum, there are a number of frequencies originated by the vibration of the whole wind turbine structure. These “structural” vibrations are wind induced and it has to be taken into account the fact that the turbine is a rather long vertical cantilever beam. The mentioned issue and this technique inherent problems do not allow the accurate measurement of the machine vibration and therefore, it does not give the expected results while used in wind turbine machinery.

As the sensors employed for this method are of the same type as the operating modal analysis, in CMSWind this technique will be used but considered as one of the methods of operation and maintenace.

Figure 13. Vibration tests

Regarding the vibration measurements, they can be processed and analysed by using a wide variety of commercial software. Usually, each HW manufacturer developes its own SW solution. This way, the signals are recorded and displayed making easier to identify failures and to compare between different severity levels of damage.

For example, a vibration raw signal is shown in next figure:

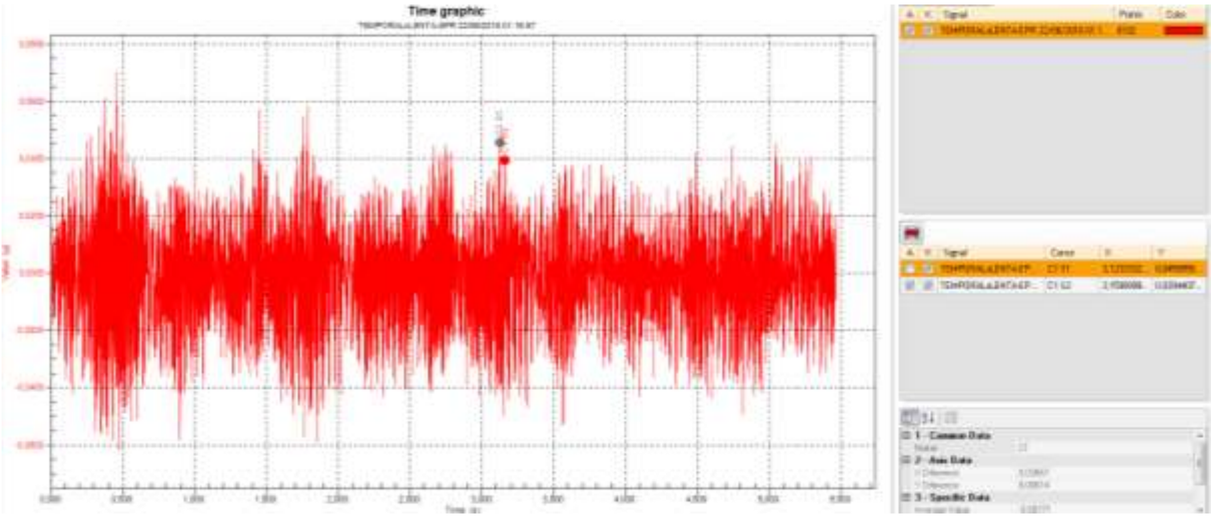


Figure 14. Vibration raw signal (individual)

Some signal characteristics as smoothness, sharpness, overall level and pulse can be seen through the single representation. Usually, cursors are also available to calculate frequencies between beats.

Other useful technic is to compare raw signals recorded at different points at the same time or the same point at differnet times:

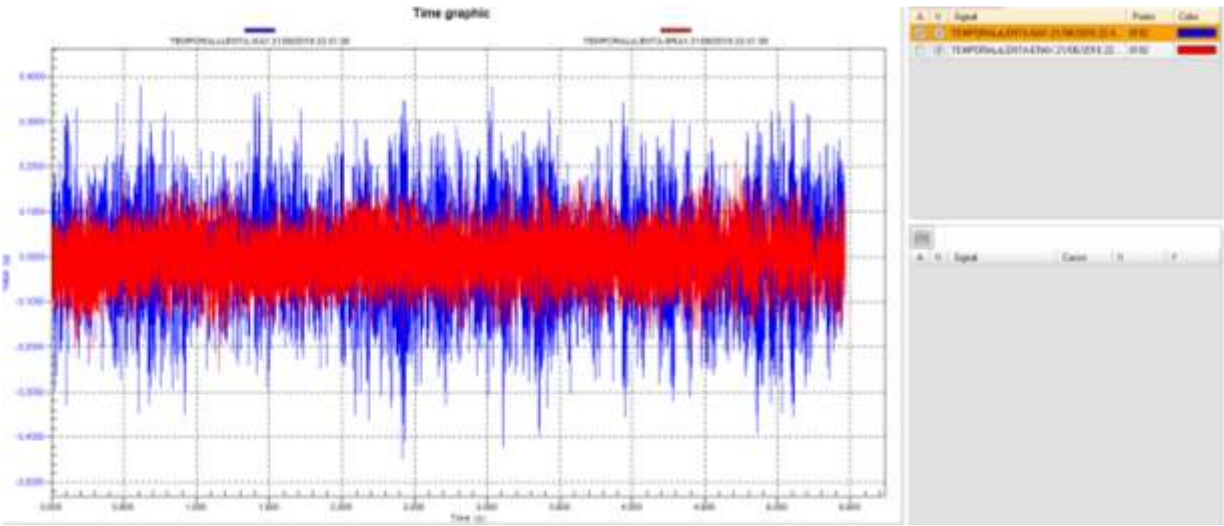


Figure 15. Vibration raw signals (ioverlapped)

The most widely used technic to analyse the raw vibration data is the Fast Fourier Transform (FFT), that allows to identify each single vibration frequency in order to match it with the physical component.

As stated before, signals can be usually displayed as individual or overlapped ones.

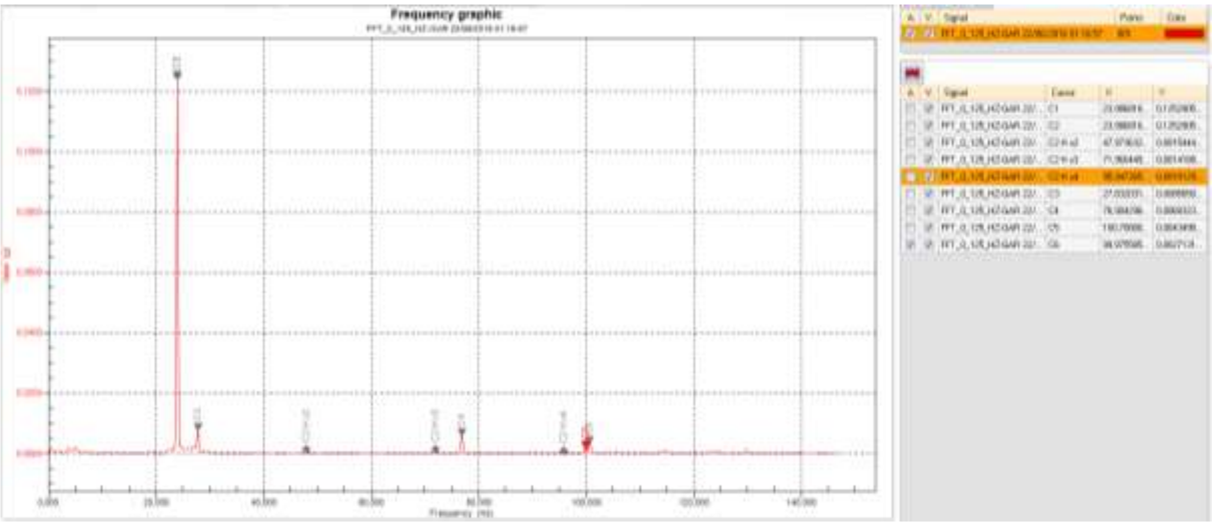


Figure 16. Vibration FFT signal (individual)

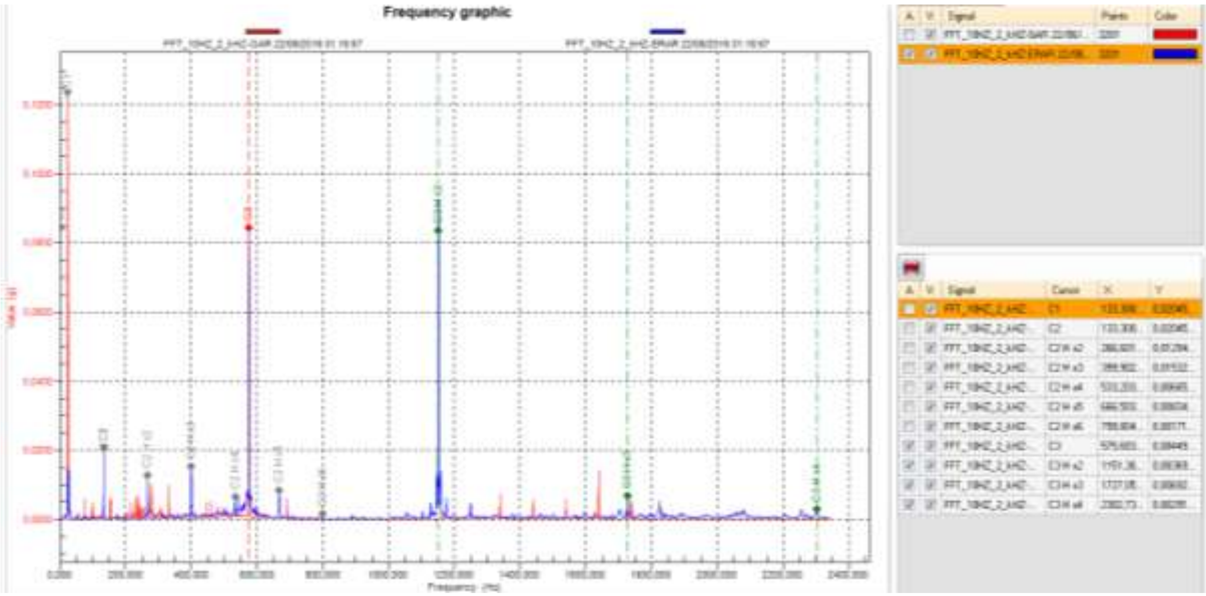


Figure 17. Vibration FFT signal (individual)

Condition monitoring utilizing vibration signature analysis is based on two basic facts:

- All common failure modes have distinct vibration frequency components that can be isolated and identified.
- The amplitude of each distinct vibration component will remain constant unless there is a change in the operation dynamics of the machine.

It is normal for machines to vibrate and make noise. Even machines in a perfect condition will have some vibration and noise associated with their operation. It's therefore important to remember that:

- Every machine will have a level of vibration and noise, which is regarded as normal.
- When machinery noise and vibration increase, some mechanical defect or operating problem is usually the reason.
- Each mechanical defect generates vibration and noise in its own unique way.

If a problem can be detected and analysed early, before extensive damage occurs then:

- Shutdown of the systems for repairs can be scheduled for a convenient time
- A work schedule together with requirements for manpower, tools and replacements parts can be prepared before the system is shut down.
- Extensive damage to the machine resulting from forced failure is minimized.

As a consequence of this repair time can be kept short, resulting in less machinery downtime. The detection would first require periodic manual vibration measurements on each critical machine. High performance machines, which develop problems very fast, are not well suited for periodic monitoring. For these systems, on-line, continuous, automatic monitoring is required using vibration sensors located at critical points on the machine. When the vibration exceeds pre-set levels, a warning sounds or the machine shut down automatically.

Time domain vibration signals can yield enormous amounts of information. Several techniques have been used in machine condition monitoring. Some techniques are waveform, indices, synchronous average, orbits and statistical methods.

Waveform analysis consists of recording the time history of the event on a storage oscilloscope or a real time analyser. Apart from an obvious fundamental appreciation of the signal, such as if the signal was sinusoidal or random, it is particularly useful in the study of non-steady conditions and short transient impulses. Discrete damage occurring in gears and bearings, such as broken teeth and cracks, can be identified relatively easy. Waveform analysis can also be useful in identifying beats and vibrations that are non-synchronous with shaft speeds, and in machine coast down analysis waveforms can indicate the occurrence of resonances.

Indices are also used in vibration analysis. The peak level and the RMS (Root Mean Square) level are often used to quantify the time signal. The peak level is not a statistical quantity and is not reliable in detecting damage in continuously operating systems. The RMS value is more satisfactory for steady-state applications.

Statistical analysis can also be carried out on time domain data. The probability density for example is the probability of finding instantaneous values within a certain amplitude interval, divided by the size of the interval. All signals will have a characteristic probability density curve shape. These curves if derived from machinery vibration signals can be used in monitoring machine condition .

Digital fast Fourier analysis of the line waveform has become the most popular method of deriving the frequency domain signal. The signature spectrum obtained can provide valuable information with regards to machine condition. Enveloping or demodulating the time waveform prior to performing the Fast Fourier Transform (FFT) is also gaining in popularity.

The vibration characteristics of any machine are to some extent unique due to the various transfer characteristics of the machine. The method of assembly, mounting and installation of the machine all play a part in its vibration response. When a machine has been commissioned a signature spectrum should be obtained under normal running conditions. This signature will provide a basis for later comparison in order to locate those frequencies in which significant increases in vibration level have occurred [31].

a.2. Inside WTG noise control.

Vibration, motor current signature and acoustic emission analysis were designed to monitor the condition of the gearbox, rotary components and generator, respectively. These components together are estimated to account for approximately 22 % of wind turbine downtime.

Acoustic Emission technique is based on the measurement of elastic waves on solid structures of frequencies much higher than the ones considered vibration (>100KHz). The occurrence of these waves is a result of rapid energy release in a structure or its surface whose origin are cracks and defects. It is a widely used Non Destructive Testing passive technique usually employed in continuous Structural Health Monitoring, and frequently in large structures. Most of its applications are structurally oriented. The wind turbine housing of this tool raises several issues of its correct placement and its sensors have to be constantly connected, it cannot be employed on moving parts.

Several advancements in signal processing technology have enabled this process to find the location of the elastic wave force, if an array of transducers is used. The following image shows a portable Acoustic Emmision sensor instrument with wireless capabilities severely hampered by the battery life and unable to be used for uninterruptable monitoring.

Figure 18. Portable AE sensor instrument

a.3. Oil-Lubricant quality control.

The objective of predictive maintenance lubricant is to detect, diagnose and predict malfunctions, so maintenance will be optimized, will increase the availability of assets and will extend the life of the components.

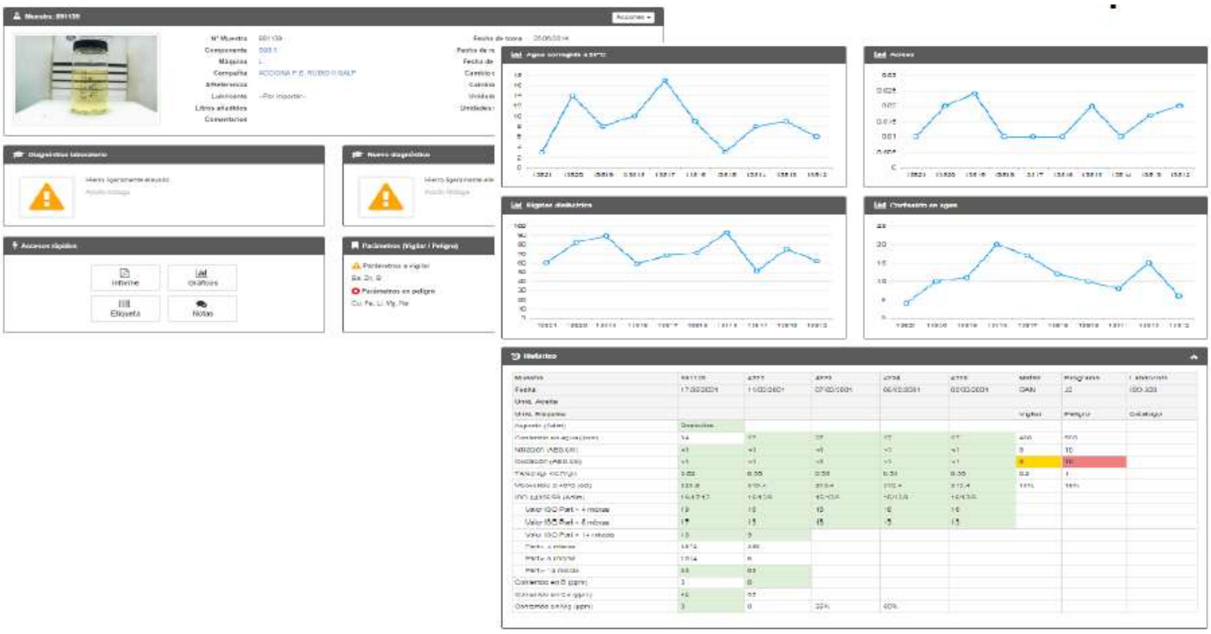


Figure 19. Oil analysis charts

The analysis of oils during predictive maintenance consists of:

- Analysis of the properties.
- Supplementation.
- Contamination.
- Scuffs.

From these analysis, the following conclusions can be obtained:

- Data analysis requires analysis of expert on friction and wears.
- It allows us to understand the failure modes in lubricated systems.
- Integration of Data Analysis Operation and Maintenance, and an expert knowledge in CM allows us to predict future events.
- Some of the advantages are the planning of maintenance.

There are a lot of parameters, which can be measured by lubricant oil. Among all, the major parameters can provide some information so as to know the condition of the oil and the lubricated machine. Some of them are:

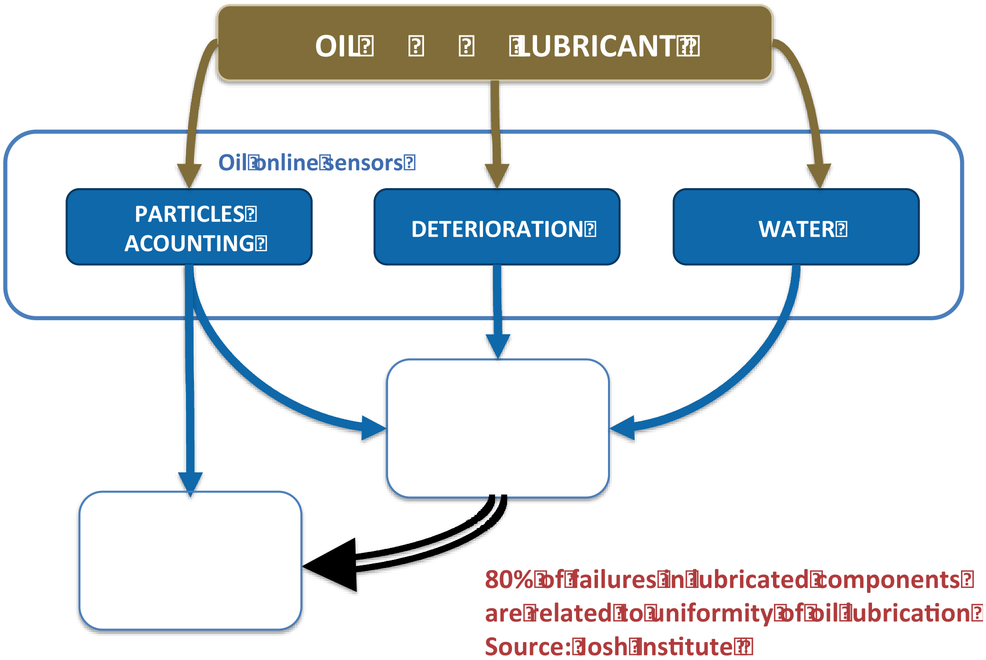


Figure 20. Oil condition evaluation

The online measurements and laboratory analysis have different advantages, that are stated below for both methodologies.

• Laboratory advantages:

- Accuracy of laboratory equipment.
- Measures in multiple parameters.

• Online laboratory:

- To avoid some errors in samples.
- To measure on service conditions.
- To improve accuracy by multiple measures.
- Obtaining trends.
- Real-time alarms.

PREVENTIVE MAINTENANCE

Designed to provide to OM technicians with the necessary knowledge in the preventive maintenance operations. This module describes the different works to be performed in each subsystem integrated within the WTG.

Lesson 1 – Introduction to Preventive maintenance

The aim os this lesson is to present the predictive maintenance as well as the periodical checking of the different components.

During this lesson the trainee will learn:
(1) General concepts.
(2) Periodical check of the different components.

In the following scheme is presented a first approach to the preventive maintenance

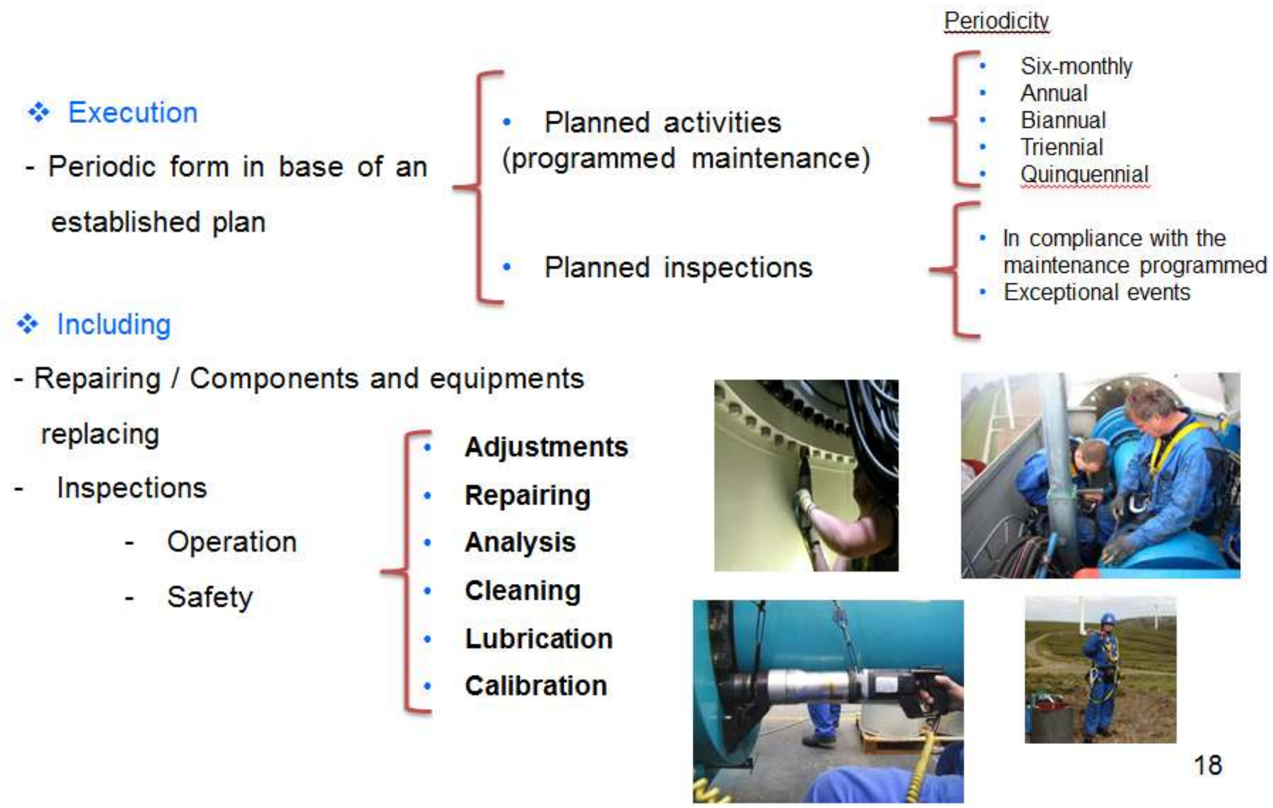


Figure 21. Preventive maintenace performance plan and tasks

In the following table the **typical frequencies in months, it depends finally on each WTG and manufacturer,** for every component are presented, for inicial periodicity is understood the early estage of the project and in general periodcity once the project is normal operation specially after the guarantee period:

System	Activity	Inicial Periodicity	General Periodicitiy
General	Tower access inspection	-	24
General	Nacelle and rotor accesses inspection	-	24
General	Anti-corrosion inspection	-	12
General	Cracks inspection	-	6
General	Structural bolted joins inspection	3	12
General	Tower bolts re-tightening	3	12
General	Nacelle Frame Re-Tightening	3	12
General	Deflector retightening	3	12
General	Lift inspection	-	12
General	Fire extinguishers inspection	-	3
General	Anti-slip surface inspection	-	12
General	Anchorage points inspection	-	12
General	Inspection of structural components	-	12
General	Nacelle Frame Re-Tightening II	-	24
General	Precast concrete tower inspection	-	12
Drive Train	Gearbox Oil replacement	-	48
Drive Train	Gearbox. Vent filter replacement	-	a/i
Drive Train	Cooling System for Gearbox. General inspection	-	12
Drive Train	Cooling System for Gearbox. Oil filter substitution	-	12
Drive Train	Rotor bearings inspection and greasing	-	12
Drive Train	High speed saft (HSS) coupling retightening.	3	12
Drive Train	Low Speed Saft (LSS) re-tightening	3	12
Drive Train	Gearbox General Inspection and oil test	3	12
Drive Train	LSS coupling inspection	-	12
Drive Train	Vring Inspection and Substitution	-	12
Drive Train	Gearbox Supports Inspection	-	12
Blades	Blade outer status inspection	-	12

System	Activity	Inicial Periodicity	General Periodicitiy
Blades	Blade inner status inspection	-	24
Blades	Blades inspection	-	12
Blades	Blade re-tightening	3	12
Yaw System	General inspection	-	12
Yaw System	Sensor inspection	-	12
Yaw System	Motorgear actuators inspection	-	12
Yaw System	Gear oil substitution	-	60
Yaw System	Track inspection	-	12
Yaw System	Gliding pads inspection	-	12
Yaw System	Guiding pads inspection	-	12
Yaw System	Crown and pinion inspection	-	12
Yaw System	Lower guide setting	-	12
Yaw System	Crown and pinion clearance setting	-	12
Yaw System	Nacelle centring	-	a/i
Yaw System	Yaw re-tightening	3	12
Yaw System	Gliding track greasing	-	6
Yaw System	Radial guide track greasing	-	6
Yaw System	Yaw crown and pinnions greasing	-	6
Yaw System	Brake pads inspection	-	12
Yaw System	Brake pads substitution	-	a/i
Park Brake	Brake disc inspection	-	12
Park Brake	Brake caliper and pad inspection	-	12
Park Brake	Park brake re-tightening	-	12
Hydraulic System	Oil inspection	-	12
Hydraulic System	Oil Substitution	-	60
Hydraulic System	Pressure inspection	-	60
Electric, Sensor & Control	Sensors inspection	-	12
Electric, Sensor & Control	Emergency buttons inspection	-	12
Electric, Sensor & Control	Thermographic inspection of the electric boxes and wiring inspection	-	12
Electric, Sensor & Control	High Voltage installation inspection	-	12
Electric, Sensor & Control	Beacons inspection	-	12
Electric, Sensor & Control	Smoke-Detector Inspection	-	12

System	Activity	Inicial Periodicity	General Periodicitiy
Electric, Sensor & Control	Ice Detector and Shadow-Flicker inspection	-	12
Generator	General inspection	-	12
Generator	Automatic grease feeding system inspection	-	12
Generator	Bearing manual greasing	-	6
Generator	Rotary connectors maintenance	-	6
Generator	Generator re-tightening	3	12
Generator	Connection boxes inspection and re-tightening	3	12
Generator	Generator vibrations inspection	-	12
Generator	Alignment inspection	-	12
Generator	Support inspection	-	12
Generator	Cooling system Inspection	-	12
Generator	Cooling system. Accumulator pressure inspection	-	60
Generator	Cooling system coolant Substitution	-	60
Ground Line & Lightning protection	Lightning protection inspection	-	12
Ground Line & Lightning protection	Earth conductor inspection	-	12
Power Cabinet	General inspection	-	12
Power Cabinet	Temperature inspection	-	12
Pitch System	General inspection	-	12
Pitch System	Pitch calibration	-	12
Pitch System	Motorgear inspection	-	12
Pitch System	Gear oil substitution	-	60
Pitch System	Inspection of the motorgear cooling system	-	12
Pitch System	Pitch re-tightening	3	12
Pitch System	Bearings inspection	-	12
Pitch System	Inspection of the clearance between pinion and crown	-	12
Pitch System	Crown grease refill	-	12
Pitch System	Bearing grease refill	-	12
Pitch System	Batteries substitution	-	48
Pitch System	Inspection of the motorgear grease feeding system		12
Converter	General inspection	-	12
Converter	Cabinet cleaning	-	12

System	Activity	Inicial Periodicity	General Periodicitiy
Converter	Components and connections inspection	3	12
Converter	Security system inspection	-	12
Converter	General maintenance of the coolers and fans of the cooling system	-	12
Converter	Cooling System Inspection	-	12
Converter	Cooling system coolant replacement	-	60
Foundation & Concrete Section	Visual inspection	-	12

1

Chart 2. Preventive maintenance periodicity per component

In the following sections are presented the main tasks of the preventive maintenance.

Lesson 2 – Preventive tasks

The objective of this lesson is to introduce the test to be performed during the preventive service and how to perfom them.
During this lesson, the trainee will learn:

(1)General concepts
(2)Check the WTG access and exit
(3)Lock/unlock the low speed shaft
(4)Lock/unlock the high speed shaft
(5)Check the structural bolted unions
(6)To inspect and identify cracks on critical areas
(7)To check the lift and service crane

Wind turbines, like any machine, need maintenance. The involved components are subjected to actions that deteriorate over time. Maintenance is to restore its similar characteristics to the initial state for not to undermine the functionality of the wind turbine. In the following diagram is presented

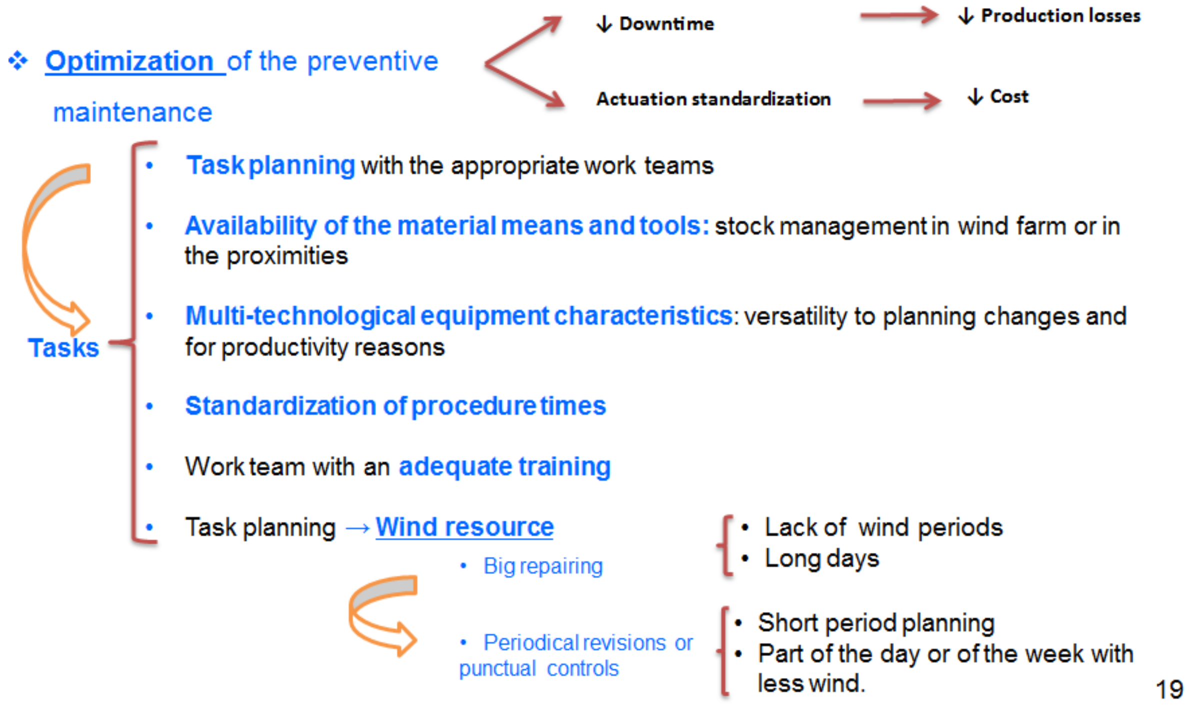


Figure 22. Preventive maintenance tasks

The machines are built with a number of materials and are subjected to a series of stresses in time, resulting in deterioration thereof, which modify its operation to some extent and thus the machine itself. While this operation modification is tolerable with no faults, it could reach a certain state of disrepair where the operation is not the expected and could cause faults.In the following figure is presented the different kind of failures and the steep of propagation which makes feasible to use the preventive maintenance.

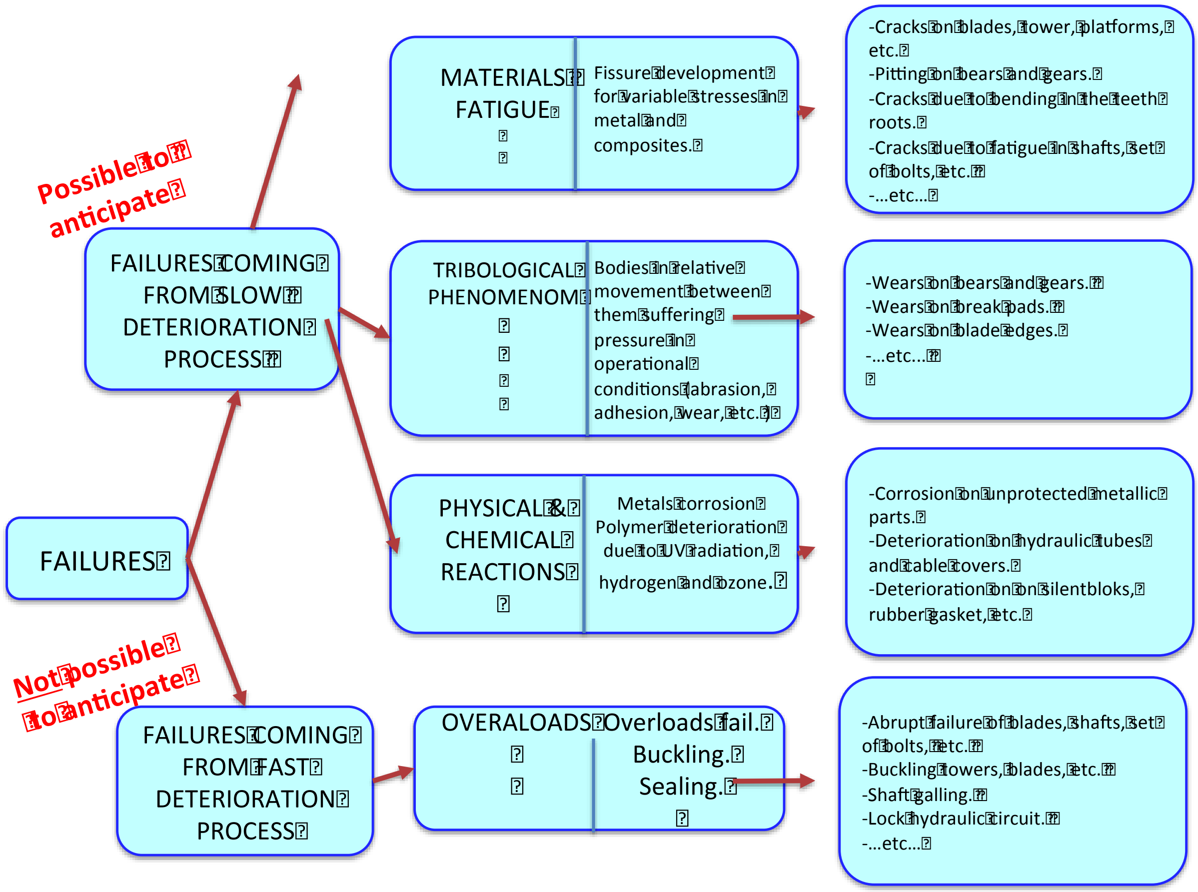


Figure 23. Failure causes diagram

The main parameters to carry out the preventive maintenance are the following ones:

- Power.
- Hydraulic.
- Temperature.
- Mechanical.
- Sample Alarm Log.
- Mechanical Operations.

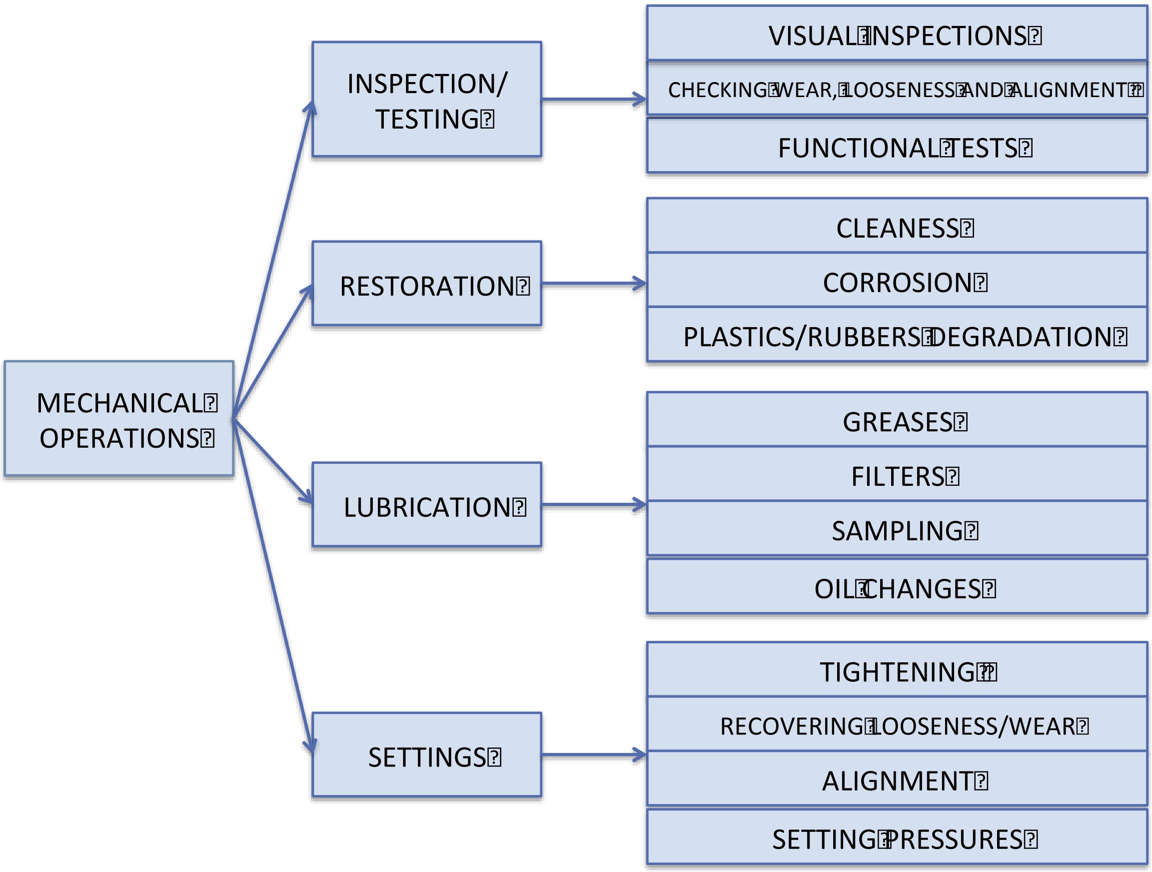


Figure 24. Preventive maintenance mechanical operations

The main activities in preventive maintenance can be summarized as follows:

- Visual inspections:
  - Revising all components to check their status (dirt, wear, corrosion, cracks, loose parts, etc.)
  - Advancing according to a checklist.
  - Reporting with pictures.
  - Specialized topics: shovel and gearbox.
- Checking wear / slacks / lineups:
  - Checking wear on brake linings, in sliding pad and in brushes generators.
  - Measuring clearance in sliding guidance system.
  - Checking alignment generator vane.
- Functional checks:

- Measurement of speed pitch and yaw system.
- Consumption of electric motors.
- Test opening / closing brakes.

- Cleaning:
  - Cleaning everything (grease, oil, dust, rags, other maintenance, carbon rings, collectors, etc.)
  - Treating waste in accordance with procedures and the type of wastes
- Corrosion:
  - Checking metal components if they have lost the protection of paint and have corroded.
- Plastics / degraded gums:
  - Chapped hoses and hydraulic circuits.
  - Plastic housings of some components.
- Fat liquors:
  - Replenishing grease under manual maintenance in blade bearings, pitch, main bearing, bearing orientation, yaw and the generator bearings.
  - Greasing manual pump or checking the automatic lubrication unit.
- Filters:
  - Inspecting filters cleaness if reusable.
  - Changing the disposable filter cartridges periodically or when directed by the signal silting.
- Sampling:
  - Sampling grease blade bearings and main bearings.
  - Sampling gearbox and the hydraulic power unit oil.
- Oil changes:
  - Gearbox oil and hydraulic oil should be analyzed periodically and if they have lost their properties substantially or have become contaminated should be changed.
- Retightening:
  - All bolted joints need to be proven to not lose their tightening.
- Lost scuffs / gaps:

  - Replacing worn brushes generator. Cheap components they are replaced every six months
  - Replacing worn brake linings.
  - Replacing skid plates worn yaw system.
- Lineups:
  - Aligning the generator with the gearbox.
  - Aligning vane with axis wind turbine.
  - Aligning rotor stator electric motors yaw and pitch.
- Setting pressures:
  - Checking nitrogen pressure accumulators.
  - Adjusting calibration of pressure relief valves.
  - Setting of pressure reducing valves.

Lesson 3 – Drive train

During this lesson, the trainee will learn: *(1)The task needed to accomplish the preventive maintenance within the drive train* *(2)How to perform those tasks* *(3)To identify the different components of the drive train and their fucntions*

Preventive maintenance within the drive train

There are preventive activities that are carried out in the orientation systems, the main ones would be the following:

  - Checking that the geared motors are turning oil
  - Greasing the sliding track crown (following lubrication instructions).
  - Greasing the teeth crown (manually or by the lubrication automatic system).
  - Manually actuating the yaw clockwise and counterclockwise.
  - Observing regularity in the rotation (without hard points, or rubbing noises) and measuring the time taken to complete one lap. Checking that turning speed (rpm) is within range.

- Checking that the WT orientation is guided correctly by the wind: vane-nacelle alignment.
- Checking the correct activation and deactivation of the active brake (if there is active brake)
- If current can be measured with current clamp individually, checking yaw motors current and verifying there are no significant discrepancies (<15%).
- If marked the geographic North (or other reference 0), checking if the position in the Nacelle is correctly oriented.
- Checking the counter right turns.
- Checking the automatic unrolling (3 or 5 laps).

Main shaft preventive maintenance

There are several activities that should be performed in the main shaft preventive maintenance and are the following:

1. Locking and unlocking of the main shaft.

Following the rotor locking procedure shown in the Engineering, commissioning and operation module..

If any of the blades is out of the flag position, THE LOCK CAN NOT BE USED.

2. Checking the torque of joint block-frame.

Visual inspection of the 100% of the joint bolts, verifying the match between torque marks.

Figure 25. Joint block frame torque checking

3. Checking the torque of the joint between hub and main shaft.

In order to check the torque fo the joint between the hub and the main shaft, the rotor protection (hexagon socket), and the round-counter plate should be removed.

Torque inspection of 10% of the bolts in the joint between hub and main shaft must be performed.

Visual inspection of 100% of the bolts in the joint between hub and main shaft must be performed, verifying the match of the torque marks and filling the checklist report.

This torque will depend on the bolt size and grade, according to the following chart (± 5-10%):

Tamaño	Grado	Par de apiete M_A en Nm para μ_K=						
		0,08	0,10	0,12	0,14	0,16	0,20	0,24
M8x1	8.8	19	22	24,5	27	30	33	36
	10.9	28	32	36	40	43	49	53
	12.9	32	38	43	47	51	57	62
M9x1	8.8	27	32	36	40	43	49	53
	10.9	40	46	53	58	63	71	78
	12.9	46	54	62	68	74	83	91
M10x1	8.8	39	45	52	57	62	70	77
	10.9	57	67	76	84	91	103	113
	12.9	66	78	89	98	107	121	130
M10x1,25	8.8	37	43	49	54	58	66	72
	10.9	55	64	72	79	86	97	105
	12.9	64	74	84	93	100	113	123
M12x1,25	8.8	65	77	87	96	104	118	130
	10.9	96	112	125	140	150	175	190
	12.9	112	130	150	165	180	205	225
M12x1,5	8.8	63	74	83	92	99	112	122
	10.9	93	108	122	135	145	165	180
	12.9	109	125	145	155	170	190	210
M14x1,5	8.8	103	121	135	150	165	185	205
	10.9	150	175	200	220	240	270	300
	12.9	175	205	235	260	280	320	350
M16x1,5	8.8	155	180	205	230	250	280	310
	10.9	225	270	300	340	370	420	450
	12.9	270	310	360	390	430	490	530
M18x1,5	8.8	230	270	310	350	380	430	470
	10.9	330	390	440	490	540	610	670
	12.9	380	450	520	580	630	710	780
M18x2	8.8	220	260	290	330	350	400	430
	10.9	320	370	420	460	500	570	620
	12.9	370	430	490	540	590	660	720
M20x1,5	8.8	320	380	430	480	530	600	660
	10.9	460	540	620	690	750	850	940
	12.9	530	630	720	800	880	1000	1090
M22x1,5	8.8	430	510	580	640	700	800	880
	10.9	610	720	820	920	1000	1140	1250
	12.9	710	840	960	1070	1170	1350	1450
M24x1,5	8.8	640	700	760	830	890	1020	1140
	10.9	900	990	1090	1180	1270	1450	1630
	12.9	1060	1170	1270	1380	1480	1690	1910
M24x2	8.8	540	640	730	810	890	1010	1100
	10.9	780	920	1040	1160	1250	1450	1550
	12.9	910	1070	1220	1350	1500	1700	1850
M27x1,5	8.8	920	1010	1110	1200	1290	1480	1670
	10.9	1310	1440	1580	1710	1840	2110	2380
	12.9	1530	1690	1850	2000	2160	2470	2780
M27x2	8.8	790	940	1070	1190	1300	1500	1600
	10.9	1130	1350	1500	1700	1850	2100	2300
	12.9	1300	1550	1800	2000	2150	2450	2700
M30x1,5	8.8	1280	1410	1540	1670	1800	2060	2320
	10.9	1820	2000	2190	2370	2560	2930	3300
	12.9	2130	2340	2560	2780	2990	3430	3860
M30x2	8.8	1240	1370	1490	1610	1740	1990	2240
	10.9	1770	1940	2120	2300	2480	2830	3190
	12.9	2070	2270	2480	2690	2900	3310	3730
M33x1,5	8.8	1700	1880	2050	2220	2400	2740	3090
	10.9	2430	2670	2920	3170	3410	3910	4400
	12.9	2840	3130	3420	3710	4000	4570	5150
M33x2	8.8	1450	1750	2000	2250	2450	2800	3100
	10.9	2100	2500	2800	3200	3500	4000	4300
	12.9	2450	2900	3300	3700	4100	4600	5100

Figure 26. Torque variation with bolt diameter

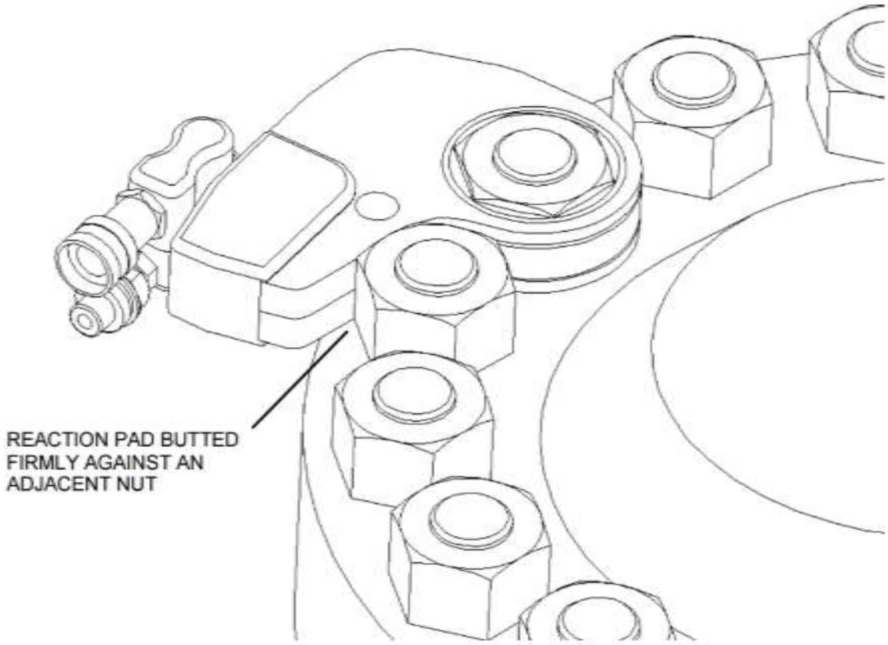


Figure 27. Reaction pad placement

The assembly the 2 halves of the round-counter plate over the joint between hub and main shaft is made using the bolts to center them.

The plates have to be joined to the bolts, tighting them with the proper torque. The distance between plate and inductive sensors should be checked considering that it must not be more than 5mm.

By turning the main shaft it is necessary to verify that all over the perimeter the distance between the round-counter and the bolt is not higher than 2mm. The main shaft turning depends on the wind speed. If wind speed is high enough and the machine is oriented properly, the shaft will turn by itself. If the wind speed is not high enough, the shaft can be moved by using the WTG control, moving the blade to a non 90º position from the control.

4. Checking the joint between main shaft bearings to nacelle front frame

It is necessary to make a visual inspection of the 100% of the joint bolts, verifying the match between torque marks.

5. Checking Main Bearing Noises

It is mandatory to listen to any noise or vibration from the bearing mounting when rotor is turning slowly.

Another verification is to make the rotor turn slowly, then stop the turbine by pushing an emergency button and looking at the clearance between the main shaft and the bearing shield.

6. Main bearing greasing

In order to grease the main bearing, the grease nipples have to be dissembled which is/are placed over the bearing shield, as well as the aeration cap/s placed on the lateral side of the front bearing tap.To be able in order to distribute the grease the rotor should be turnning slowly. Then through the grease nipple placed on the top side of the bearing, introduce the proper proper grease in recommended quantities.

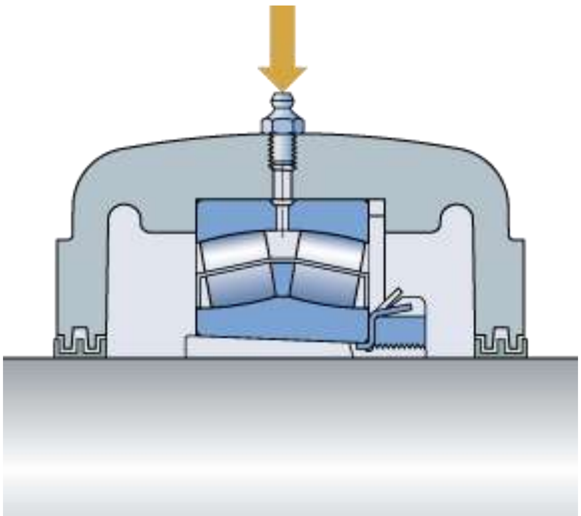


Figure 28. Greasing through the grease nipple

In case of grease leaking out the bearing, an extra quantity of grease should be added depending on the amount of used grease founded in the grease-collecting tray.

Figure 29. Grease leaking out of the bearing

After greasing the bearing, the upper grease nipple and the aeration cap should be assembled.

7. Checking torque of the fastening bolts of the locks

It is necessary to disassemble the hub protection to perform this operation. Then,the torque of four bolts, which should be diagonally opposite, according to the torque table, should be verified.

Once accomplished this operation, put the protection on its right position.

8. Checking torque of the fastening bolts for the lock tap.

It is necessary to disassemble the hub protection to perform this operation then both front and back support bolt torque should be verified. At the end of the operation, the protection should be reassembled back in its right position.

9. Checking the remaining grease

Any existing leaks through the main shaft lockers should be searched. If leaks appear, it is necessary to introduce into the bearing the same quantity of grease which has been founded in the grease-collecting tray and clean the tray.

Gearbox

As it was done with the main shaft, all the elements of the gearbox that are crucial to prevent faults would be checked in preventive maintenance.

1. Gearbox silent blocks

A visual inspection of the 100% of the joint bolts in gearbox silent blocks should be done verifying the matches between torque seals. The shock elastic material should be checked, if any fissure is found, or extension or weathering signals are detected, the rubber should be changed.

2. Gearbox and main shaft joint.

The distance between the two coupling rings should be checked with a gauge, it must be between 5 and 15 mm, depending on the WTG model.

3. Gearbox oil level.

The gearbox oil level should be checked after having stopped it during at least 10 minutes. If the level is low, inspecting the gearbox to look for leaks is mandatory(also the electric rotary joint). If no leaks are detected, it has to be filled-in with oil by following the right instructions of this document and registered into the Preventive Maintenance Control Register.

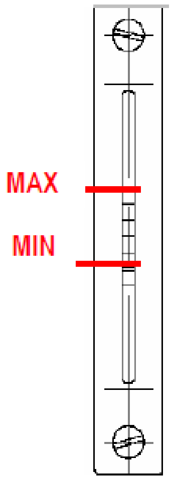


Figure 30. Gearbox measurement levels

An oil sample should be taken in order to be analyzed in a laboratory. The analysis results will be determinant to define the oil changing time.

4. <u>Air filter change.</u>

The air filter condition in the gearbox has to be verified. When the silicon gel balls change their color to pink, the filter has to be changed

5. <u>Gearbox gear, bearing and carter checkout.</u>

It has to be confirmed with a magnetic finger if there are any shavings in the gearbox Carter as well as performing visually inspection of gears and bearings, looking for damages while the gearbox is turning slowly to avoid the acceleration of the turbine.

6. <u>Re-circulation and cooling systems</u>

The V/f variator (frequency switch) condition, the V/f variator wiring and fastening clamps and the torque of the variator plate fastening bolts should be checked.

It is necessary as well to look for dirt between the slits in the intercooler. If any dirt is found, it should be cleaned up.

It should be verified that the fastening flanges of the canvas bellows cover the canvas at the intercooler output. In addition, it is crucial to check the canvas condition and if there are any fissures or weathering sings. If these are found, the canvas has to be changed.

7. Checkout of the joint bolts torque at the gearbox intercooler support.

All the joints and circuit components should be checked in order to verify that there are no leaks or fissures in each of them, paying special attention to those areas where hoses are in contact with any other element.

The fitting and hose tightening all around the circuit should be revised carefully so as to if any gaps between elements are found, re-tighten them.
After performing the maintenance tastks, the valve block pressure switch is to be set-up.

8. Checking the oil pressure at gearbox entry.

Before beginning this test, it has to be verified that there is a minimum lubrication pressure.
The test sequence is the following:

- Putting the pressure-gauge of the distribution block, at the minimess connection, left side of the block.
- Activating the gearbox re-circulation.
- Verifying the pressure gauge pressure. Pressure must never exceed the 6 bar level. In case reaching or exceeding this level, stop the test and check the system looking for any obstruction.

9. Gearbox filter clogging indicator.

The correct operation of the pressure switch, which measure the differential oil pressure between the input and output of the filtering system from the gearbox oil re-circulation system, has to be verified.

Its function is to detect when the filter is obstructed by dirt and the oil circulation is bypassed through the auxiliary parallel circuit without being filtered.

To test this element, it is better to use cold oil, which when circulating through the circuit, will create a high charge loss.

The visual sensor indicator, indicates the differential pressure evolution in the filter. During the test starting time, the indicator must be in the green area, indicating a normal situation in the filter (clean filter). When input pressure increases, it will gradually pass to the red area (dirty filter).

This test sequence is the following:

- Activating the gearbox re-circulation
- Digital input in the I/O module must be switched off. If switched on, the pressure switch connection to the gearbox should be checked.
- Checking that the visual indicator of the pressure switch moves from green to red area. At this moment, digital input in the I/O module must be switched off.
- Disabling the re-circulation test.

After finishing the test, the clogging indicator should be checked, with the oil at 50 or 60ºC and the cooling circuit working, verifying that the indicator is placed in the green area.

10. Silent blocks condition.

The rubber joints in the filter silent blocks have to be checked and if any fissure, gap or weathering problems are found, it should be changed.

In addition, it is necessary to check the torque of the fastening bolts in the silent-blocks filter

11. Valve block fastening bolts.

The torque of the bolts in the joint between the valve block and the gearbox has to be checked out.

12. Filter change

The 0.5 µm filter (micro-filter) has to be changed, so the the cartridge of the 50 µm dirty filter should be removed and the tray cleaned up.

After the filter change the gearbox air filter should be revised in order to check is is dirty, in that case the little balls would be coloured in pink and it has to be changed.

13. Pump silent blocks

The torque of the pump silent blocks as well as the rubber joint in re-circulation pump have to be checked out paying special attention to fissures, gaps or weathering problems. If any of those are detected, the silent-blocks should be changed.

Lesson 4 – Blades & Pitch

The objective of this lesson is to introduce the blades preventive tasks to the trainees.
During this lesson, the trainee will learn:
(1)The tasks needed to accomplish the preventive maintenance within the blades
(2)How to inspect and maintain the pitch system, gears and blade bearings
(3)How to perform those tasks
(4)The different forms to be filled

The tasks needed to accomplish the preventive maintenance within the blades

To accomplish the preventive maintenance within the blades, the following maintenance task should be fulfilled:

First it is necessary to remove the blade drive crashes. The rotor has to be blocked and this test should be performed with wind speed under 9 meter pers second(11 meters per second when the system is individualised by blade). The nacelle should be oriented to wind. With these preparations, the maintenance tasks to be developed are:

- Checking and adjusting the span ends and the pitch position sensor (usual 0-10 Vdc)
  - Negative stop (blades at 0 °). The physical stop of the blades should be checked.
  - Positive stop (blades at 83º). The physical stop of the blades should be checked
- Control test (offset). reduced signal control is applied to make full tour of 0-83º in both directions.
- Checking the speed range of the pitch actuator. It should be under 2 degrees per second.
- Flow test. a high signal control for the 0-87º full travel in either direction is applied. Checking the speed range (> 5 ° / s) of the actuator pitch.
- Breast Test. From an intermediate position (about 40 °), demand signals are applied to regular monitoring on both directions in steps to -3°, 83°.

In addition, it has to be verified that the pitch is positioned correctly in the demand points

The objective of this lesson is to introduce the tasks to be performed in the drive train, and how to perform this task.

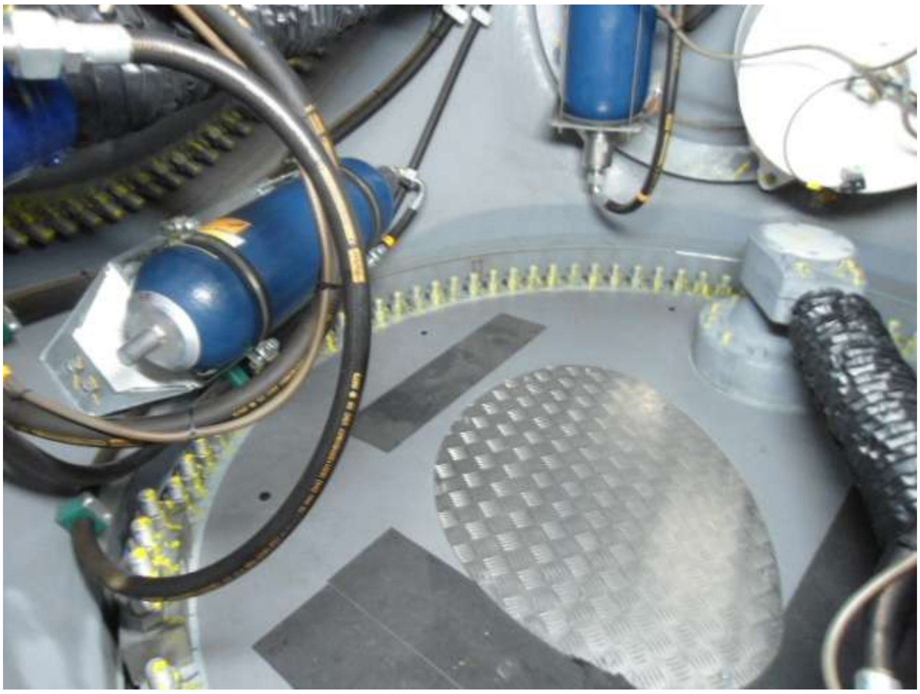


Figure 31. Blade yaw

BOLTS TORQUE IN THE CONE SUPPORT.

It has to be visually checked the bolts which are placed in the cone support.

BOLTS AND RING U-CLAMPS BOLTS.

It has to be visually checked the two bolts placed at the joint in the supporting flange which fastens the ring to the cone fiber in addition to check two bolts in the joint u-clamps of the joint with the ring.

CONE SUPPORT WELDINGS

Checking and looking for possible fissures in the cone support and its weldings is mandatory. If any fissure is found, it has to be photographed and recorded it in the Check-list.

FIBERGLASS CRACKS

It has to be performed a visual checkout at the cone to found possible fissures around the bolts, or simply on the hole cone. If any fissure is found, it has to be photographed and recorded in the Check-list.

L-SUPPORT BOLTS IN THE NOSE-CONE JOINT.

A checkout of the torque marks should be performed, making sure that they have not rotated and check the screwing torque of the nose-cone joint.

BLADE-BLADE BEARING JOINT TORQUE.

A checkout of around 10% of the bolts would be performed by choosing the bolts diagonally opposite of the joint between the blade bearing and the blade. The remaining bolts will be visually inspected by ensuring the torque marks are still in their right position.

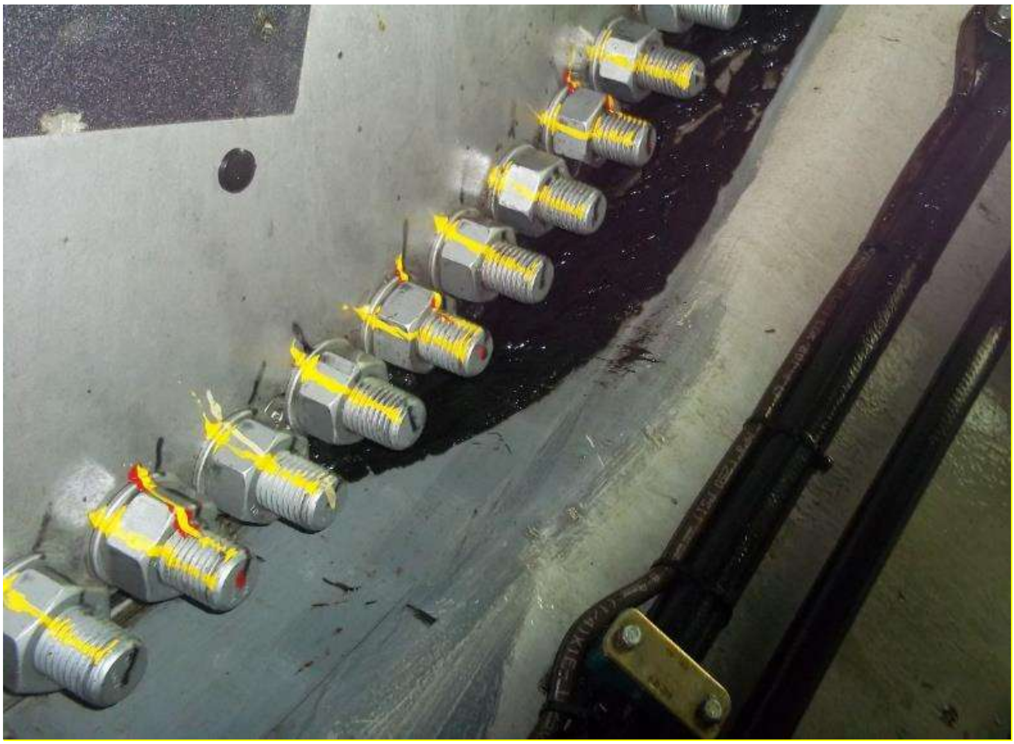


Figure 32. Blade Bearing joint bolts with torque marks

FASTENING BOLTS OF THE PITCH PLATE

Two of the fastening bolts in the joint between pitch plate and blade bearings should be checked.

BEARINGS

The blade bearings have to be re-greased according to the manufacturer recommendations (grease types and quantities).

The inner and outer edges of the bearing holder lips have to be checked to be placed in their right position. Then, it has to be verified that they are in good condition, and that there are no leaks. This operation must be accomplished after having re-greased the bearings.

PITCH PLATE BALL-JOINT

Check 2 bolts diagonally opposite which joint the ball-joint to the pitch plate. This operation will be accomplished in every ball-joints of the blade cylinders.

In case of finding some bolts out of tolerance, readjust all the bolts.

PITCH BALL-JOINT WITH GREASING.

A pump has to be connecte to the ball-joint greaser and pumped until the grease overflow from the ball-joint housing. Then, the blades should be rotated, one by one, from 0 to 90 and from 90 to 0 by using the WTG pitch control.

To finalise the procedure, the excess of grease should be cleaned.

BALL-JOINT-PITCH FASTENING BOLTS TORQUE.

A visual check of the screwing torque of the ending shaft bolt should be performed in the pitch ball-joint. This check must be accomplished for the 3 ball-joints. In case of being out of tolerance, readjust the bolt.

HYDRAULIC CYLINDERS

A visual check of the cylinder protective bellows should be performed, looking for fissures or any flaws.

Then, the screw torque of two of the fastening bolts should be checked in addition to the screwing torque of the joint between the pitch piston rod and the ball-joint.

To conclude, the bolts of the bellows that were loosened should be fastened verifying that the flat faces of the cylinder are in perfect contact with the cylinder wrist.
It has to be checked one of the bolts in the fastening pitch-cylinder to hub lugs. In case of being out of tolerance, the bolts should be readjusted.

In addition, it should be verified that there is not any gap between the cylinder rotating shaft and the sleeve and visually checked that the fastening bolts of the joint between the hub and the cylinder block. In case of being out of tolerance, the bolts should be re-adjusted.

PITCH POSITION TRANSDUCERS.

The condition of the transducers of the blade has to be verified.

HYDRAULIC PITCH VALVES BLOCK

It has to be performed a visual check of the distribution valve block, looking for any existing oil leaks or any other problem as well as a visual and general checkout of all electric connections and the hoses tightening.

Finally, the fastening bolt torque in the joint between the valve block and the hub should be checked.

PITCH ACCUMULATORS.
It has to be perfomed a visual check of the torque in the fastening flanges of the pitch accumulator bolts.
In case of being out of tolerance, the bolts would be readjusted.
Then, a general check of the condition of the welding and flanges, the condition of the shocks rubber in the accumulator supports and the plugs of the accumulator pressure

transducers of each blade should be performed. In addition, the bolts torque in the union between the blade blocking cylinder and the pitch plate should be checked.

HUB HYDRAULIC DISTRIBUTION BLOCK.

The distribution valve block has to be checked by looking for any oil leak or any other problem.

In addition, a general check of a all the electric connections in the block, the hose tightening, the bolt torque in the main hub valve block and the hose and fiting condition, looking for friction points should be performed paying special attento for any hydraulic leak.

PIPES WAY THROUGH THE MAIN SHAFT

The sealing has to be checked in the electric hose pipes and the hydraulic hose pipes in the main shaft joint. The area around Teflon plate of this joint has to be sealed as well.

CONNECTION BOX

It has to be checked the enclosure of the connection box plug, including the sealing.

If the latest is not OK, silicone has to be applied in order to seal the box holes, and the entry of the hoses.

CONNECTIONS IN THE TERMINAL BOX

The connection box terminal state should be checked, paying special attention to corrosion or humidity related problems. In case of detecting any humidity (as green areas in stain parts) the terminals affected should be changed.

GENERAL INSPECTION AND CLEANNING

The hub components condition should be checked in hoses, wire hoses, clamps and other elements. The, the remaining of oil or grease leaks inside the hub should be cleaned.

HUB VISUAL INSPECTION.

While doing the cleaning up tasks, it is necessary to verify the absence of any failure (gaps, fissures) in the internal surface of the hub.

Before going out of the hub, it should be revised that there are not any objects or tools left behind.

Lesson 4 – Yaw System and brake pads

The objective of this lesson is to introduce the preventive tasks to be performed on the yaw system.

During this lesson, the trainee will learn:

(1)The tasks needed to accomplish the preventive maintenance within the yaw system and how to perform those tasks

(2)How to adjust the yaw motors and nacelle centring

(3)How to change the brake pad

The task to be fulfilled in maintenance terms in the yaw systema and brake pads are stated below for each of the main components that form part of those systems.

Figure 33. Yaw hidraulic system

OIL AND GREASE

It has to be checked if there are any oil leaks in the drives.

The oil has to be changed in the 4 drivers, using the right oil type and according to the frequency and quantities required.The gears in the drivers should be filled with grease.

ELECTRIC BRAKE

The electric brake operation and the driver turning should be checked. In order to do that the drivers have to be unlocked by releasing the brakes.

In addition, the electric brake status is to be revised. It is necessary to disassemble the cooling fan protection cap, lift up the braking surface protection rubber and checkout the rusting, the amount of dust and the wear of the brake pads.

To check the electric brake air gap it is necessary to disassemble the cooling fan protection cap, and measure the motor air gap. Right measures are in the range of 0,3-0,4mm.

In order to inspect the electric brakes torque it has to be introduced the torque wrench in the upper side of the motor, in the center of cooling fan and the torque of motor electric brakes should be checked..

MOTOR FAN

Firstly, the motor cap should be removed, using a cross-head screwdriver. Secondly, the condition of the blades have to be inspected, paying special attention to that there are no obstructions or frictions for their right operation.

JOINT BOLTS BETWEEN DRIVER AND FRAME.
The torque of the bolts in the joint between driver and frame should be checked.

HYDRAULIC (ACTIVE) BRAKE SYSTEM
The joint bolts between brake caliper and frame should be checked as well as the brake caliper bolts, paying spcial attention in checking that the torque seals have not moved.

YAW BRAKE PADS
Both pads, the one on the front side and other on the back side, should be verified to be in good condition.
Aditionally, the gap between the frame and yaw gear has to be inspected, checking the visibility of the steel side of the brake pad from this position. It visible, all calipers should be lifted up and the brake pads checked as stated below:

Without pressure in the hydraulic unit, the discharge valve from the yaw circuit should be opened with an allen wrench and the pressure checked with a pressure gauge placed in the inlet, makien sure that there is not hydraulic pressure in the yaw brake calipers.
The supply hoses of the calipers and the fastening bolts should be released by using a magnet, and the the pusher and the brake pad would be removed.

If any problem is found (for instance in brake pad wear), all the pads should be checked and the defective ones replaced. In addition, the rest of brake pads would be measured, and if their width is 3mm or less, it would be replaced.

LEAKS IN THE BRAKE CIRCUIT

All the connections in the yaw hydraulic circuit should be checked, verifying that there are no leaks or fissures in any component.

If drain bottles are full of oil, it is necessary to proceed with further inspection disassembling the caliper and inspecting the joint, replacing them if necessary. The o-ring fo the brake units would be replaced al well if necessary.

Ageneral check should be done paying special attention to to those areas where hoses are in contact with any other element.

FITTING AND PIPES TIGHTENING.

Check the fitting and pipes tightening in the circuit. If any gap or leak is found, they should be re-tightened and this fact recorded.

CALIPER BRAKE-SUPPORT JOINT.

The caliper-frame joint bolts tightening would be verified.

PRESSURE INSPECTION.

A pressure gauge would be placed in the return of the GH inlet in order to verify the operating pressures and residual pressures (for measuring the residual pressure it is necessary to turn the nacelle).

BRAKE DISK INSPECTION

The brake disk and brake surface condition should be verified. This surface must not have any fissure or rusted areas.In addition, it has to be checked specially that the brake disk is not contaminated by grease or oil. If it happens, it is necessary to clean it with paper and solvent. To conclude this task, the brake pad seating would be accomplished by turning the nacelle 2 complete turns, one in each way.

BRAKE PAD WEAR.

The brake pad wear has to be ckecked,as well as the visibility of the pad pin. From the lateral side of the caliper, it has to verified that the brake pad has at least 3mm of braking material. If one of these conditions is not accomplished, the caliper must be disassembled.
Furthermore, it has to be verified the possible presence of braking material along the disk. For this purpouse, the disk would be inspected, lookin for the existence of this material between sectors.

PASSIVE BRAKE SYSTEM.
The bolts of the brake caliper to the main frame should be fastened and checked.

BRAKE PAD WEAR.

The center bolt should be re-tightened and loosen it one time. Then, the gap between the upper side of the bolt and the cover would be measured. If the difference between the starting measure and the measure obtained is higher than 3mm, change the brake pads.
Then, the brakin surface would be greased by applying a brush to the braking surface from the outside of the nacelle frame and turning the nacelle one turn.

BRAKING SURFACE.

The braking surface has to be checked. This surface must not have fissures or rusted areas. It
is very important for the braking system to clean up the gear braking surface, by turning the nacelle while it is being cleaned. For this operation, the plate from the cover has to be released and if there is some reminder oil or grease, proceed to the brake pad seating.

YAW BRAKE PAD SEATING.
The system hydraulic actuator has to be braked. If there is grease or oil in the braking surface or if new pads that have been installed, the Yaw brake pad seating should be accoplished.

If any vibration is produced at the beginning of the seating and the crown is cleaned up, the break pads must be replaced.

GREASING THE TURNING GEAR TOOTH.

The condition of the crown tooth and grease with a brush should be checked.

TURNING BEARING.

The yaw bearing should be re-greased.

INTERNAL BEARING SEAL.

The bearing seal lips should be in their right position, verifiying that they are in good condition of and ensuring that there are no leaks.

TURNING TESTS.

To accomplish the turning test the orientation test from the WTG control has to be activated and then a visual inspection of possible trackings, noises or vibrations from the yaw system would be made.

TOWER-NACELLE JOINT.

BEARING-TOWER JOINT BOLTS.

A sampling torque inspection of 10% of the bolts in the 3rd tower section joint with the Yaw bearing must be done. The remaining bolts will be inspected by verifying the match between torque marks.

A visual inspection of the 100% of the joint bolts must be performed.

BEARING-FRAME JOINT BOLTS.

A visual inspection of 100% of the joint bolts will be accomplished, verifying the matching between torque marks.

Lesson 5 – Hydraulic system

The objective of this lesson is to introduce the preventive tasks to be performed on the Hydraulic system.

During this lesson, the trainee will learn:

(1)The tasks needed to accomplish the preventive maintenance within the hydraulic system & how to perform those tasks

(2)Get familiar with the different parts and functions

(3)How to check the pressure settings and maintain the hoses

Figure 34. Hydraulic system

FASTENING PLATE TORQUE

The torque of two of the bolts in the fastening plate of the unit to the back frame and one of the support arms should be verified as well as the plate condition against possible fissures or deformations.

SILENT BLOCK TORQUE

The torque of two of the bolts which join the silent blocks to the fastening plate of the unit has to be verified.

Then, the condition of the rubber in two of the silent blocks would be checked. If any problem is found,this issue should be recorded in the Check-list.

Finally, the torque of two of the fastening bolts of the silent block to the oil-collect tray would be checked.

STRUCTURE

The condition of the oil-collect tray and the oil tank of the hydraulic unit would be checked, paying spcial attention to possible deformations or fissures.

HYDRAULIC OIL

An oil sample would be taken in order to analyze it in laboratory. Hydraulic oil changing will be accomplished when the analysis recommends it.

A revision of the oil level and the level sensor would be done as well.

Figure 35. Oil level indicator

When the accumulators (general and blades accumulators) are discharged, the oil level is as indicated in the picture.If it it necessary, the accumulators would be filled-in with the proper hydraulic oil.

RETURN FILTER CHANGING.

The return filter would be changed by opening the filter red tap with the hand or if it is not possible with a wrench.

VENTILATION FILTER CHANGING.

Ventilation filter ensures that the air which goes into the tank is clean and water-free. It is composed by blue silicagel grains.

When balls change their color to pink, filter must be changed, or every 12 months.

LEAKS INSPECTION

The hose and fitting condition, yaw brakes connection, brake disk and rotary joint should be checked, verifying that there are no leaks and checking if there is friction between hoses. In case of finding any friction areas, protectiosn would be placed.

To conclude, a inspection of the valve block and all valves looking for leaks would be carried out.

PRESSURE REDUCING AND ADJUSTEMENT OF VALUES

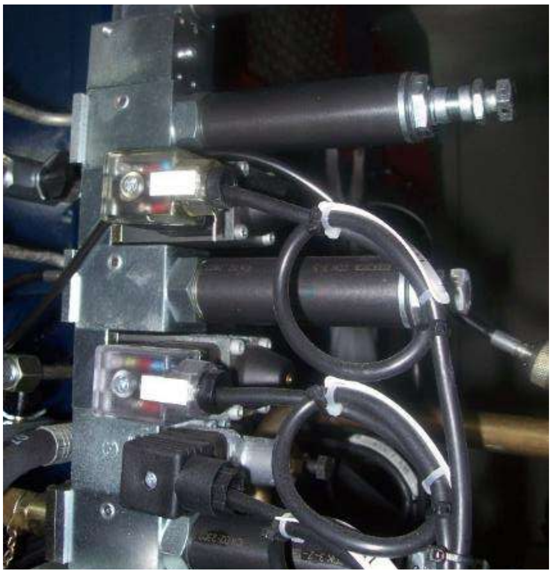


Figure 36. Pressure valves in yaw circuit

-High pressure reducer value in Yaw circuit

To measure this value it is necessary to place a pressure gauge 0-160 bar in the pressure inlet. The hydraulic unit would be started up and it would be verified if the pressure reaches a constant value of 130±2 bar. If not, the wrong value would be noted down and the procedure to its set up would be started.

- Low pressure reducer value in Yaw circuit

Pressure: 0±2bar

To measure this value it is necessary to place a pressure gauge 0-160 bar in the pressure inlet. The hydraulic unit would be started up and the Yaw Turn swiched of by using the WTG control, then it has to be verified if the pressure reaches a constant value of 0+5 bar. If not, the wrong value would be noted down and the procedure to its set up would be started.

-Brake disk pressure reducer value.

Pressure 130±2bar

To measure this value it is necessary to place a pressure gauge 0-160 bar in the pressure inlet. The hydraulic unit would be started up and the high speed shaft brake would be swichted on by using the WTG control, then it has to be verified if the pressure reaches a constant value of 130±2 bar. If not, the wrong value would be noted down and the procedure to its set up would be started.

PRESSURE SWITCHES ADJUSTMENT VALUES.

The unit using WTG control would be charge, verifying that the pressure switch is activated when the pressure reaches the set value.

- Brake accumulator pressure switch. Pressure: 100±2 bar.
- Yaw circuit pressure switch. Pressure: 100+1 bar.
- Pressure switch in brake disk. Pressure: 100±2 bar.

ACCUMULATOR

The torque of that flanges would be checked in addition to the condition of the seals between flanges. If any problem is found, it has to be noted down in the Check-list.

NITROGEN PRESSURE IN GENERAL ACCUMULATORS.

To check the hydraulic unit, the discharge valve would be open to empty the main accumulators reading on the WTG control the value of the pressure in general accumulators.

It has to be noted that nitrogen pressure must be about 150-200 bar ± a tolerance, depending on the WTG model. If read value are not in the tolerance values, the accumulator would be filled andt he flow regulator valve must be completely open.

NITROGEN ACCUMULATOR PRESSURE IN BRAKING SYSTEM.

The hydraulic unit would be stopped and then the discharge valves would be opened to empty the accumulators. The pressure value would be read on the WTG control in the braking system accumulator.

Nitrogen pressure must be about 60-100 bar ±a tolerance, depending on the WTG model. If the read value is not into tolerances, the accumulator would be filled in.

NITROGEN PRESSURE IN BLADE 1 ACCUMULATOR

The hydraulic unit would be stopped and the discharge valves opened to empty the accumulators. The pressure value of the blade accumulator has to be read on the WTG control.

Nitrogen pressure must be about 60-100 bar ± a tolerance, depending on the WTG model. If read value is not into tolerances, the accumulator has to be filled-in.

NITROGEN PRESSURE IN BLADE 2 ACCUMULATOR

The procedure would be done in the same way than in blade 1 accumulator.

NITROGEN PRESSURE IN BLADE 3 ACCUMULATOR

The procedure would be done in the same way than in blade 1 accumulator.

Lesson 6 – Electric, sensors and control system

The objective of this lesson is to introduce the preventive tasks to be performed on the electric, sensor and control system.

During this lesson, the trainee will learn:

(1)The tasks needed to accomplish the preventive maintenance within the electric system and how to perform those task

(2)To get familiar with the different parts and functions

(3)How inspect the main sensors

CABLE CONDITION CHECKING.

The cables conditions has to be verified in different joint points with frame or metal points.

Cable control .

- Joint with the beam which supports the power hoses.
- Input to frame.
- TOP box input.
- Verifying that hoses have not mechanic tension.
- Possible friction when passing the loop and change the loop to the pipe plate.

Power cables.

- The hose fastening should be preformed.
- Verifying that the cables are well tightened to the preform.
- Checking the cover condition.

CABLE TEST.

All cables would be checked looking for damages or defective areas. If cables are damaged, those must be replaced. The cable wear is to be avoided and fixed if found. Loop glands should be checked to be right placed and making sure that they do not damage the wiring. If there is a lot of grease in cables, they have to be cleaned up.

VERIFY CABLE FLANGES.

It is necessary to verify the good condition of the flanges which fasten the power cables both to the pipe supports and to loop and rings, replacing those which are damaged.

CABLE PROTECTION WHEN CABLE PASS THROUGH PLATFORMS.

It has to be verifoed that protections are well placed and that they accomplish their protection task. If not, they have to be placed in their right position.

Lesson 7 – Generator

The objective of this lesson is to introduce the preventive tasks to be performed on the generator. *During this lesson, the trainee will learn:* *(1)The tasks needed to accomplish the preventive maintenance within the generator and how to perform those task*

(2)How inspect the slip rings and brushes

(3)To take thermal images and inspect the cooling system.

(4)How to align the generator and taking vibration measurements

GENERATOR SILENT-BLOCKS.

It has to be checked if there is any fissure or weathering in the silent-block rubber joint in addition to the torque of the frame-silent block joint.

To conclude, it has to be verified that the generator earthing system contacts with the cover.

WINDINGS

This operation should be accomplished with the generator stopped, disconnected from the network and the rotor locked.

STATOR

The insulation of the stator windings has to be meassured, with the generator stopped locked and disconnected from the network. In order to do that, the supply stator switch in Ground must be in OFF position.

ROTOR

The insulation of the rotor winding has to be meassured, with the generator stopped, locked and disconnected from the network. In order to do that, the supply rotor switch in Ground must be in OFF position.

Finally, it is necessary to clean up the sliprings with a specific solvent.

TORQUE IN STATOR TERMINALS

This operation has to be accomplished with the generator stopped, disconnected from the network and the rotor locked.

After having measured the insulation the power wires would be connected and the tightening of the bolts verified in power plugs and the stator connection box.

TORQUE IN ROTOR TERMINALS

It is necessary to accomplish this operation with the generator stopped, disconnected from the network and the rotor locked.

In addition, the tightening of the rotor terminal bolts and rotor box bolts has to be verified.

BRUSHINGS

It has to be checked the contact surface between the brushes and the sliprings, looking for any kind of mark or fissure in addition to check if there is uniform and regular wear of all brushes. If not, they will be changed.

Also the brushes have to be replaced before the available length is reached.

For checking of the available length, the brushes have to be pulled out of the brush holder.

At the latest the brush has to be replaced before the center of the mark is reached.

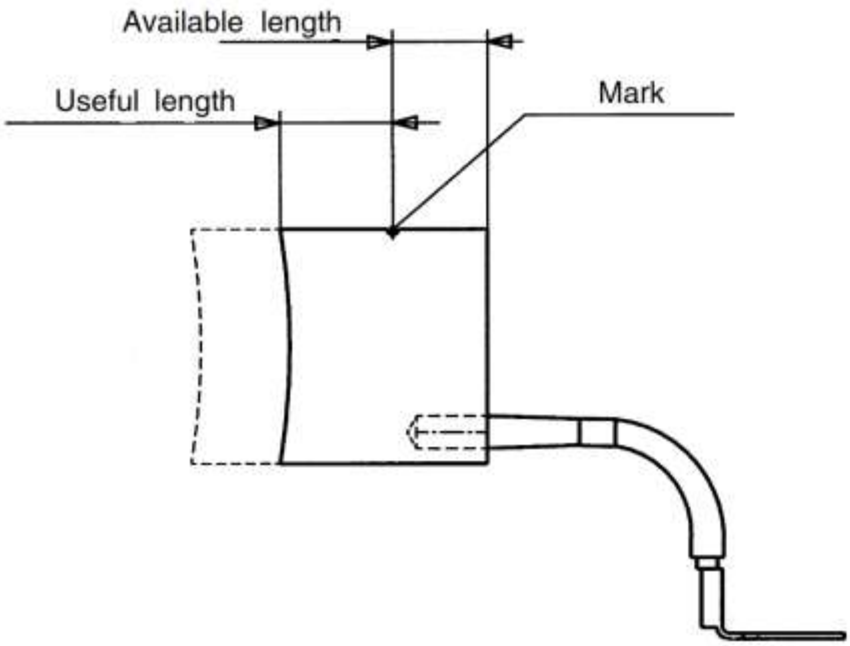


Figure 37. Brushings lenthg

At every maintenance it has to be checked if the useful length is still sufficient until the next maintenance, so that the available length is not becoming too short.

Burnt sliprings have to be replaced as they are not admissible to continue operation.

If the generator is provided with filters in the air guide of the slipring enclosure, this filter has to be cleaned at every replacement of the brushes.
Clogged or damaged filters have to be changed at every replacement of the brushes.

It will be also changed when the brush wear reaches the minimum limit mark (16-24 mm, depending on the WTG model), placed on one of the lateral sides of the brush.

When mounting new brushes they must be carefully seated with the aid of abrasive cloth placed round the sliprings, until approx. 90 % of the contact face is lying on the slipring.

The brush changing procedure follow the next steps:

- Loosening the bolt which fastens the brush.
- Lifting up the holding slide of the brush-carrier.
- Taking out the brush from its housing in the brush-carrier.
- Repeating the same task with all brushes.
- Puting the new brush.
- Screwing the fastening bolt of the brush.
- Puting the brush into its housing.
- Put ingover the slipring (once placed the two brushes of each one of the brush-carrier) a piece of sandpaper (number 2) with the sandpaper side on the top.
- Closing the holding slides of the brush-carriers.
- Moving the sandpaper following the ring curve, ensuring a good seating of the brush with the rings.
- Repeating the operation with all the brush couples of each brush-carrier arm.

BEARING NOISES.

It is necessary to unlock the rotor and listen to any strange noises from the inside of the generator, while it is rotating without generating energy.

GENERATOR DRIVE-END (DE) BEARING GREASING.

To complete this task, the greasing pump socket would be introduced into the greaser, which is on the right side of the tap. The grease kind to be introduced will be found in the characteristics plate.

Figure 38. Greasing pump

The bearing must be greased with the amount of grease indicated in the characteristics plate. With every pumping, a fixed amount of grease is introduced, so it will be necessary to pump as many times as necessary to reach the right quantity. Grease is distributed through the bearing, pushing the old grease to a container.

It does not have to be introduced more grease than necessary, because having too much grease can cause an overheating of the bearings.

It has to be ckecked if there are some grease in the vessels, cleaning them up if necessary. In case of this grease being black, it may indicate that there is a lack of grease in the bearing.

It is necessary to clean up the areas where dirt could appear in the DE and NDE bearings, which can reduce the isolating of the bearing.

GENERATOR NON DRIVE-END (NDE) BEARING GREASING.

The same steps stated at the previous paragraph should be followed.

INTERCOOLER.

The condition of the intercooler unit has to be checked, including the exhaust bellows and verifying that the condition of the fan blades and the protection grills.

CLEANING OF THE ELECTRIC COOLING FANS.

The electric supply automatic switches have to be disconnected, releasing the protection grill of the fan and cleaning the grill and the blades. The same task with the other fan has to be accomplished.

JOINT TORQUE BETWEEN INTERCOOLER AND GENERATOR

It has to be checked the torque of 2 bolts, diagonally opposite, according to the metric and size of the bolt.

DRIVE-END (DE) BEARING SHIELD TORQUE

The same checking task specified for the joint toruque would be carried out.

HEATERS

The heaters in the generator winding and the slipring have to be checked. In order to accomplish that tast, the bolts in the auxiliary connection box tap have to be released.

WINDING HEATERS

Firstly, it is necessary to disconnect the automatic switch.Then, the resistance connected would be released and it would checked that the resistor is not open. If it is open, it must be changed.

SLIPRING HEATER.

It should be done in the way it was specified for the winding heaters.

CHECK THE ALIGNMENT.

It is necessary to check the generator alignment with respect to the gearbox by using an aligning laser tool.

Figure 39. Alignment tools

Firstly, the high speed shaft should be stopped and locked and the turbine yawed to back wind before lining up the generator.

Secondly, the distance at the top and at the bottom would be measured as well as the distance between the opposite faces.

It is necessary to remark that each laser head must be fitted at 12 o'clock at the top of the flange on the gear side and the generator side respectively.

Figure 40. High speed shaft alingment

The laser heads must be positioned directly opposite each other but making sure that they do not touch other turbine parts when the flanges are turned. There is a “moveable” (generator side) and a “stationary” (gearbox side) laser head.

The “stationary” laser head should be fitted on the gearbox side with a magnet on the brake disc, having cleaned previously the brake disc before the fitting to ensure that the magnet does not move.

The “moveable” laser head would be fitted on the generator side with a bracket on the generator flange, aligning with the center between the two bracket legs and fitting the laser head such that its mirror image can be seen in the opposite laser head, visible in the vertical slit.

The two laser heads should be adjusted such that the red line hits the bright area on the laser head. Firstly, it would be adjusedt the line hitting **M** by adjusting the **S** head. Then, this operation should be repeated for the opposite adjustment.

The tolerance in the laser console/screen has to be set depending on the WTG model for the following values:

- Angular deviation: it indicates the maximum bend of the coupling permitted
- Parallel displacement: it indicates the maximum vertical and lateral deviation permitted between generator and coupling.

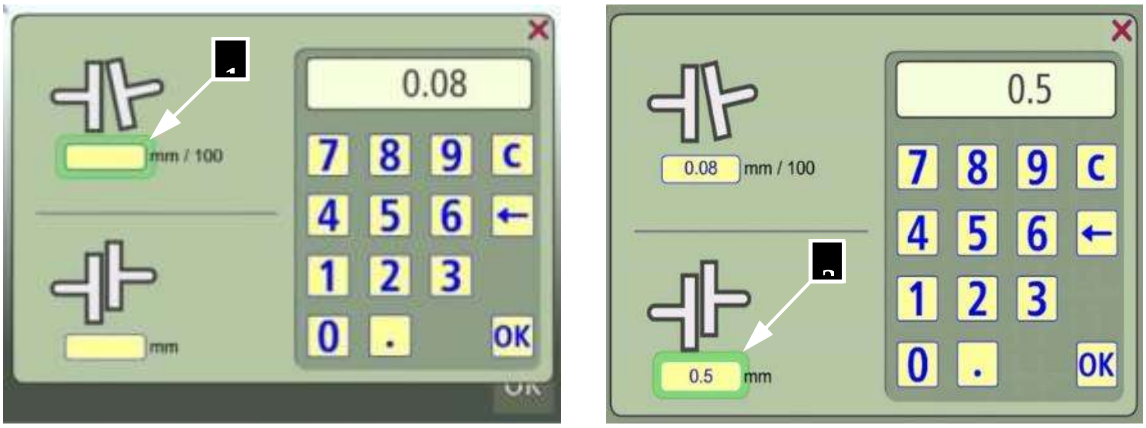


Figure 41. Deviation vertical and lateral values

The laser console/screen will now ask for some measurements that would be performed as it is stated below:

- The first measurement the computer will asks for is **measurement A** that measures the distance between the centers of the two stud bolts on which the laser heads are fitted
- The computer will divide **measurement A** by two.

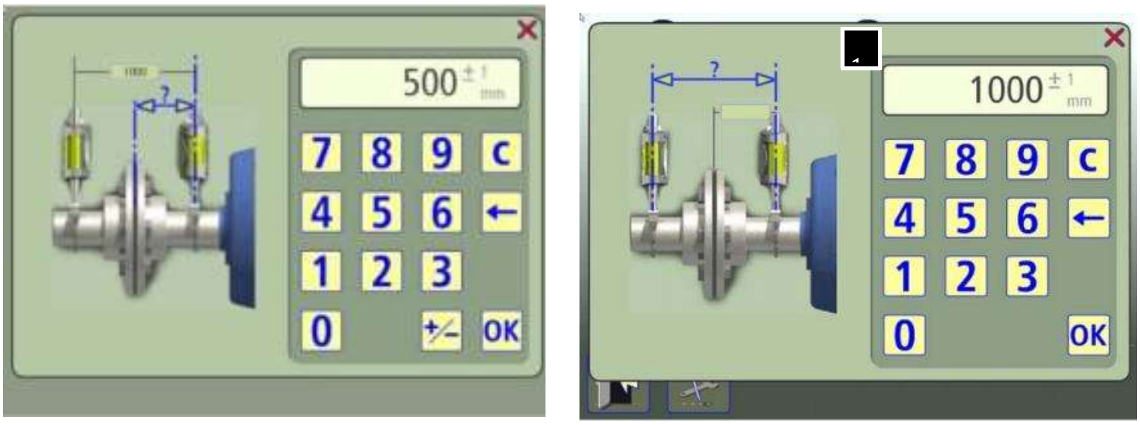


Figure 42. On the left picture measurement A divided by two and on the right picture measurement A

- The third measurement the computer asks for is **measurement B,** from the rear sensor (sensor M) to the center of the front foot.
- Measurement **C** is between the feet, it measurse from center to center of the bolts in the generator feet.

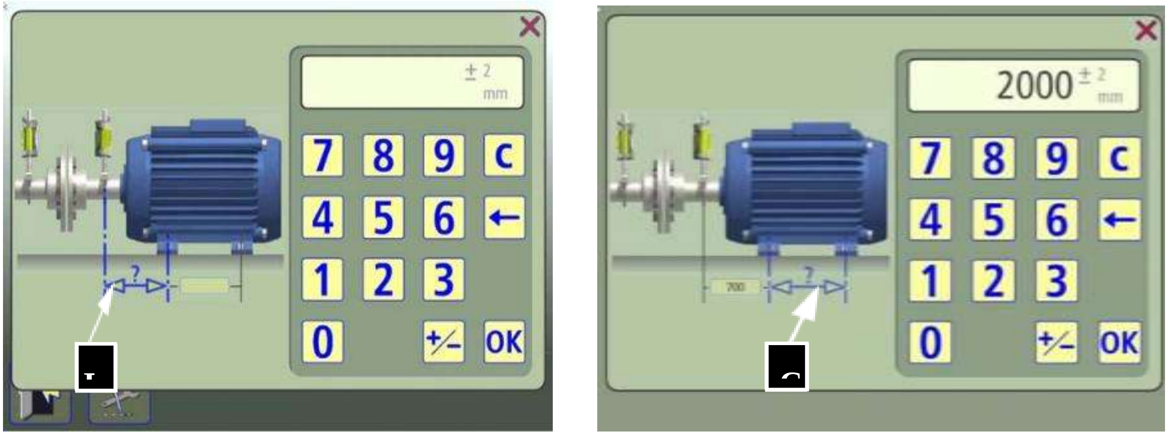


Figure 43. Measurement C

The laser measurement procedure would follow the following steps:

- Dismounting the HS rotor lock
- Then, turning the lasers outside the red area to take the next measurement B
- Turning the coupling. The red lights from the laser heads must hit inside the bright area all the time.
- Take a second measurement
- Finally, turning in the opposite direction to take the last measurement

The laser screen picture below shows the position of the generator relative to the gearbox and displays all the deviation measurements.

Vertical angular deviation.
Vertical parallel deviation.
Horizontal angular deviation.
Horizontal parallel deviation.

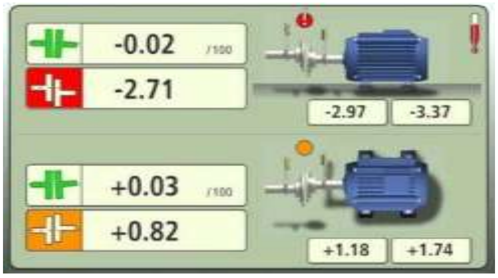


Figure 44. Gearbox measurement angular and linear deviations

After obtaining the measurements, the element deviations would be reducing by adjusting them. Firstly, the height of the generator (vertical parallel deviation) would be settled because the generator might shift sideways when it is lifted.

ADJUSTMENT OF GENERATOR WITH FIXED FEET.

The generator silent blocks should be adjusted by using shims if necessary It would be used the number of mm of shims at each foot that the laser equipment shows.

The nuts would be loosened using a hydraulic piston when inserting shims as well as for the horizontal alignment of the generator.

Finally, the laser alignment equipment would be dismounted and the high speed shaft unlocked..

Unlock high speed shaft.

MEASUREMENT OF THE INSULATION OF THE BEARING.

The insulation resistance of the front bearing should be checked. It will be done with the generator stopped and locked.

1. First, the generator ground brush should be taken out of its housing in addiction to the rest of brushes in ring body.

2. Secondly, the insulation resistance should be meassured between the shaft and a steel point in the generator shield. For that task, a maximum of 100VDC have to be applied. The resistance value must be over 10kΩ. If it is lower than that, the dust and dirt should be cleaned from the bearing shield.

Lesson 8 – Ground line & lighting protection

The objective of this lesson is to introduce the preventive tasks to be performed on the ground line and the lightning system.

During this lesson, the trainee will learn:

(1)The tasks needed to accomplish the preventive maintenance within the earthing system and how to perform those tasks

(2)To get familiar with the different parts and functions.

(3)How to inspect the earthing brushes.

EARTHING WIRING SYSTEM.

Every 12 months, it has to be verified that all earthing wires are well tightened and connected (the terminal has a good support base), which are the following:

- Cover earthing wires.
- Generator earthing wires.
- Hub earthing wires.
- Hydraulic earthing wires.
- Tower base earthing connection.
- Top box earthing wires.
- Ground box earthing wires.
- Tower section earthing wires.
- Pipe base earthing wires.
- Lightning conductor wires.

Lesson 9 – Power cabinet

The objective of this lesson is to introduce the preventive tasks to be performed on the power cabinet.
During this lesson, the trainee will learn:
(1)The tasks needed to accomplish the preventive maintenance within the power cabinet and how to perform those tasks
(2)To get familiar with the different parts and functions

HEATSINK

The operating temperature of the heat sink should be verified to proceed to clean it up as follows:

- Removing the fan as it was described later
- Reading and following the steps described in Safety Instructions.
- Opening the box doors.
- Removing the fan supply connector.

- Removing the fastening bolts.
- Removing the fan through the rails.
- Cleaning up the compressor from the bottom side to the upper side by using a vacuum machine to avoid the dust between gaps.
- Placing again the fan.

AIR FILTER

To change the air filter, the following task should be performed:

A. Accessing to the grill filter by removing the upper side clamp (a), then raising the grill (b) and removing it from the door (c).

B. Accessing to the air filter unit by releasing the bolts (d) and pulling out the filter Verifying that the box is cleaned up.The inside of the box would be cleaned if necessary using a brush or a vacuum machine.

TERMINALS AND WIRES

The right guide of the wires should be checked and it has to be ensured that they are not in contact with any bare plate.

The possible problems in insulations and hot points should be checked, verifying the color of insulating and terminals.

It has to be checedk that the wiring which goes to the fast connector have enough tension. The DC input and the terminal torques are described in the table.

CABLE TERMINAL	TORQUE
DC	50 Nm
Input and output busbars (L1, L2, L3, U, V, W)	70 Nm

Figure 45. Wiring tension and torque

To finalise this procuedure:

- Taking out one unit from the box.

- Cleaning up all contact surfaces of the fast connector.
- Inserting the unit and repeating the process with each one of the remaining units.

Lesson 10 – Converter

The objective of this lesson is to introduce the preventive tasks to be performed on the Converter system.
During this lesson, the trainee will learn:
(1)The tasks needed to accomplish the preventive maintenance within the converter system and how to perform those tasks
(2)To get familiar with the different parts and functions

To carry out inspection tasks is necessary to open all the supply switches and fuses that apply at each box and to accomplish handling tasks is necessary to open it and auxiliary devices switch; wait 10 minutes until capacitor bus discharge.

BOXES, LOCKS AND HANDLES
Every 6 months, an overall visual inspection of covers is needed, verifying the condition of locks, doors and handles. If any problem is found, it should be noted down and fixed it as soon as possible.

TIGHTENING TORQUES CHECK
Every 12 months, the visual check of tightening torques in joints between busbars and external hoses should be perfomed including .bolt seal condition and power cables condition. In case of finding any handling, check the tightening and then seal the bolts.

OVERVOLTAGE PROTECTIONS
Every 12 months,an overall visual check of the overvoltage protections should be performed, by checking if there are any defective indicators in upper side. In case of having any defective element, it should be changed and placed a new protection element.

TERMINAL AND CABLE CONDITIONS

Every 12 months, a visual check of the right cable guide should be performed, ensuring that any cable is in contact with any bare plate.

Every 12 months, It has to be visually checked and looked for possible defective areas in insulations and hot points, verifying the insulating and terminal color. If any problem is found, it should be noted down in the CKL.

To conclude this task, a visual check of the processor of the connector condition should be performed.

RELAYS

Every 12 months, it has to be visually checked the manual force elements of the relays, in case of finding any forced relay,it has to be tried to change it to its working position.

FAN FILTERS

Every 12 months, the air extracting fan filter condition has to be cheked and if it is necessary, the filer should be changed.

HEATING RESISTOR

Every 12 months, the operation of the heating resistor inside the processor compartment should be cheked. First, the circuit breaker should be opened to disable the fan and then increasing the adjust in thermostat until the resistor starts working.

FANS

Every 12 months, the right fan operation should be revise. Firstly open the electrical breaker and then decreasing the thermostat value until fans start working.

TEMPERATURE SWITCHES

Every 12 months, the thermostats tare would be revised.

CIRCUIT BREAKERS

Every 12 months, the heading circuit breakers set has to be checked..

POWER SUPPLIES

Every 12 months, it has to be checked the right condition of the power supplies by looking at the OK led, in each power supplies.

CAPACITORS

Every 12 months, a visual check of the bus capacitor condition of the power equipment should be made, looking for possible defective areas in their covers.

HARMONIC FILTER RESISTORS

Every 12 months, a visual checkout of the condition of harmonic filter resistors and their wiring has to be perfomed, because they can be affected by thermal efforts. If any wear detected which can affect the machine behavior due to heating,the defective element should be prelaced

FILTER CONDITION CHECK

This task should be performed every 12 months, checkoing the EMC filter condition.

UPS

Every 6 months, the UPS operation should be checked.

Lesson 11 – Tower & Foundation

The objective of this lesson is to introduce the preventive tasks to be performed on the Converter system. *During this lesson, the trainee will learn:* *(1)The tasks needed to accomplish the preventive maintenance within the converter system and how to perform those tasks* *(2)To get familiar with the different parts and functions.*

CONCRETE BASE CRACKS

It has to be perfomerd a visual checkout that there are no cracks in upper side of concrete crown. If any problem is found it has to be noted down on the Checking List.

FOUNDATION SECTION CLEARANCES

It has to be checked that there are no clearances between internal bottom flange of the first section and the concrete foundation. Check that there are no rusted areas in founding section.

LADDER AND LIFELINE FASTENINGS

The torque of the fastening bolts of the ladder should be checked, making sure that they are fastened to the foundation.

FALL ARREST SYSTEMS

A complete checkout of the fall arrest system would be make, paying special attention to the following aspects:

- There are no bundles or pinches.
- There are no damages.
- There are no rusted areas.
- There are no free wires.
- There is no grease along the cable.
- Nylon guides are not broken or damaged, and keep working.

TAP PLACING IN PLATFORMS.

A visually checkout would be performed in order to check that bolt access taps in tower platforms are placed rightly. If not, they should be placed in their right position.

PLATFORM CLEANING

Overall cleaning of tower platforms.

JOINT BOLTS BETWEEN FOUNDATION AND FIRST TOWER SECTION

A sampling inspection of the 10% of the bolts in foundation should be accomplished by,using at the same time 2 pullers (one inside the tower and other outside it).

Figure 46. Joint bolts inspection

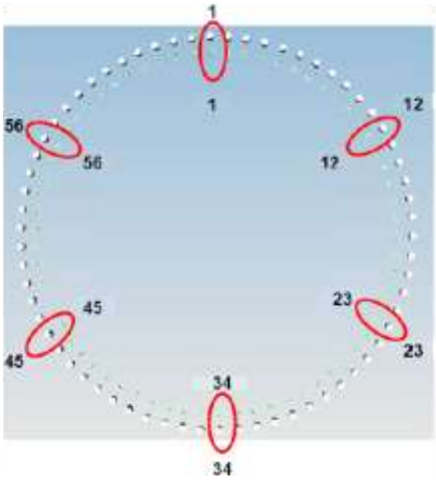


Figure 47. Two puller inspection for joint bolts check

A visual inspection of the remaining bolts should be carried out, verifying the match between torque marks. An extra inspection would be made every 2 years, checking the 10% of the bolts by using 4 pullers and only one hydraulic pump.

Every 6 months, a visual inspection of 100% of the bolts should be carried out, verifying the match between torque marks. Those bolts must be tightened with a puller.

STEEL TOWER

The protection caps has to be placed on the bolts when the inspection or the tightening has ended.

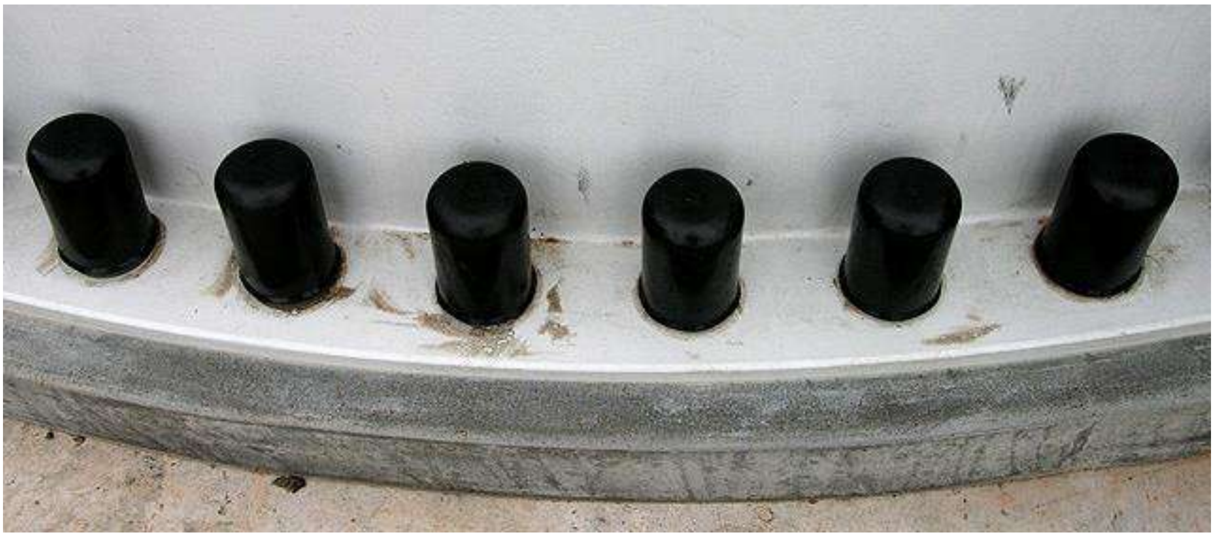


Figure 48. Joint bolt protection caps

JOIN BOLTS BETWEEN FIRST AND SECOND TOWER SECTIONS

A sampling inspection of 10% of the bolts have to be carried out as well as accomplishing a visual inspection of the remaining bolts, verifying the match between torque marks. Every 6 months, it has to be accomplished a visual inspection of 100% of the bolts in the joint, tightening them with a torque wrench with torque multiplier or with hydraulic screwdriver.

JOIN BOLTS BETWEEN the SECOND AND THIRD TOWER SECTION.

3 months after the turbine startup, and then every 2 years, it has to be carried out a sampling inspection of the 10% of the bolts, by accomplish a visual inspection of the remaining bolts, verifying the match between the torque marks. Every 6 months,it has to be accomplished a visual inspection of 100% of the bolts in the joint, verifying the match between torque marks.

They would be tightened if necessary with a torque wrench with torque multiplier or with hydraulic screwdriver.

LADDER AND PLATFORMS BOLTS

It has to be checked that there are not loosen bolts in tower ladders and platforms. Then, they would be tightened if necessary..

DOOR STRUCTURE WELDINGS

The door structure weldings have to be checked, both inside and outside, and the door frame.

TOWER SURFACE TREATMENT

The surface treatment should be checked by using binoculars.

LOOP CONDITION

The tightening of the loop to the tower should be checked, verifying with spcial attention the tightening of the cable fastening bar. The Loop bolts must be tightened but ensuring that they allow the loop movement. Then, the bolts should be greased and it has to be checked if cable clamps are in good condition.

SAFETY SIGNS

Every 12 months, it has to be checked that all safety or prevention posters or signs are placed. If not, new safety signs should be placed.

CORRECTIVE MAINTENANCE

Designed to provide the OM technicians with the necessary knowledge in corrective operations. This module is divided in the three main groups or systems: mechanical, electrical and control / communication systems.

This training is aimed to learn how to top perform WTGs corrective maintenance and its different tasks. Moreover, at the end of this training, the trainee will have learnt and understood how to carry out a preliminary analysis and the proper actions to troubleshooting WTG level 1 incidents.

Lesson 1 – Introduction to Corrective maintenance

The objective of this lesson is to introduce the corrective maintenance to the newly wind technicians.

During this lesson, the trainee will learn:

(1)General

(2)To understand the troubleshooting guides, the different control routines and reactions in case of failure

(3)The different parameters, values and limits

(4)How to locate the different alarms on the electrical drawings

(5)How to check the correct signal of each alarm

The wind turbine machines are made of several components which are built with a number of materials that are subjected to a series of stresses in time, that may modify its operation to some extent and thus the machine itself. While this operation modification is tolerable if no faults appear, if reached a certain state of disrepair the operation is outside the specified or expected parameters and could arrive at fault.

Nowadays in the WTG, all maintenance companies apply preventive maintenance and corrective maintenance once failure is produced.

Predictive maintenance has recently begun to be used with the multi-megawatt wind turbine arrival, where the relative cost of the necessary resources (sensors, communication, analysis) is less than for smaller wind turbines, and it allows the use of these techniques.

The corrective maintenance in wind turbines is done in two different ways:

- In-site reparations of the damaged component.
- Replacement of the damaged component.

Most of the corrective interventions are in fact component replacements, for instance, if the bearing of a gearbox has failed and is replaced on-site, it is said that the gearbox has been repaired on-site, although, what has been done is a component replacement.

All on-site reparations related to nacelle machinery are also called up-tower reparations. For this reason, it’s normal to watch in the multiplier corrective interventions stadistics, the separation of the gearbox replacement cases from gearbox reparations up-tower cases.

One of the few components that is usually repaired on-site, not replacing any of its pieces or subcomponents, is the blade. In this case, most of the corrective reppairs applied to the damaged area, are materials to restore its properties.

Within the corrective maintenance with replacement components, it is to mention specially the cases where the affected component is a big component (blade, main shaft, gearbox, generator, nacelle…). These cases are named Big Correctives because they require special means that are not usually part of a wind farm.

There are other component replacement operations which require the same special means, even if they are not big in size, they are also considered big corrective maintenance operations.

Lesson 2 – Communications and Network

The objective of this lesson is to introduce the communications and network corrective maintenance to the newly wind technicians.
During this lesson, the trainee will learn:
(1)The differences between WTG communication and network.
(2)How to identify and check the communication wires.
(3)How to locate the different alarms on the communication systems.
(4)How to check the correct address for the communication devices.

The historic Alarm Log shows when the alarm was activated (in red) and when it was reset (in green) and the indicators Time On and Time Off show the time that the alarm has been activated. If the duration of an alarm is short it could indicate that it was possibly a false alarm
The indicator of Active Alarms shows the full list of active alarms and pushing on the arrow more information about each alarm would be displayed.

There are a lot of possible netwok configurations deployed in a Wind farm. The most used one is:

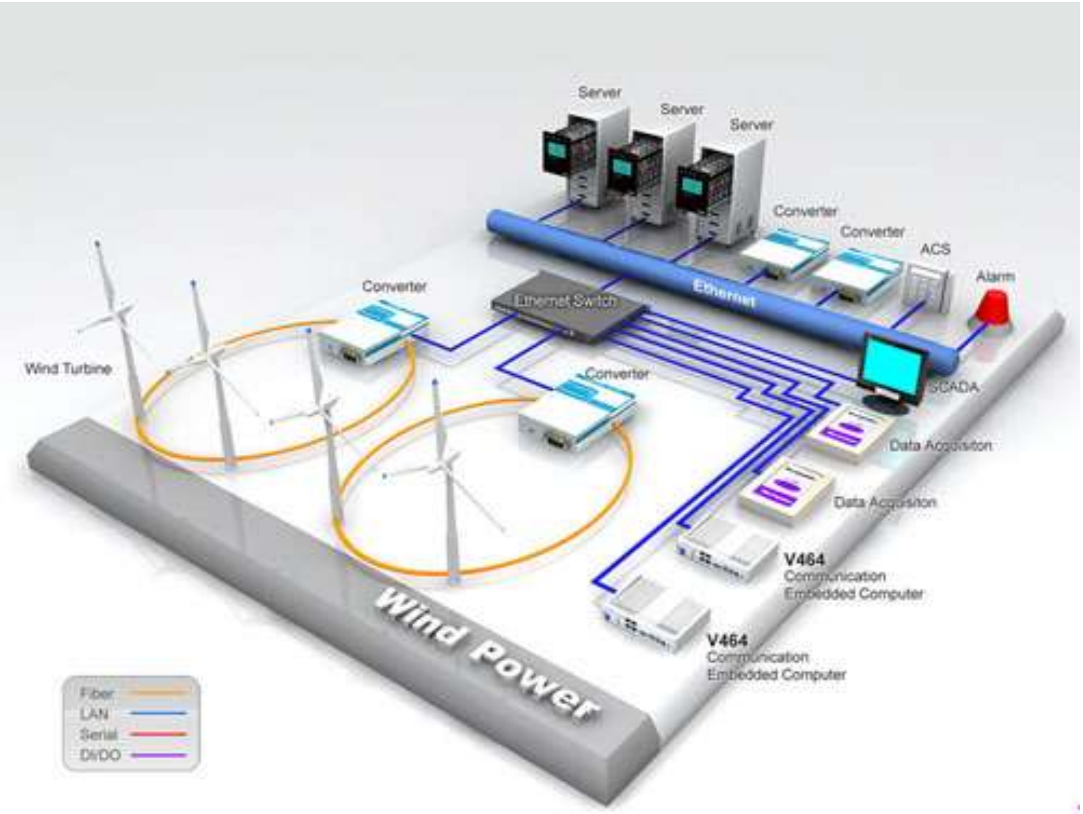


Figure 49: Wind farm comunications levels

So, the first step is to define the network layout.

How to identify and check the communication wires.

Testing Wiring

Since UTP Cat 5e/6/6A cable is used to the fullest extent of its performance envelope, testing is very important. There are three basic tests for all UTP cables: wiremap, length and high speed performance.

Wiremap

Wiremap tests to make sure the cable is connected properly, according to the standard for connecting pin-to-pin. Basically, wiremap is a continuity test using an inexpensive tester.

Wiremapping simple means that each wire is hooked up correctly, with no opens or shorts. That's mostly very straightforward. Each pair must be connected to the correct pins at the plugs and jacks, with good contacts in the terminations.

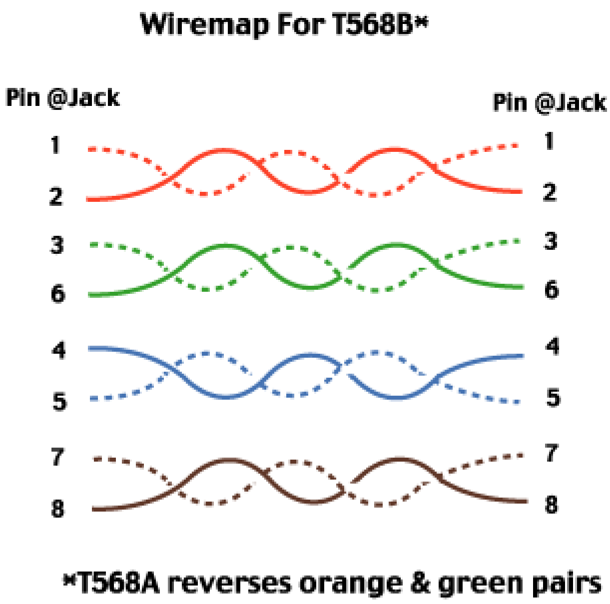


Figure 50: Wiremapping of UTP cables

Most of the failures are simple enough to understand, like reversed wires in a pair, crossed pairs, opens or shorts. One possible failure, crossed pairs, is caused when both wires of a pair are crossed at one termination. The usual cause of a crossed pair is a 568A termination on one end and a 568B on the other.

The most difficult wiremap problem is a split pair, when one wire on each pair is reversed on both ends. It causes the signal to be sent on one wire each of two pairs. The usual DC wiremap will pass but crosstalk will fail. It takes a more sophisticated wiremapper or Cat 5e/6 tester to find a split pair, as some wiremappers which use only DC tests do not check crosstalk. In our experience, a split pair is usually caused by someone using punchdown color codes on jacks which splits the pairs.

Length

Test is done with a "time domain reflectometer" which is a fancy term for cable "radar". The tester sends out a pulse, waits for an "echo" from the far end and measures the time it took for the trip. Knowing the speed in the cable, it calculates the length. All cable certification testers include a TDR to measure length.

If you have a short or open, the TDR will also tell you where the problem is, making it a great tool for troubleshooting problems.

Attenuation

The proper operation of a LAN on the cable plant requires the signal strength be high enough at the receiver end. Thus the attenuation of the cable is very important. Since LANs send high speed signals through the cable and the attenuation is variable with the frequency of the signal, certification testers test attenuation at several frequencies.

This test requires a tester at each end of the cable, one to send and one to receive, then one of them will calculate the loss and record it. There are pass fail criteria for the cable at Cat 3, 4, 5, 5e, and 6 max frequencies.

Crosstalk (NEXT)

It's called NEXT for "near end cross talk" since it measures the crosstalk (signal coupled from one pair to another) at the end where one pair is transmitting (so the transmitted signal is largest causing the most crosstalk.) Crosstalk is minimized by the twists in the cable, with different twist rates causing each pair to be antennas sensitive to different frequencies and hopefully not picking up the signals from it's neighboring pairs. You MUST keep the twists as close to the terminations as possible to minimize crosstalk.

Cat 5e /6 testers measure crosstalk from one pair to all three other pairs for each pair and compare it to the cable specifications, giving a pass/fail result. Some also calculate "ACR" or attenuation/crosstalk ratio, as it is a measure of how big the crosstalk signal is to the attenuated signal at the receiver. You want this number as big as possible, as it is an indication of the signal to noise ratio.

More Tests for Gigabit Ethernet

The latest generation of test specs for Category 5e and 6 includes a number of new tests to insure higher performance from the cable. These tests relate to higher bandwidth usage of the cable and simultaneous use of all four pairs, even in both directions at once.

Powersum NEXT is the NEXT on one pair when all three others are carrying signals. This is realistic with 1000Base-T Gigabit Ethernet where all pairs carry signals simultaneously.

Far end crosstalk, looking at the effect of the coupling from one pair to another over the entire length, measured at the far end. As tested, it's ELFEXT or equal level FEXT, or the ratio of FEXT to attenuation, sort of like ACR.

Delay Skew measures how much simultaneous pulses on all 4 pairs spread out at the far end. This measures the speed on each pair, which may be different due to the variations in number of twists (more twists means longer wires) or insulation. Since 1000Base-T Gigabit Ethernet uses all 4 pairs with the signals split into 4 separate signals, it's necesary to have all arrive simultaneously. Testers measure Propogation Delay, the actual transit time on the pairs to calculate Delay Skew.

Return Loss is a measure of the reflections from the cable due to variations in the impedance. These reflections can cause signal degradation, especially if the pairs are used in a full-duplex (bidirectional) mode. With 1000Base-T Gigabit Ethernet transmitting in both directions on each pair, return loss can cause big problems.
The "augmented" Cat 6 spec will have reference to "alien crosstalk" or the signal coupling from one pair in a cable to the same pair in another cable, a consequence of higher frequencies and the consistency of twists.

Testers

Wiremappers test the connections and Cat 5e/6 certification testers test the performance at high frequencies. Cable Certification testers are mostly automated, "push a button get a pass/fail" simple. In fact, certification testers test everything, wiremap, length, attenuation and crosstalk in one connection, give you a pass/fail result, help on troubleshooting and store the result for printing reports for the customer.

Some installers use the certification tester for all testing, after the cable is installed. But it's a very expensive unit that needs a trained operator and many failures are simply wire map problems. Others have each crew use an inexpensive wiremapper to make sure all connections are correct before the certification tester is brought in. By having each crew find and fix their own wiremap problems, testing and corrections are done as the cable is installed and the cost of the certification tester is not wasted on simple problems. It's just provides the high frequency tests and documentation required by most users.

Host Addressing

For purpose of addressing network layer uses a specific kind of addressing scheme called IP Address (Logical Address). IP address is composed of 32 binary bits. Its' written in decimal form using 4 octets (1 octet is of 8 bits) (32 / 8 = 4). Example of IP address version 4 – 192.168.5.10. IP address contains two part in them – Network part and Host part. Host part defines unique address of host and network part define network of that host (to which network host belongs). Network is kind of group and hosts are people in them. Two different networks cannot communicate with each other at layer 2 but can communicate using layer 3 Message Forwarding devices (Layer 3 Devices).

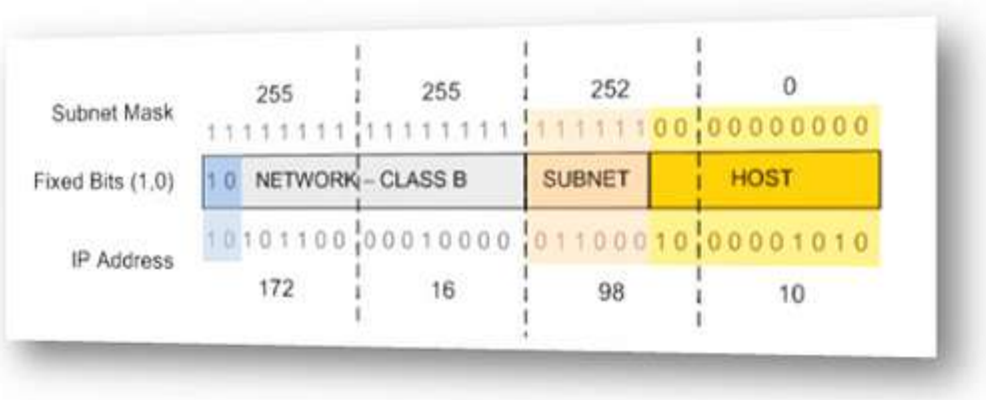


Figure 51: Adressing scheme

Lesson 3 – Electrical corrective maintenace

The objective of this lesson is to introduce the electrical corrective maintenance to the newly wind technicians *During this lesson, the trainee will learn:* *(1)How to check the different electrical protections* *(2)How to check and differentiate AC or DC motors* *(3)Checking the actuators control and motor drives* *(4)How to check different electronic components* *(5)Identify some HV system failures*

The components of the electrical system are:

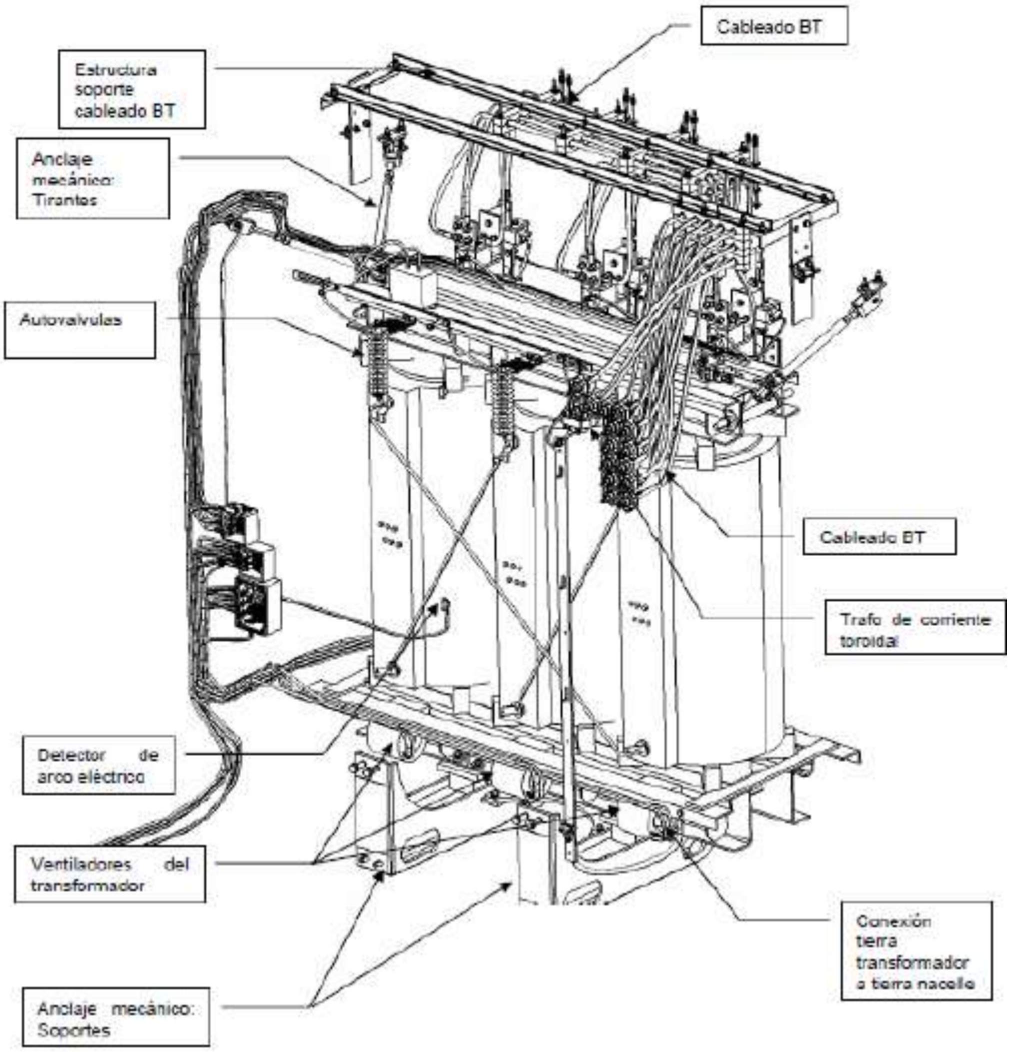


Figure 52. Transformer diagram

The transformer could have two different corrective maintenance operations:

- Replacement in case of failure.
- Centering coils in case moves are observed.

The procedure of centering coils is made in order to maintains the same distance between the three phases and to check that LV and HV coils are concentric.

In order to do that procedure it is necessary to ground the transformer and to lock some disconnections in accordance with the instruction manual consignment. First, the silicone plug screws that hold the coils have to loosened. Then, it is necessary to place the coils of the central phase from and be constantly checking distances in order to be able to place the other coils correctly.

Finally, the silicone plugs have to be retightened to hold the assembly (a slight deformation of the blocks could occur, approx. 2 mm).

Figure 53. Centering of Transformer coils

Corrective maintenance of electrical cabinets is made to replace the internal components that are defective or under doubt to be, after detecting a malfunction or an alarm it is necessary to do checks isolating the offending component.

For safe and effective corrective maintenance of the electrical cabinets the following statements should have been taken into account:

- To have complied with the consigment instructions of the cabinets.
- To have the wiring diagrams to guide the location of the fault.

Lesson 4 – Mechanical corrective maintenance

The objective of this lesson is to introduce the mechanical corrective maintenance to the newly wind technicians
During this lesson, the trainee will learn:
(1)The possible failures in gearboxes
(2)How to inspect the gearbox
(3)How to check the different bearings in the turbine
(4)How to change the generator bearings
(5)How to check and differentiate hydraulic system and liquid cooling systems
(6)How to change valves and actuators
(7)How to change small motors and gearboxes

(8)The different correctives on yaw and parking brakes

DRIVE TRAIN:

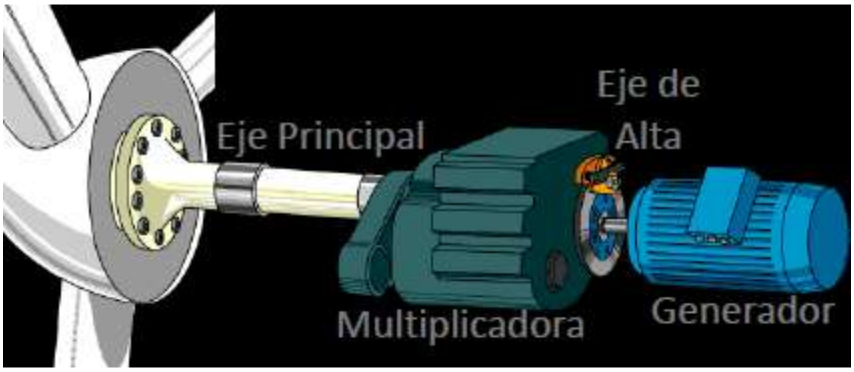


Figure 54. Gear box connection diagram

To repair the up-tower gearbox, the axial adjustment of the shaft have to be measured with a caliber, checking the depth in the bearing outer race (after pushing the butt rings), "Hrod", and heel cap bearing, "hTAP". The distance between those measures, "Hrod and hTAP", has to be verified to be within tolerance. If there is an excess (too much slack) the inside of the lid would have to be machined and if there is a default in the messure the neck of the lid would have to be machined.

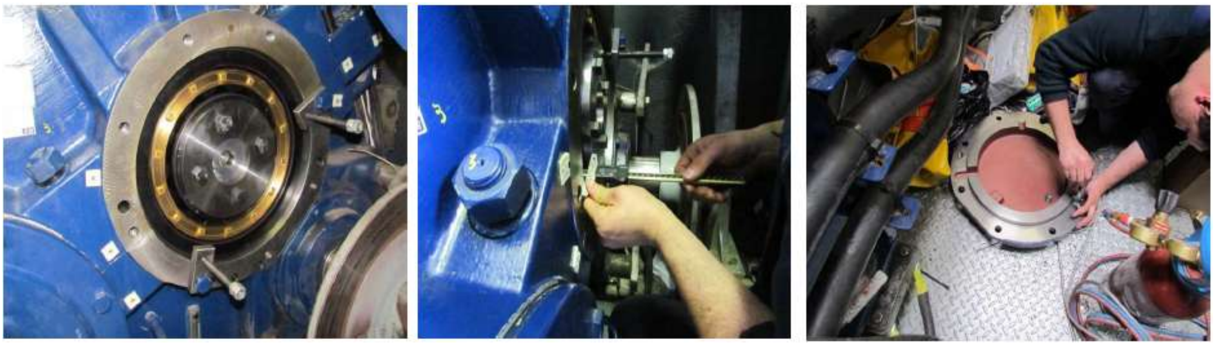


Figure 55. Gearbox assembly

These are the steps to change the bearing :

- The faulty bearing is removed by an extractor.
- The shaft has to be checked out as well as the house diameters
- The new bearing is mounted on the inside track with preheating by an induction heater.

Figure 56. Bearing change pictures

HYDRAULIC SYSTEM:

The components of the hydraulic system are signaled in the following figures:

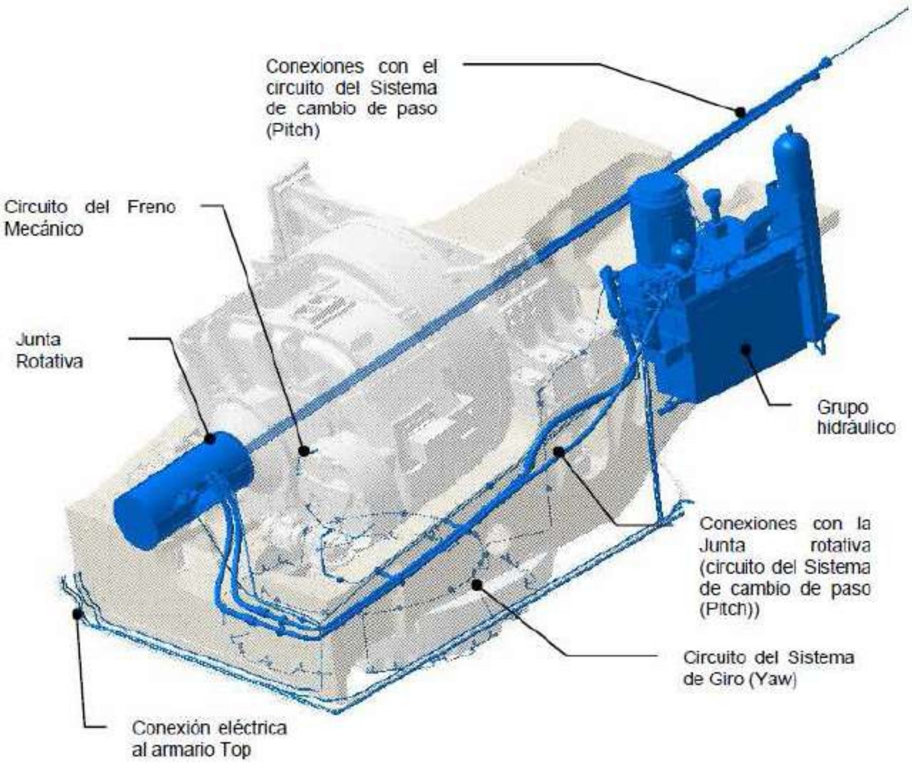


Figure 57. Hydraulic system

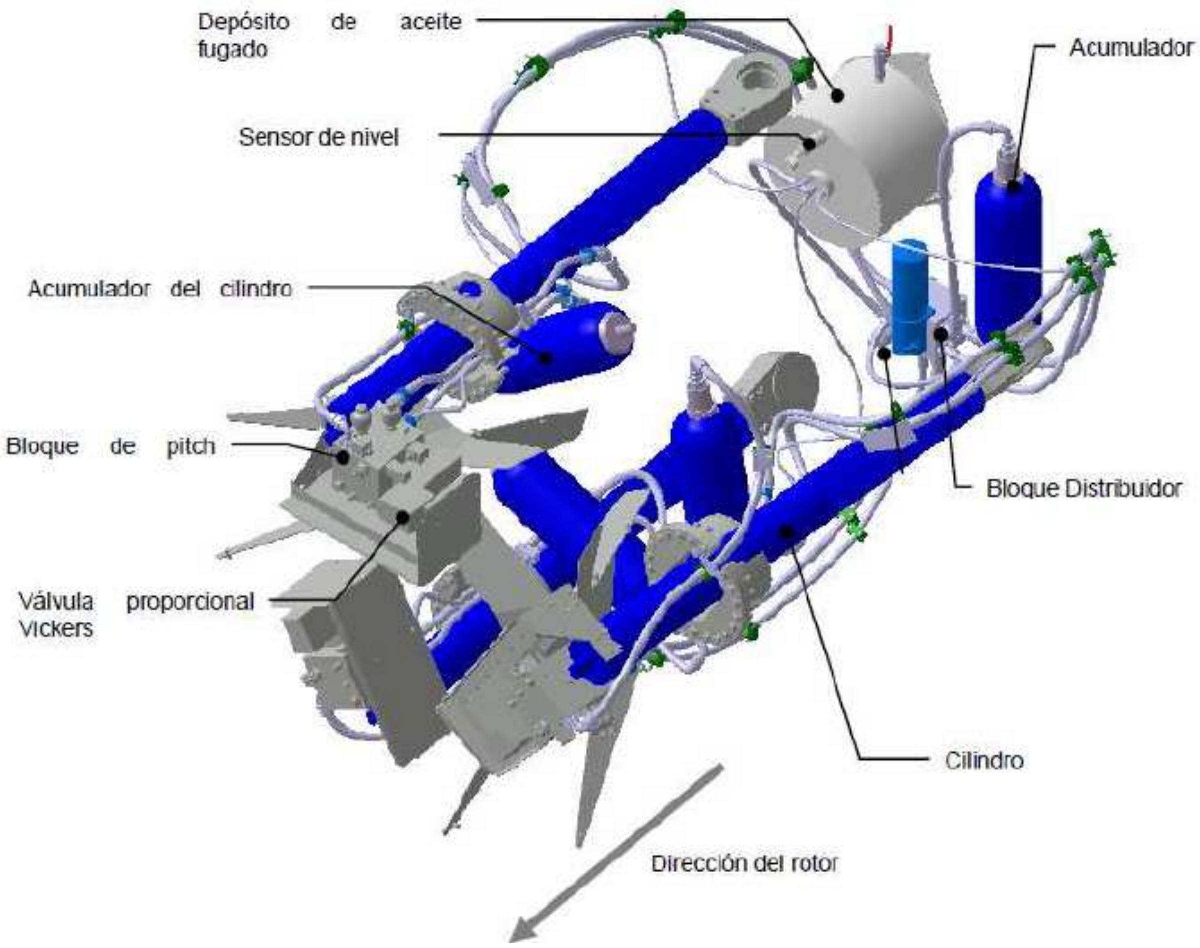


Figure 58. Hydraulic system main components

One of the main problem or better stated, main indicator of a problem in the hydraulic system, would be the presence of leaks.

If there is a leak tearing or a drop hanging, the fitting or plug should be tightened. This type of leak can take an hour to be visible since the hydraulic unit is set to automatic mode.

If the leak is dripping or jet fitting, the plug have to be disassembled to verify the existence and condition of the sealing ring. This type of leakage usually causes a pressure drop in the hydraulic load group.

If a damaged sealing ring is detected it has to be replaced by a new ring and the fitting will be tightened.

Before releasing any fitting or plug both keys of the hydraulic should be opened. The cylinder has to be opened as well when working inside the hub.

If the accumulator has to be changed, first, the oil should be drained completely by opening the corresponding valve faucet and removing the tubes and fittings. Then, the battery holder can be removed.

To change a solenoid, the electrical circuit that feeds it has to be de-energized. Firstly, the mounting screws of the valve have to be removed. Then an exhaulst valve would be mounted on and fixed using the thread at the end of it. The valve would be removed by gently tapping the extractor.

The pump of the hydraulic unit would switch off by activating the "emergency stop" button. Then, by opening the valve tap. completely the tank would be completely emptied. To access the pump, the top cap should be removed.

To replace the rotary joint, the following steps have to be followed:

- To stop the machine and lock the rotor.
- To remove the protection of the rotary joint.
- To disconnect the auxiliary ,in order to not do short circuit in the electrical rotary joint.
- To release the electric cables board noting the order in which they are connected.
- To depressurize the hydraulic unit the needle group keys should be opened (yaw, pitch and brake). Once the group is depressurized, it has to be closed again in order not to leave much oil by the board.
- To hang the electrical and hydraulic rotary joint, it has to hoisted with a sling to be hold when released.
- A bottle should be placed with a funnel below the board to collect the oil.
- To remove the electrical rotary joint, the screws have to be loosened and there is a waiting time until the oil starts to flow out. Then, the board would be released by pulling back.
- To assemble the replacement rotating joint the same steps that were explained have to be taken but in reverse order.
- To test electrically and hydraulically system.
- To collect work remains and clean.

Figure 59. Acumulator removal operation maintenance procedure

To change the orientation system components: the hydraulic unit should be turned off by activating the "emergency stop" button. Then, the accumulator should be discharged by opening valve corresponding needle and the system completely drained.

To change a heat exchanger the ball valve should be closed. Then, the the radiator and hoses that feed it have to be drained. Finally, after changing the damaged component, the valve could be reopened and before leaving the system operation should be checked.

Lesson5: Rotor and blades

The objective of this lesson is to introduce the main concepts of maintenance of rotor and blades:
During this lesson, the trainee will learn:
(1) The blades structure.
(2)Typical blades reparation

(3) Reparation of the pitch system.

THIS SECTION IS GOING TO BE COMPLETED IN THE PATH2.

The rotor is composed by the rotor blades and the hub as it can be observed in the following figure.

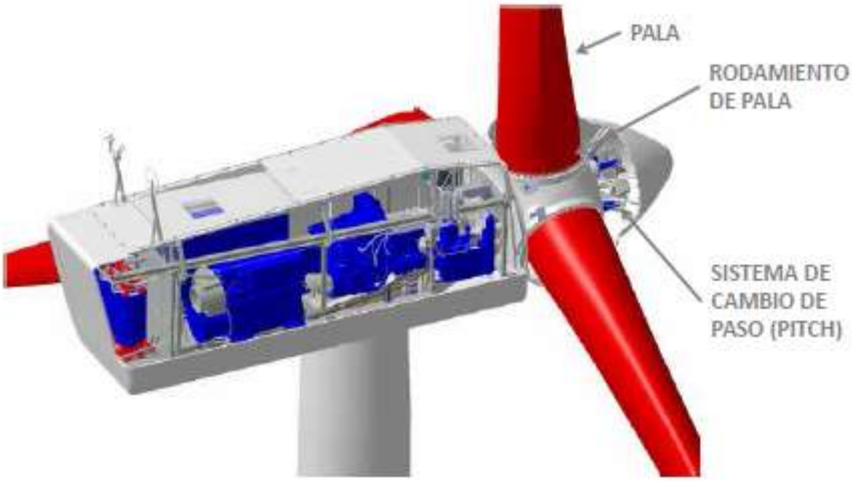


Figure 60. Rotor components

Some repairs on the blades are:

- Cosmetic repairs of blades.

Figure 61. Blade external aspect

- The principle of structural repairs of blades is to recover the carrying capacity by:
  - The ahesive bonding of the glue joints.
  - Pasting composites fabric patches on fractured areas in order to by-pass efforts. These patches are composed of a fractured equivalent composite

fabrics and are overlapped in different sizes to achieve a gradual tension transition.

Figure 62. Blade structural repair

To repair the pitch hydraulic system the following steps should be followed:

The first one is to deconstruct the cylinder:

- To lock the rotor blade vertically upwards.
- To lock the blades in a position 29º.

The hydraulic unit weighs approximately 90 kg, so some precautions have to be taken, in addition to the use of appropriate means for its removal:

- To operate the cylinder, it is necessary to reduce the weight by removing the hydraulic block at the rear of the cylinder.
- The cylinder must be disconnected from the cradle of patella loosening the 4 screws and unscrewing the cylinder rod.

To replace the spherical:

- To lock rotor blade horizontally.
- To lock the blade in 29º position.
- To loosen the 6 screws and to remove the cover.
- To remove the clip ring hairpin kneecap.
- To loosen the lock nut and press the pin system feathering out so that the ball can be replaced.

Replacing slip caps:

- To lock the rotor with the current blade in the upright position and in this position removing the cylinder.
- To remove the 2 cylinder brackets and replace the sliding caps

➢ 

Figure 63. Hydraulic system cylinder deconstruction

Lesson 6: yaw system

The objective of this lesson is to introduce the main concepts of maintenance of yaw system:
During this lesson, the trainee will learn:
(1) The yawing system layout.
(2)Typical reparation of the yaw system
(3) Replacement of the main components

The components of the yaw system are:

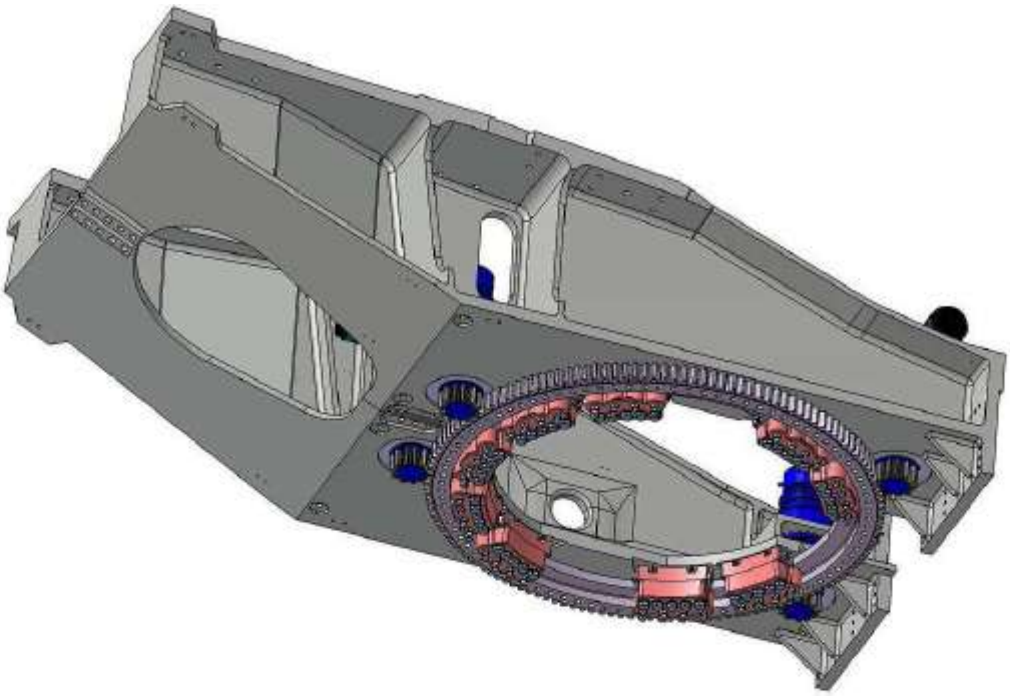


Figure 64. Yaw system components

The instructions to repair up-tower gear motors are the following:

- To replace the electric motor.
- To replace friction discs.
- To change oil.

Figure 65. Friction disc of the gear motors

The gear motors should be replaced as it is represented in the following figure:

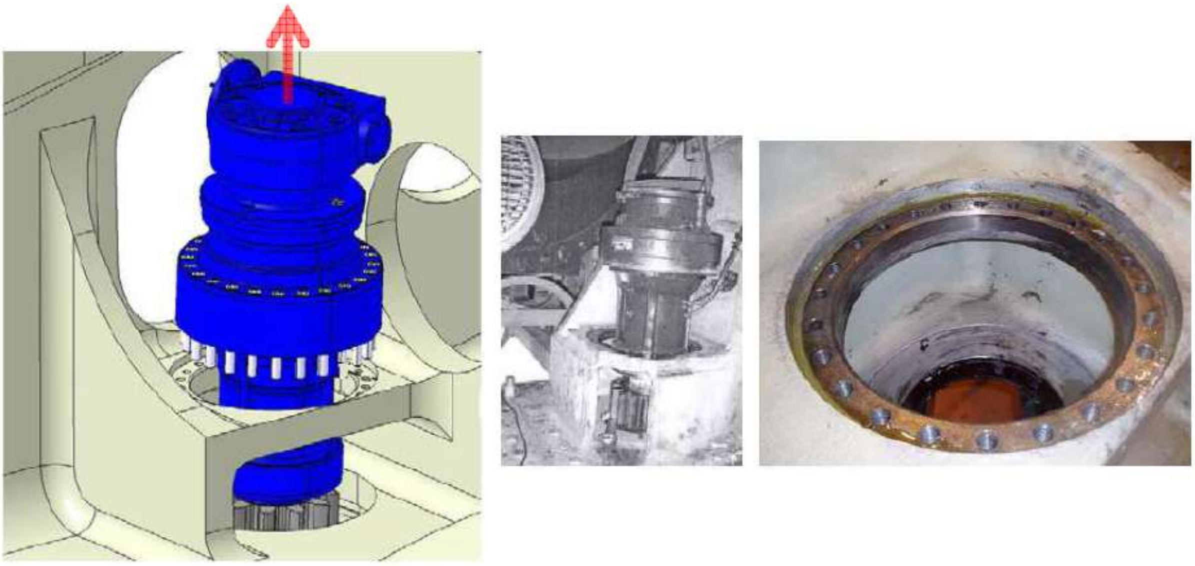


Figure 66. Gear motor replacement

Brakes or clamps replacement should be carried out as represented in the figure below:

Figure 67. Brakes and clamps replacement

Brushing slipping pads should be replaced as shown in the figure below:

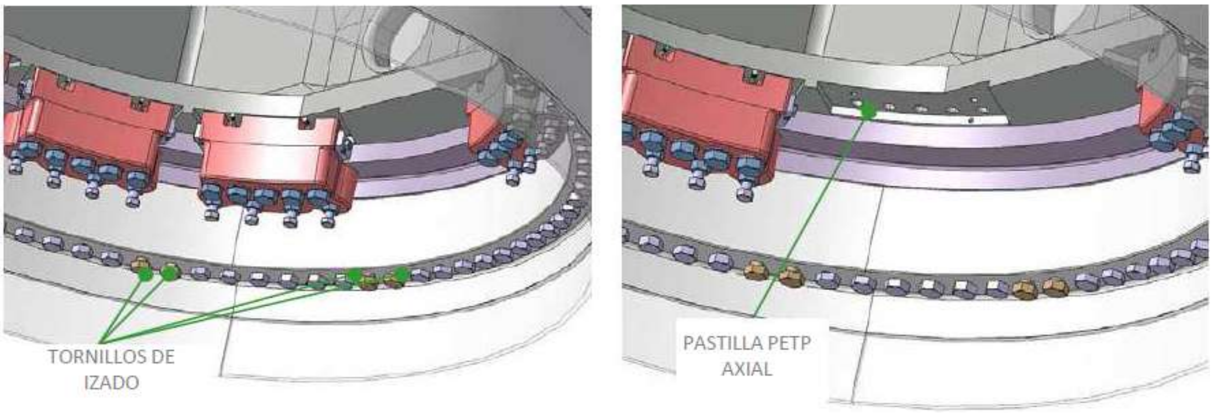


Figure 68. Brushing slipping pads reparing

The steps to follow to repair of dentures slewing rings are:

- To place a router to start milling the damaged parts.

Figure 69. Placing the router to mill the damaged parts

- To shap the affected area and to place the new insert.

Figure 70. Sharpened area

- To drill and to thread.

Figure 71. Drilling and threading

- To place the insert and to apply the resin.

Figure 72. Aplying gum

The crowns are made of sectors and allow replacement sector by sector. Other crowns are made in 1 piece and if they have fault it must be completely replaced. It involves removing the rotor and nacelle and moving them down to the ground.

Lesson 6: Platform, Tower and foundations

The objective of this lesson is to introduce the main concepts of maintenance of the platform, tower and foundations:

During this lesson, the trainee will learn:

(1) The structure of the main components.

(2)Typical tower reparation

(3) Typical foundation reparation.

A wind turbine generator tower is structured as described in the following picture:

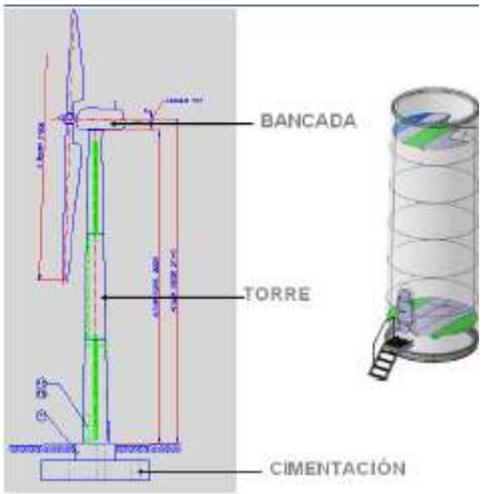


Figure 73. WTG tower structure

Bedplate

The padding welding is done in three batches, each depositing about 5 mm thick. Between batches it is necessary to remove the slag using a hammer.

Grinding with a radial and a router, to leave the top and bottom flushed with the base metal faces. Finally, it should be smoothed with a sandpaper disc booklet to get free from defects or notches and obtain smooth surfaces.

Figure 74. Bedplate padding welding

Tower

The rotor, nacelle and tower sections are removed. These are transported to the workshop where they would be recovered with different techniques depending on the level of deformation:

- Recovery dents by deformation with hydraulic jacks.
- To court of deformed ferrules recovery and subsequent welding.
- To court for scrapping damaged ferrules and new welded ferrules.

At the end of dimensional controls, if they are not destructive to welding and painting tests.

Figure 75. Nacelle and tower removal

Foundation

A study is done through various inspections: Bare land for surface cracking, concrete crushed to check state of superior armor.

Figure 76. Superior armor state checking

A civil engineering study is needed in order to perform a reinforcement for the foundation. It is projected through a new concreted slab over the original, connected to the tower by framess and connectors attached to the original slab by rods anchored in holes with mortar.

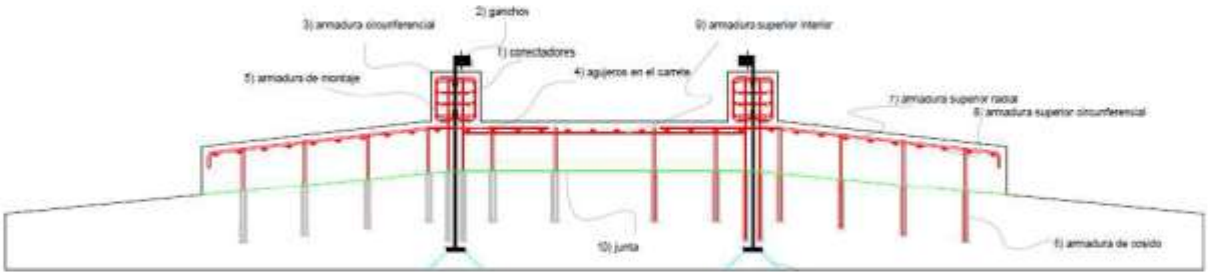


Figure 77. Foundation reinforcement

Lesson 7 – Fault finding practices

The objective of this lesson is to show on a WTG what was learnt in the class previously. *The trainer will produce a series of failures in the WTG* *The trainees have to perform the proper fault finding and apply the proper corrective techniques* *The main objective of this lesson is to explain how to analyze an alarm root cause and how to use a troubleshooting guide.*

A typical troubleshooting list is shown below as an example for each of the main alarms that could trigger in a wind turbine generator:

<u>YAW ALARMS</u>

Twist sensor fail

- Checking to see if counters are working correctly in manual yaw. If not, the enconder has to be replaced
- Untwisting the turbine, reseting turtle, and reseting the counters on the touchscreen
- Checking wiring breaks, connection points, cuts
- Checking connection on the I/O card

- Checking that the I/O card is working

Maximum winding error

- Checking to see if counters are working correctly in the manual yaw. If not, the enconder has to be replaced.
- Untwisting the turbine, reseting turtle and the counters on the touchscreen
- Checking wiring breaks, connection points, cuts
- Checking the connection on the I/O card
- Verifying that the I/O card is working

Yaw motor feedback failure

- Checking to see if the counters are working correctly in manual yaw mode. If not, the enconder should be replaced
- Untwisting the turbine, reseting the turtle and the counters on the touchscreen
- Checking for wiring breaks, connection points or cuts
- Checking the connection on the I/O card
- Verifying that the I/O card is working

Maximum twisting time

- Checking for wiring breaks, connection points or cuts
- Checking the connection on the I/O card
- Verifying that the I/O card is working

Unwinding error

- Checking for wiring breaks, connection points or cuts
- Checking the connection on the I/O card
- Verifying that the I/O card is working

Yaw motor thermal fuse trip:

- Checking the yaw motors wiring
- Megger Yaw Motors
- Checking the yaw sensor
- Reseting the thermal breaker

- Ensuring the breaker amps set to the proper amps
- Greasing the yaw
- Checking that the oil in the worm gear & planetary gear is at appropriate levels
- Turning the yaw breaker amps up

Low pressure on yaw brake

- Checking pressure with manometer
- Adjusting it accordingly
- Checking if the pressure switch is wired correctly

High pressure on yaw brake

- Checking the pressure with manometer
- Adjusting it accordingly
- Checking if the pressure switch is wired correctly

Yaw motor error*:* The turbine has not moved enough after several seconds of requesting CW or CCW rotation.

- Revising if encoder is counting
- Checking the wiring breaks, connection points, cuts
- Checking the connection on the I/O card
- Verifying that the I/O card is working
- Changing the yaw encoder
- Changing yaw motor

HYDRAULIC GROUP ALARMS

Pump time exceeded: The oil pressure is low and the pump is activated for a long time.

- Inspecting the pump motor rotation
- Verifying the wiring on motor if the rotation is wrong
- Checking all the valves to ensure they are closed
- Checking for leaks

Brake circuit low pressure

- Checking if there are leaks

- Checking pressures with manometer

Low pressure in the hydraulic group

- Checking the needle valves
- Checking the I/O card in the hub
- Checking the pressure switches
- Checking the proportional valve for leaks

Dirty hydraulic filter

- Checking the wiring
- Checking for cable for cuts, breaks or stretching
- Checking the connections at the filter and terminal block
- Replacing the filter

Low hydraulic oil level

- Checking the oil level by draining needle valves
- Checking for leaks
- Filling the reservoir with hydraulic oil
- Checking the oil level sensor (making sure the sensor stops is in place)

High temperature on the hydraulic oil:

- Checking the temperature on the regulating electrovalves
- Checking for magnetism when brake is on
- Opening the needle valve (if it is tight it could be a defective needle valve)
- Verifying the proportional valve leaking. Proportional valve is controlled by a variable electrical signal that controls the stroking of the valve spool over metering ports. This produces a variable flow of fluid thereby providing the ability to vary the speed of the actuator being controlled. This valve allows to change the oil flow to the actuator.

ENVIRONMENT

Anemometer failure

- Checking the wiring of the juntion box

- Checking for ice presence
- Checking for the appropriate voltages in the connection box

High wind speed: This alarm is activated if the wind speed is above the design levels.

- Checking the on-site wind speed
- Checking the wires and voltages in the connection box
- Checking for ice build up on the Sonic and Anemometer

Environment high or low temperature: After checking the real ambient temperature, and if discrepancy is found:

- Checking low temp parameters
- PT sensor
- Checking the card and connections

Overheating on the transformer winding

- Checking low temperature parameters
- Opening the louvers below the transformer
- Checking the fans
- Swaping to reserve PT sensors
- Check if the PT card is OK

Zero degrees in the hub

- Checking the thermostat settings in the hub cabinet is set to zero degrees
- Verifying that the hub cabinet heater is working
- If there is no power in the hub, the thermostat should be turned below zero degrees to enable the heater to engage, then reset to zero degrees when the cabinet heats up and is warm enough
- Checking the thermostat wiring

Very high wind direction misalignment: There is discrepancy between the wind vanes.

- Checking if the wiring the connection box is correct
- Checkting the alignment of the sonic with the alignment tool
- Check for Ice on the Sonic
- Checking for the proper voltages in the connection box

High or Low nacelle temperature

- Checking the temperatures
- Checking the PT sensor wiring
- Checking the PT placement
- Checking the PT card connections

GEARBOX ALARM SCHEMATICS

Low pressure in the gearbox

- Checking the pressure parameters
- Adjusting the pressure switch of the gearbox with a manometer
- Checking the gearbox filter cleanness
- Checking for leaks

Oil level low in the gearbox

- Checking that the level of oil in gearbox is appropiate, after stopping it for a few minutes
- Verifying the wiring
- Verifying that there are no cuts, crimps or stretches in the cable
- Checking for loose connections

High temperature on the gearbox oil

- Checking the adjustment of louvers
- Gearbox PT sensor
- Checking the card
- Checking the wires for damages and appropiate connections
- Making sure the bearing temperature is higher than oil temperature, if not the wiring could be swapped

High temperature on the gearbox bearing :

- Looking for bearing damages
- Making sure the bearing temperature is higher than the oil one (if not wiring could be swapped)

- Checking the multiplier pump/ cooling units
- Checking the wiring and cables for damages

High RPM in the rotor or the generator : After one minute in EMERGENCY or STOP mode, the rotor speed should be over certain rpms.

- Checking the high speed shaft for slipping
- Checking the rotor sensors
- Checking the encoder shaft alignment
- Checking the wiring and cables for damage

High speed in the generator: The generator speed is over the limits.

- Checking the high speed shaft for slipping
- Checking the rotor sensors
- Checking the encoder shaft alignment
- Checking the wiring and cables for damage

Rotor overspeed: The rotor speed is over the limits.

- Checking the inductive speed sensor in the junction box
- Checking the rotor sensors and spacing from rotor plate
- Verifying the rotor cable
- Burs on the rotor plate. If there are any, they need to be removed with a grinder.

Generator-rotor speed discrepancy

- Checking the high speed shaft for slipping or damage
- Checking the rotor sensors
- Checking the encoder shaft alignment
- Checking the sensor wiring and cable damages
- Checking the sonic alignment

VOG-OGS Overspeed guard: If the OGS input signal is deactivated.

- Checking the OGS connection box
- Checking the OGS button in the ground cabinet
- Inspecting the OGS in the top cabinet for correct settings.
- Checking the rotor sensors and wiring

- Checking for burs on rotor plates

Gearbox fan feedback failure: Discrepancy between the drive signal from the fan(s) and the feedback.

- Checking the nacelle fan motors with a megger
- Checking the wiring connections and cables for damage
- Verifying the amps on breakers
- Replacing the fan motor

Low temperature on the gearbox oil: The temperature of the gearbox oil is below the limit.

- Checking the heater element wiring

Vibration sensor: The vibration sensor signal is deactivated.

- Checking the wiring
- Making sure the weight on pendulum is adjusted correctly

Gearbox main or auxiliary filters are dirty

- Checking the wiring and cables for damage
- Checking the connections at the filter and terminal block
- Replacing the filter (it is rarely the cause)

Gearbox pump feedback failure: There is a discrepancy between pump operation signal and its feedback.

- Checking the wiring and cables for damage
- Verifying the motor condition

Temperature switch of the gearbox pump

- Reseting the switch/breaker
- Checking the amp settings
- Checking the pump/motor condition
- Checking the motor activation contactor
- Checking the wiring and cables for damage

- Making sure the PLC is reading oil temperature correctly. If it is too high, it implies that the pump is running too often. (Gearbox bearing temperature should be higher than the gearbox oil)

GENERATOR

Generator winding temperature alarm

- Checking the direction of the motors in the cooling fans
- Checking the louvers above the slip ring to make sure they are opened
- Checking the wiring throughout the system

High temperature on bearings (DE or NDE)

- Listening for any unusual noise coming from bearing (could be a bad bearing)
- Checking the temperature touchscreen. Replacing the PT100 or temperature card
- Making sure the lubber has enough grease and it is flowing into the bearing

Generator fan switch

- Checking the motor fan condition
- Checking the signal wires
- Checking the connection between breaker and motor
- Checking the amp settings

High temperature on generator's slipring

- Opening the louvers on generator
- Checking the motor fan condition
- Checking the PT sensor
- Checking the Temperature I/O card

PITCH

Pitch Activation Error: if the pitch of any of the blades differs some degrees from the reference pitch for a short period

- Making sure the balluf cable is not disconected
- Checking the balluf condition

- Checking proportional valve or cable
- Electrovalves on pitch blockling should be activated and magnetized when trying to pitch
- Checking the relays for each blade in the hub cabinet
- Checking the connections inside all electrovalves

Low pitch value in stop: The position of any of the 3 blades is less than 80º in STOP mode for a specific time

- Looking for looses at the balluf cable
- Checking the power supply
- Verifying the appropiate wiring and voltages
- Checking the cables and electrovalves

Possible existence of ice on blades

- Checking the rotor sensor connection
- Checking for loose connections in the A-9 box
- Checking for damaged cables
- Verifying the wiring
- Visually inspecting the blades for ice build up

Blade Position Error

- Checking the power supply
- Checking the cables and electrovalves for damage
- Verifying the I/O modules in the hub
- Swaping the cards between blades to see if fault is associated to one specific blade.
- Verifying the balluf settings

OPERATION STATUS

Emergency circuit not OK

- Checking the wiring throughout the circuit
- Checking the arc detection system and neutral detection system

TRANSFORMER COOLING, LINE PROTECTION, OVERVOLTAGE PROTECTION, TEMPERATURE MODULE, PLC SCHEMATICS

Turbine does not couple: The stator contact input is not received after requesting connection.

- Checking the contactor and its wiring

Transformer fan circuit breaker: The thermal fuse of the trafonsmer fan is deactivated.

- One of the transformer fans is damaged
- The resistance of the fans has to be measured (cheking the Ohm obtained values)
- Checking the signal wires for circuit breaker

Circuit Breaker Not Ok: Any thermal fuse signal is deactivated for more than 5s.

- Checking the description for location
- Checking the digital inputs
- Checking the I/O card in hub
- Making sure that the 24VDC is going through line protection.

PLC Module Failure: Peripheral Module Failure

- Checking the PLC for module failure
- Checking the bus structure and bus history for failure

Temperature measurement module failure: Error in Temperature card (RTD)

- Checking the bus structure

Analogue module failure: Error in analog card

- Checking the bus structure on the PLC/ touchscreen
- Replacing the card
- If replacing the card doesn't solve problem, removing the wires/ jump to see if the alarm clears out.
- Replacing the necessary parts.

Communication error

- Replacing the communication cards
- Reseting the PLC
- Checking the fiber from the ground to the top cabinet

UPS failure:

- Making sure that connectors are attached to back of UPS and that the wiring is correct
- Replacing the UPS

CONVERTER ALARMS SCHEMATICS

Grid problems

- Checking and saving the fault log and data logger
- Checking failures and sparks in boards or cabling
- Checking the incorrect grid underfrequency parameter value
- Checking the transformer fuses
- Checking switches
- Checking the Delta rod

IGBT high temperatures

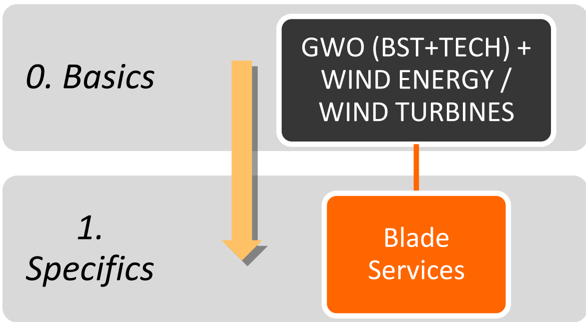
- High temperature on INU IGBT's
- Checking and saving the fault log and data logger
- Checking the ambient temperatures
- Checking the air flow and fan operation
- Checking and clearing air filters in the cabinet and drivers

Converter earths failures

- Generator/grid sides insulation fault.
- Incorrect insulation level parameter value
- Checking and saving the fault log and data logger
- Checking the slipring brushes
- Measuring generator and cabling insulation resistance
- Checking the crowbar

- Checking the parameter EARTH FAULT LEVEL
- Checking dirtiness of Slip Ring (cleaning it if necessary)
- Swaping drives to see if fault is associated to a specific drive

PATH #2. BLADE SERVICES TECHNICIAN



1. BLADES INSPECTION

EVALUATION OF DAMAGE

Most common types of damage are:

- Erosion damage (without major fiber damage)
- Minor scratches or dings affecting surface ply
- Damage into or beyond outer ply of laminate
- Damage into sandwich core structure (debonding)
- Damage though structure (main spar)
- Bond failures

Figure 78. Blades most typical damages

The location of these damages in the WTG blade is:

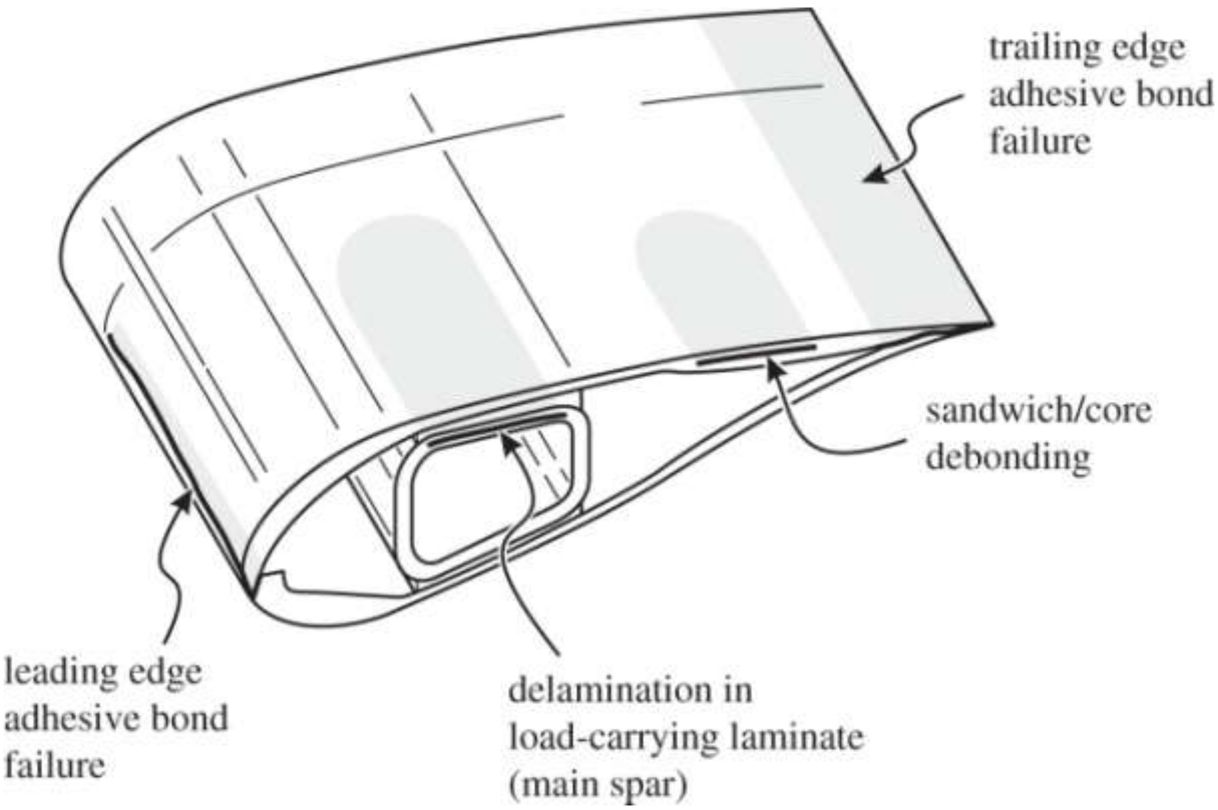


Figure 79. Blade damage location

Reporting:

The location of damages and dimension (inspect the leading edge, trailing edge and both shells) must be reported in a template designed for this purpose and including pictures:

A picture of the blade showing where the damage is observed.

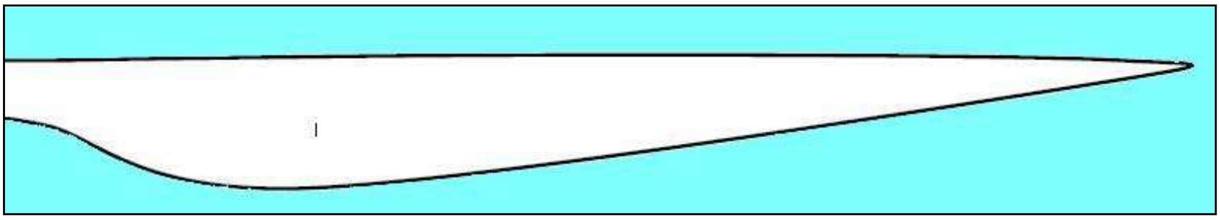


Figure 80. General picture of the blade

A picture which shows the chord of the blade where the damage is.

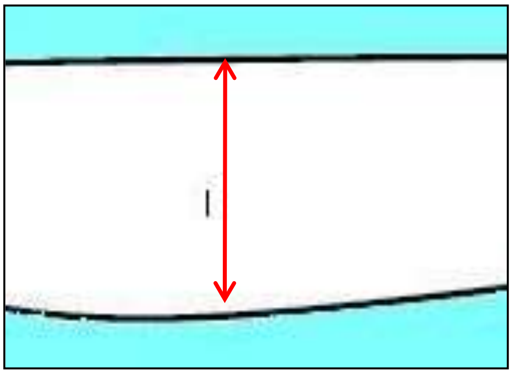


Figure 81. Picture showing the chord of the blade where the damage is

A Detailed picture of the damage.

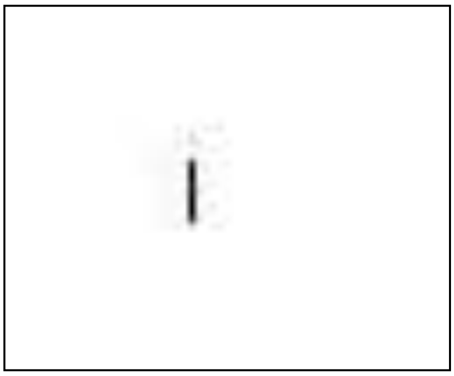


Figure 82. Detailed picture of the blade damage

For inspections the tools and equipment typically used:

- Posters numbering the blades.
- Telescope
- Tripod
- Camera

- Drones

Drones are starting progressively to be used but the blade maientance is normally more complex because it requires two people: drone pilot and expert on blades

INSPECTION PROCEDURE

The first step upon arrival is to stop the machine with the rotor on "Y" position and the hub hatched on top, as it will be the reference point for the numbering of the blades.

Once the wind turbine is stopped in this position, with two blades up and one blade straight down along the tower, the numbering of the blades is done as represented in the picture below.

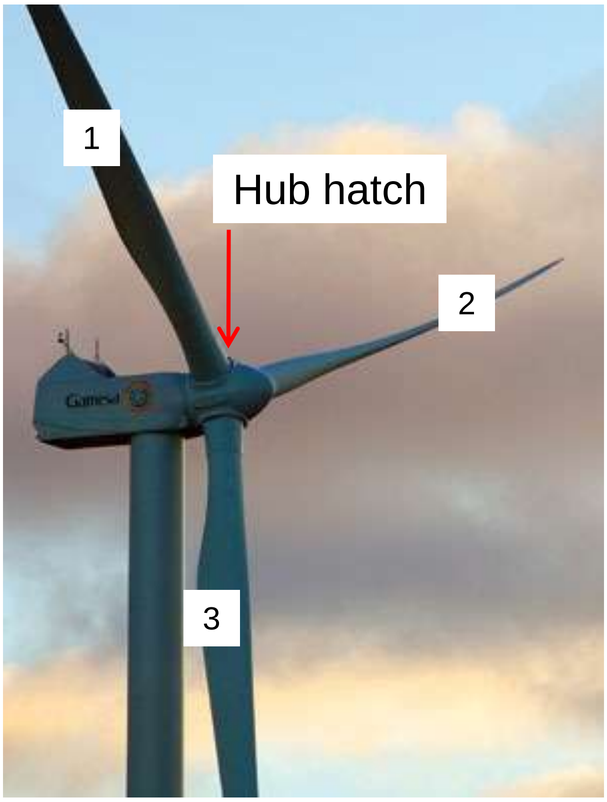


Figure 83. WTG position for numbering blades

After numbering the blades, it has to proceed to inspect each blade as it is described below, with the blade to be inspected first locked in the straight down position:

1. Taking a picture of the turbine number.

2. Taking a picture of the inspected blade's number.

3. Setting up equipment to inspect the blade:

4. Proceding to the blade inspection by surfaces:

- Setting the leading edge: in front of the turbine
- Upper shell: the side corresponding to the upper or outer shell
- Bottom shell: the side corresponding to the lower or inner shell
- Trailing edge: the rear of the blade slightly to the right facing the rear of the nacelle

5. Looking for damages and taking pictures as discussed: a picture of the complete blade showing the damage, a picture centered on the damage showing the chord of the blade where the damage is and a detailed picture of the damage itself should be taken.

Note:
If necessary, the position of the rotor could be changed to see the total surface of the blade.
If necessary, the nacelle could be rotated to prevent sunlight affect the inspection.

2. BLADES REPAIR

INTRODUCTION

The repair approaches can be broadly divided into nonpatch, usually for minor defects, and patch, usually for more major defects and damages. However, these two procedures may be employed in combination for some types of repairs. In general for composite material structures there are four basic levels of generic repair designs. Although, not all of them are applicable to wind turbine blades, these are listed below:

(a) Non-structural or cosmetic repairs. Filling and sealing the damaged areas where damage significance is minor, but environmental protection is necessary, it is a cosmetic or nonstructural repair.

(b) Semi-structural repair. Filling the internal cavity with an adhesive foam or core replacement and applying a doubler patch to the damaged area is a semi-structural repair. The double patch can be non-load-bearing, either load-bearing or to have some intermediate load carrying capacity.

(c) Adhesively bonded structural repair. A flush patch adhesively bonded over the damaged area, is a major structural repair using a scarf of stepped-lap joint. The flush patch is generally applicable to thin skin structures only.

(d) Mechanically fastened structural repair. Another structural repair is the bolted patch. This is used primarily on thick structural components.

BLADE REPAIR ZONES

In the following figure are presented the repair zones of the blade:

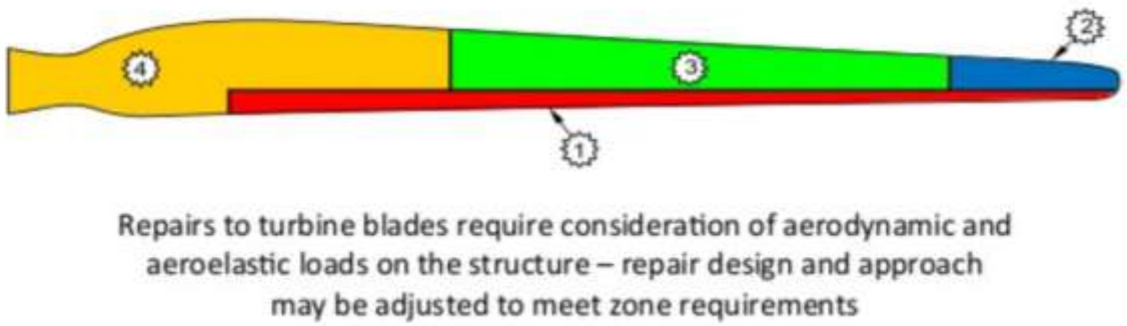


Figure 84. Blade repair zones

1. For both, aerodynamical and structural purposes; the blade leading must be maintained for the laminar boundary layer. Zone 1 is from the 20% to 100% span length and to 20%-30% of the local chordline. Zone 1 will always require a flush repair.

2. For aeroelastic purposes; do not add significant weight to this zone of the blade, so as to maintain mass balance. Even not being a major structural region of the blade, however the repair needs to be an aeroelastic semi-structural repair.
3. Firtly, for aeroelastic purposes; the repair does not necessarily need to be flushed for airflow aerodynamics, but it do not have to add significant weight behind the shear center. However, trailing edge repairs are typically flushed for aeroelastic requirements.
4. It does not require to be aerodynamically smooth, but it may need to be a semi-structural or structural repair based on the severity of the damage and the proximity of the damage to the main load bearing region. Because of the large enclosed area of the blade in this zone, the torsional rigidity is much higher than in other locations in zone 3 and aeroelastic requirements are not necessarily critical.

REPAIR PROCEDURE

A typical repair procedure consists of the following steps:

1. INSPECTION
2. LAMINATE GRINDING AND CHAMFERING
3. CLEANING
4. REPAIR RECORDING
5. LAMINATE BUILD-UP
6. EDGE REINFORCEMENT BUILD-UP
7. ADHESIVE FLANGE BUILD-UP
8. BASE LAMINATE GRINDING AND CHAMFERING
9. CLEANING
10. BASE LAMINATE BUILD-UP
11. FINISH

All of them would be described as follows:

1. INSPECTION

The inspection(already presented) step consist in:

- Checking and marking defective areas before repairing.
- Gathering partly connected defective areas as one larger defective area. This could mean that an intact laminate has to be ground off.

2. LAMINATE GRINDING AND CHAMFERING
   - Grinding defective areas avoiding air bubbles, foreign matters, cracks or dry glass.
   - In the event that the blade demoulding has not been performed yet, max. 2/3 of the total glass layer should be grounded off. If dry glass or air bubbles still appear, the internal grindings should be stopped to perform the repair.
   - After demoulding, the blade would repaired from the outside.

Main laminate

The bottom of the grinded defective area must be rectangle-shaped in order to ease the subsequent laminate build-up.

Edge reinforcement (UD-laminate)

The bottom of the grinded defective area must be rectangle-shaped in order to ease the subsequent laminate build-up.

Towards blade assembly it may be advantageous to remove all glass in the layer to be ground. This is an alternative to chamfering.

In case of internal blade repairs

When chamfering is performed in core material, the chamfering procedure should continue to match the normal core material chamfering.

Above the core material, the overlapping grinding would be measured prior to re-continuing the chamfering procedure.

Any chamfering made should appear evened.

3. CLEANING

The surface of the ground laminate should be vacuum-cleaned using a mouthpiece with stiff brushes. All abrasive dust should be removed.

4. REPAIR RECORDING

All the repair data should be notee down including the following aspects:

- Defective extension.
- Repair extension including chamfering
- Number of ground-off glass layers
- Type of ground-off glass layers
- Any consolidation of the main laminate repair

5. LAMINATE BUILD-UP

To build-up the laminate the following requirements should be met:

- Prior to build-up, polyester should be rubbed hand laid-up into the entire surface using a stiff brush or paintbrush.
- The glass has to be rolled thoroughly between each layer.

Procedure:

- Apply ingfiberglass layers according to the number of fractured layers recorded.
- Offset each layer along fibre direction and across fibre direction starting from the large-sized layer.
- Applying glass in such a way that length ends project from the final level of the repaired area.
- Laminate must be cured until the polyester has peaked and temperature is decreased.
- In the event that the repaired area size requires several glass layers, the chamfering has to be checked and improved prior to applying a new glass layer.
- Checking the newly applied glass for irregularities/buckling.

6. EDGE REINFORCEMENT BUILD-UP

Requirements:

- Prior to build-up, a polyester lay-up should be rubbed by hand into the entire surface using a stiff brush or paintbrush.
- The glass should be rolled thoroughly between each layer.

Edge reinforcement build-up prior to blade closure

- Glass layers should be applied according to the number of fractured layers recorded.
- Towards the blade assembly, applying glass until reaching the level prescribed in the blade moulding working instruction. It is necessary to comply with the glass levels specified, i.e. offsetting away from leading and trailing edges, and this particularly applies to the trailing edge as the blade thickness will otherwise increase, thus, causing problems during blade assembly.
- Offseting each layer along fibre direction and across fibre direction away from the blade assembly, starting from the large-sized layer.
- Applying glass in such a way that length ends project from the final level of the repaired area.
- Laminate must cure until the polyester has peaked and temperature is decreased.
- In the event that the repaired area size need several glass layers, the chamfering should be checked and improved prior to applying a new glass layer.
- Checking newly applied glass for irregularities/buckling. In the start-up of the build-up procedure, if any irregularities/buckling are detected in the newly applied glass, it should be grinded off.

7. ADHESIVE FLANGE BUILD-UP

Requirements:

- Prior to build-up, a hand of a polyester lay-up should be rubbed into the entire surface using a stiff brush or paintbrush.
- Rolling the glass thoroughly between each layer.

Procedure:

- Applying the glass layers according to the number of fractured layers recorded, starting from the large-sized layer, with CSM side facing upwards.
- In the event that all adhesive flange width has been grounded off, each layer would be offset longitudinally. Offseting in transversal blade direction depends on the original offseting of the adhesive flanges.
- In the event that only one part of the adhesive flange width has been ground off, each layer should be offset longitudinally and transversally.
- After building-up the repair laminate, an extra layer shall be applied on the repair with an longitudinal and transversal overlap
- Laminate must cure until the polyester has peaked and temperature is decreased.

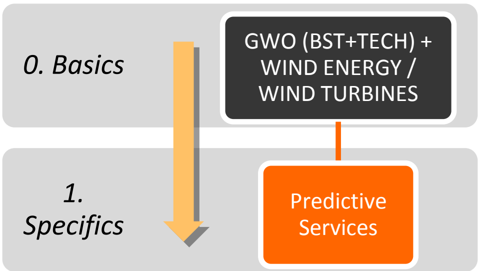
8. BASE LAMINATE GRINDING AND CHAMFERING
   - Grinding off all projecting laminate ends in order for the bottom of the defect to appear as an even surface.
   - Chamfering each base of laminate layer longitudinally and transversely.
   - Any chamfering made should appear evened. This should be checked by means of a surface plate.
   - Grinding off gel-coat in wide area along the edge.
9. CLEANING

It is the same cleaning procedure described in the third step.

10. FINISH

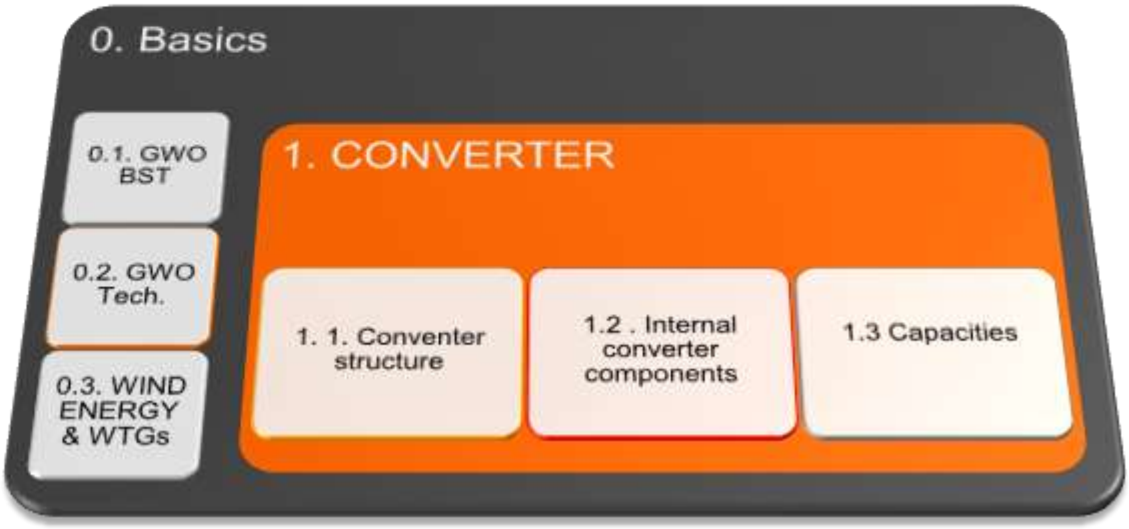
Prior to finish, the re-inspection of repaired blade area must be performed. Finally, the finish on the repaired blade area should be performed.

PATH #3. PREDICTIVE SERVICES TECHNICIAN



The contents of Predictive maintenance are included in Path 1 training contents. Please go to Path 1 of this manual for further information.

PATH #4. CONVERTER



1.1 CONVERTER STRUCTURE

The maintenance is focused on the different stages that form part of a converter, without ignoring external components that have direct influence in the operation of the converter. Their malfunctioning could cause severe damages in the converter, for instance, the stator contactor and its handling , automatic switch, generator rotor and the auxiliary source 230V UPS.

Every preventive maintenance would be registered, noting the performed activities, the detected anomalies and how they were corrected. Every document would be stored for subsequent analysis.

1.2 INTERNAL COMPONENTS OF THE CONVERTER

Subsequently, it is presented the maintenance for all the different components of the converter.

1.Power wires

The power connections are formed by wires through which high intensities run, converter input and output and its rotor exits, connected with ring connectors through whose hole passes the screw that is to join them to the terminal passes.

- Checking that the wire has not slipped out of the ring connector as could happen to short stretched wires. In case there is a sudden jerk it could make the wire slip from the connector and disconnect. In case of detection, it may be possible that all the affected wires are to be changed by long enrooted ones, preventing stretches.
- An incorrect torque of the ring connector could cause vibrations and as time passes the wire may be disconnected.
- The absence of dark coloring should be checked. It is due to the heating caused by bad contact between the wire, terminal, edge…
- The torque between the screw and the connector should be checked, paying special attention to the [Nm] proposed by the manufacturer.

Figure 85. Wires mounted over reactance (Source. GDES-COMSA)

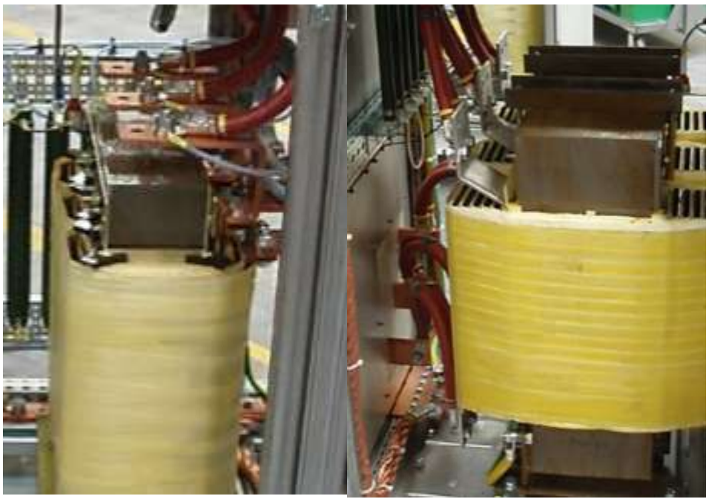


Figure 86. Entrance reactance, 'Main Choke', and the reactance of the current output of the rotor, dv/dt (Source: GDES-COMSA).

2. Connections in power gusset.

It is necessary to check out the torque of all the screws that form part of the power connections as well as avoiding loose connections; due to the high intensities the high temperatures reached in the contact area could even melt the copper.

The converters placed in the nacelle are more affected by these phenomena, where they perceive higher tower oscillations and vibration form the generator, creating strains in the different gussets that could loosen them.

An appropriate strategy should be planned according to the converter typology.

Figure 87. Converter gusset(Source. GDES-COMSA)

Figure 88. View of the converter gusset(Source. GDES-COMSA)

1.3 CAPACITIES

A summary of the capacities of the different components will be found below:

1. DIRECT BUS CONDENSERS.

In the majority of converters it is not possible to measure the capacities of the condensers from the direct current bus, DC link. They are many condensers and they are not easily separable to measure, so this is omitted in the preventive plan. They are changed in corrective maintenance, as they usually short-circuit internally and burst. Furthermore, because of being of film typology, they are highly safe and stable, even though they have been working for long periods of time.

A visual inspection could be carried out, searching for possible damages as cracks, holes or spark marks. It is advised to measure and change the ones that are affected.

2. HARMONIC FILTER CONDENSERS.

The checkout of these condensers should be included in the preventive plan, as they are connected in the alternating current line, and use to wear away and lose their capacity. A malfunctioning of these filters increases the electrical noise that may be noted in other components as lapses in communication. The iron of generator could suffer of harmful harmonic components to even overheating. In addition, the functioning of the IGBTs is affected because of the traffic of these components.

For a correct measurement the condenser should be insulated, even though it could be measured a group connected in star or triangle. The expected theoretical measurement is to be checkout and should be the same in every possible combination.

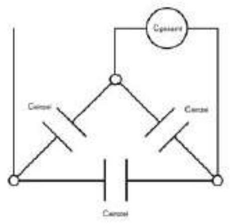
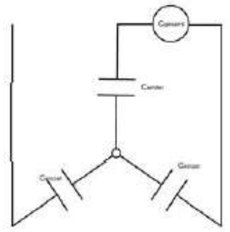
Circuito en triángulo de los condensadores $C_{total} = 1,5 \times C_{individual}$	Circuito en estrella de los condensadores $C_{total} = 0,5 \times C_{individual}$
	

Figure 89. Condensers in a converter (Source. GDES-COMSA)

A strategy has to be elaborated, based on the typology and power of the converter, the higher number of revisions depending on the number of condensers.

Important:

It has to be verified that the condenser is not charged, because it may cause severe damage by electrocution.

3. INDUCTANCES.

The 'Main Choke' inductance stands high strains due to be connected against the input grid to increase the DC bus voltage: It could be damaged short-circuiting some spires which may cause overstrains in IGBTs to increase the voltage additionally to the creation of more electrical noise.

The inductance will be measured phase; consequently at least one connection should be disconnected in order to measure. The values should be contrasted with other phases, and they should be the same.

4. OVERVOLTAGE PROTECTIONS.

The protections of overvoltage act during the overvoltage periods, causing a brusque lowering of their ohmic value, therefore absorbing the overvoltage peak and protecting the feed circuits. But this decrease in their resistance generates a high intensity through the protection which can even melt it or damage it. In this case a flag is activated to signal its state. There are cases in which the device could be damaged but the flag has not been activated, for this reason, a visual inspection has to be performed in order to detect cracks or flashes.

Figure 90. Overvoltage protections(Source. GDES-COMSA)

5. DISCHARGER CONDENSERS.

They are components whose mission is to prevent that the condensers keep charged once the converter has been de-energized. This produces a fake perception that there are no voltage which can cause an accident by electrocution or burns due to sparks. It affects mainly the condensers of filters which are connected to alternating current. In many cases these elements are simple resistances which are placed in parallel with the condenser, but in other cases they are reactances with a high reluctance to the grid frequency, 50 or 60 Hz.

Once the condensers are lacking a fixed current, this reactance presents null resistance to the direct current, discharging the condenser.

In addition, the trigger of protections is produced when the converter is re-connected when the condenser are charged. There is a current peak similar to the one that is produced in short circuit and the grid voltage does not match the condenser voltage.

Figure 91. Discharger converters(Source. GDES-COMSA)

6. CROWBAR.

The Crowbar unit is fundamental to protect the converter against a sudden increase in the voltage coming from the generator rotor. This system short-circuits the connection to the generator rotor suddenly, preventing that this surge reaches the converter.

It is usually composed by a set of thyristors, with a resistance where they would unload the great current caused by the short-circuit. It may as well include a set of inductances to moderate the current increase.

Figure 92. Crowbar (Source. GDES-COMSA)

For each converter model the manufacturer could have developed a method to activate the Crowbar in testing mode. A visual inspection should always be performed, especially in the shock coils, considering that they may be visually detected damages. The thyristors when failing are short-circuited, so the converter would be in failure mode that would lead to a corrective maintenance.

7. Control System.

The converter has two different control systems, control unit boards, one to the current control of the input reversible rectifier system and the other to generate alternating current for the rotor. Both control units have systems to measure the different voltages and currents, as well as measuring the encoder signal. A manual trigger has to be performed with the converter stopped and another with the converter switched on in order to evaluate the operation of the measuring system.

Figure 93. Converter control unit boards(Source. GDES-COMSA)

8. AUXILIARY SYSTEM.

This system feeds the different auxiliary systems such as fans, heating, protections and safety lines. It is maneuver formed by contactors and circuit breakers.

All the circuit breaker tares are to be inspected and checked to be of the value specified by the manufacturer and the humidity and temperature sensors.

All the connections are to be checkout, making sure that their torque and restraint. A bad contact may originate faults that would be difficult to diagnose.

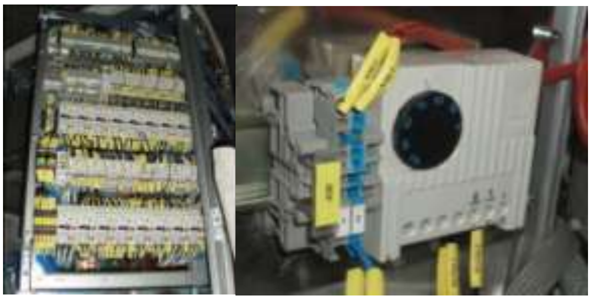


Figure 94. Auxiliary systems(Source. GDES-COMSA)

The correct functioning of the safety line has to be verified, checking its performance when triggering its protections.

Figure 95. Protections(Source. GDES-COMSA)

9. Cooling system.

It could be cooled by air or liquid cooling, glycol or water.

a. Air cooling.

- Cooling engines.

The estate of the fan engines has to be checked. It will be done from their maneuver contactor and the consumption of intensity will be checked with a current clamp. In case a higher that usual consumption is detected it may be sign of engine damage, either mechanical by friction with the bearing or electrical if the coil spires are short-circuited their substitution will be evaluated or their repairing in a specialized repair factory.

In statics the shaft of the engine will be moved and the lack of friction of the existence of play will be checked.

- Radiator cleaning.

The radiator fins will be cleaned of dust and dirt, assuring a good heating exchange.

b. Liquid cooling.

- Liquid pressure.

The liquid pressure is to be verified form the manometer of the pumping station. If it is low, it may be a leak or a malfunction of the expansion tank, breakdown and flooding of the internal bag or simply a loss of nitrogen. For more details, please revise the station manual in the section expansion tank.

Figure 96. Expansion tank (Source. GDES-COMSA)

- Liquid leaks.

It has to be observed in connectors and fittings the presence of oxide or lime marks that may indicate possibly a fluid leak. In this case it has to be considered the substitution of the affected fitting or simply revise its assembly just in case it has only loosened. In addition, the over pressured valves and the air evacuation are to be checked.

- Fast connectors.

They are devices that allow the disconnection of the circuit without any liquid loss allowing the substitution of components without needing to empty the circuit. These mechanisms have a check valve with a spring closure. This spring could oxide, break down and accumulate particles that may lead to brake or block the fluid flow resulting in an efficiency loss. It is recommended to unplug every connector and check the lack of sediments and the good operation of the spring system and the check valve closure assuring that the fluid circulates with the minimum resistance. In case of defect or sediment excess it is recommended to change it.

Figure 97. Fast connectors(Source. GDES-COMSA)

- Liquid state.

The estate of the liquid has to be checked and if it contains sediments or dirt it has to be evaluated the possibility of its substitution. The circulation of sediments may block the fast connectors or break down the pump.

Figure 98. Example of liquid in a bad state(Source. GDES-COMSA)

- Heat exchanger.

The direction of the turn of the main fan has to be checked. There have been detected some cases in which it turns in the wrong direction, producing a reduced air flow that causes overheating and miss indicates that the problem might be in the components.

The date of the last checkout has to be checked and if it has been postponed it is possible that there is a fairly high amount of sediment getting dirty the circuit.

Figure 99. Heat exchager (Source. GDES-COMSA)

10. External components

They influence the operation of the converter and they should be taken into account in the converter preventive maintenance.

a. Stator contactor maneuvers.

It closes when the voltage wave generated in the stator is identical in range, frequency and phase to the grid. A defect in the system will close it not reaching the condition stated before and will cause a great current in the stator, with high induced voltage in the rotor, especially if the generator is stopped. It will damage the circuit condensers in the direct current bus due to the great rectified voltage by the diodes of the IGBTs on the rotor side.

The maneuver circuit of the stator has to be revised, checking the intermediate auxiliary relay that triggers it. There has to be taken into account that the stator contactor does many maneuvers, wearing out the components of the intermediate maneuver. It has to be evaluated when it is necessary to change this relays as preventive maintenance that could take place every 4 years.

In addition, the recognition relays would be checked with the contactor closed, considering that it may cause alarms in the converter if it does not perceive recognition.

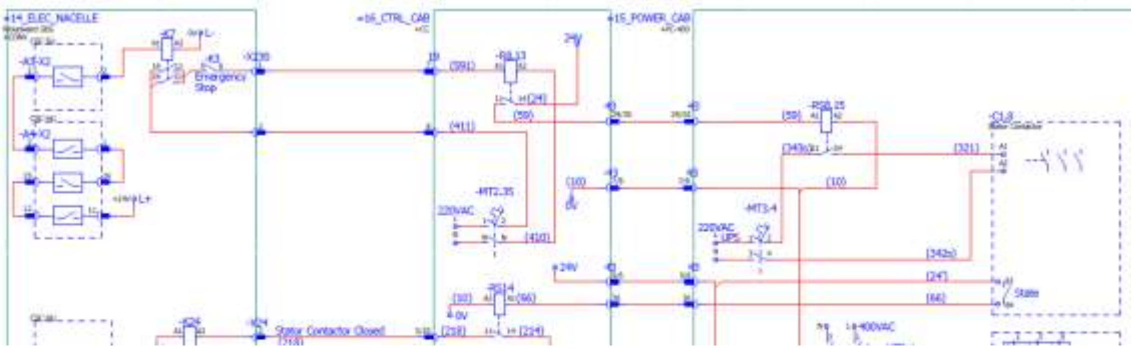


Figure 100. Contactor maneuver circuit(Source. GDES-COMSA)

Due to the great number of maneuvers that this contactor suffers and eventually some of them with power in case of disconnection of the converter due to failure and sudden opening of the contactor. It may have the chambers and contacts darkened by fire risking being stick together in the following maneuvers. All the damaged contacts would be substituted and the chambers would be cleaned up.

Figure 101. Darkened contactor visible from the outside. The exit of the chamber fires against the intensity transformer and damaging them*(Source. GDES-COMSA)*

b. AUTOMATIC SWITCH.

It is a very important component from a safety point of view, as it helps to protect the wind turbine from fire in case a short-circuit is produced at the converter. So there is no excuse to avoid its checkout.

It should be checked by a specialist, correctly trained by the manufacturer. This person would check the correct state of the trigger mechanism, both mechanically (springs) and electrically (trigger coil,), substituting the components as opportunely considered. It would be marked with a sticker including the checkout date, company, name of the technician, considering that in case of accident responsibilities may be claimed.

All the checkout periods advised by the manufacturer should be respected.

Figure 102. Automatic swicht (Source. GDES-COMSA)

All the tares and adjustments are to be completed as it is stated in the launch chart.

0. Glossary of terms, diagrams and definitions

0.1. Lesson 0: Glossary of terms, diagrams and definitions

The objective of this lesson is to present the common terms used in the wind sector, the typical diagrams and some of the more usual definitions, to be used all through the different modules of this training course.

The list is not complete and it could be completed once the material had be practically used.

0.1.1. Glossary of terms

In the following list some the most comment terms of these training contents can be found:

GWO: Global Wind Organization

BMT Basic Maintenance Training

OEM: Original Equipment Manufacturer

PPE Personal Protective Equipment

LOTO Lock Out Tag Out

WTG Wind Turbine Generator

WF: Wind farms integrated by one or several WTGs

DOWN TIME: time without WTG generation.

MTTRST. ACUMULATED: Total time with the alarm activated.

ALARM TIMES: Number of times of the activation of a specific alarm

MTBF: Mean Time Between Failures.

MTRH: Mean Time to Recovery.

UNAVAILABLE TIME: Unavailable time due to a specific alarm.

TTR: Time to repair

0.1.2. Diagrams

Typical hydraulic and electric diagrams of the most common WTG in operation in the market:

Hydraulic diagrams and symbols

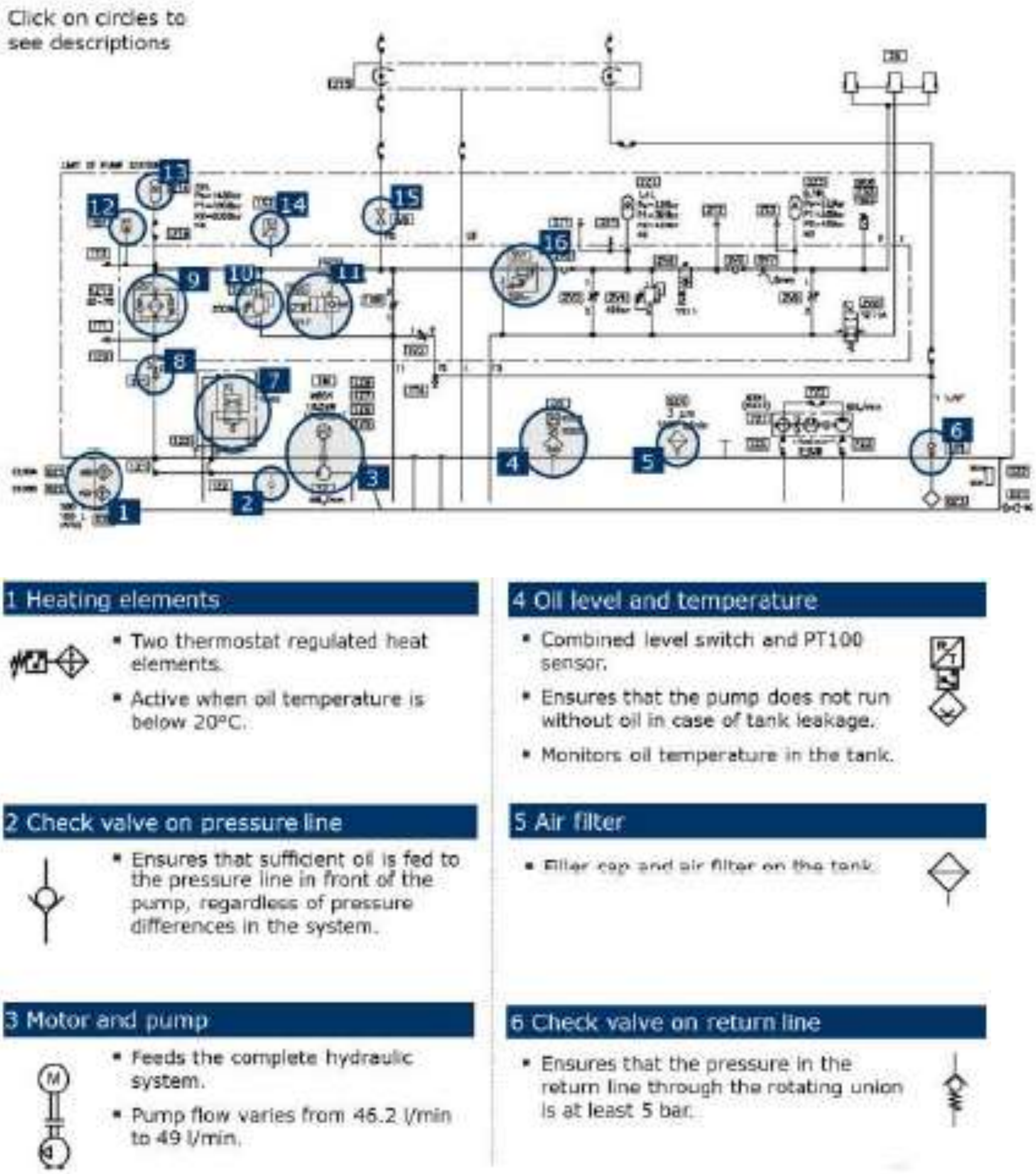


Figure 103. Hydraulic diagram components and sensors

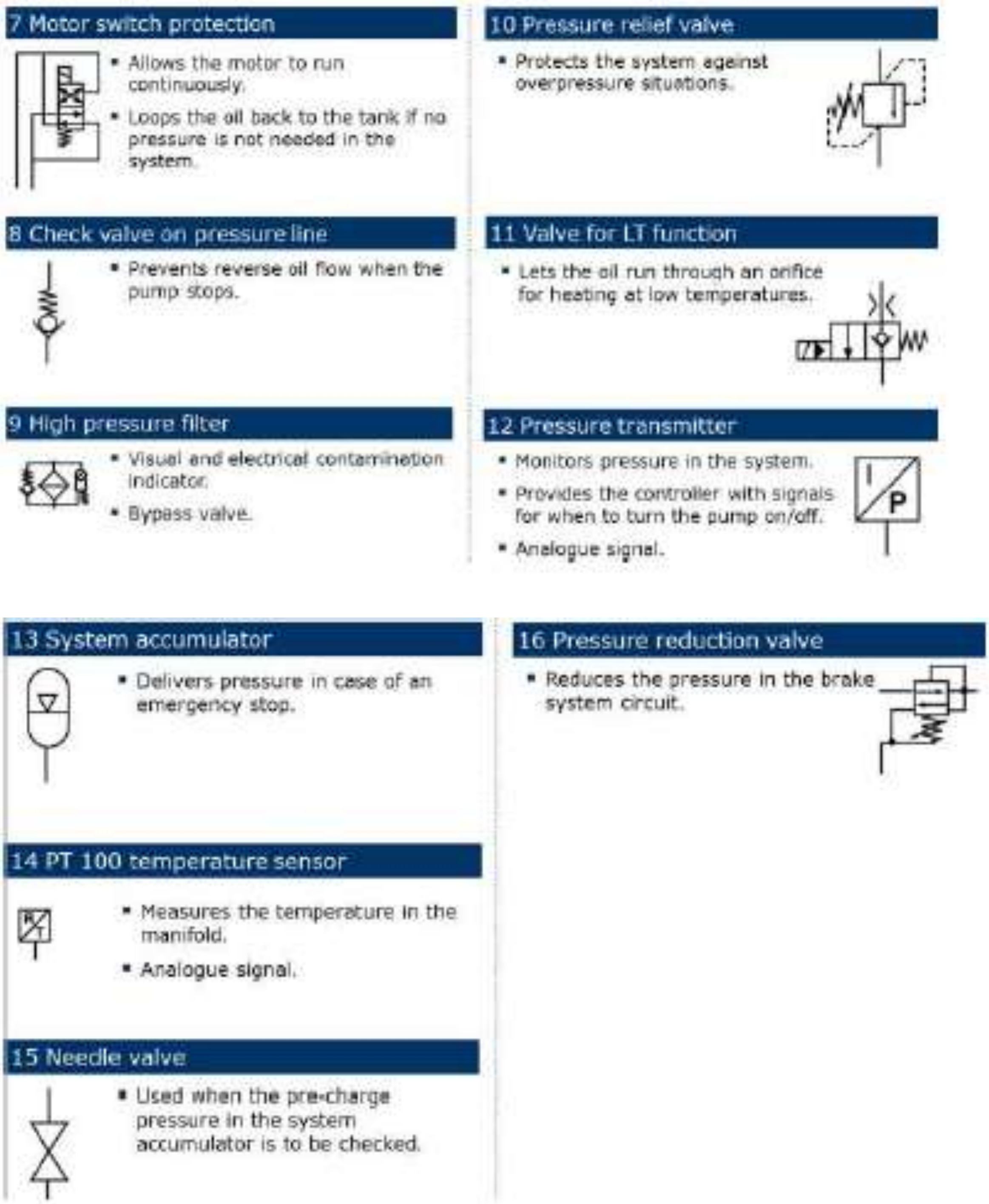


Figure 104. Hydraulic diagram components and sensors

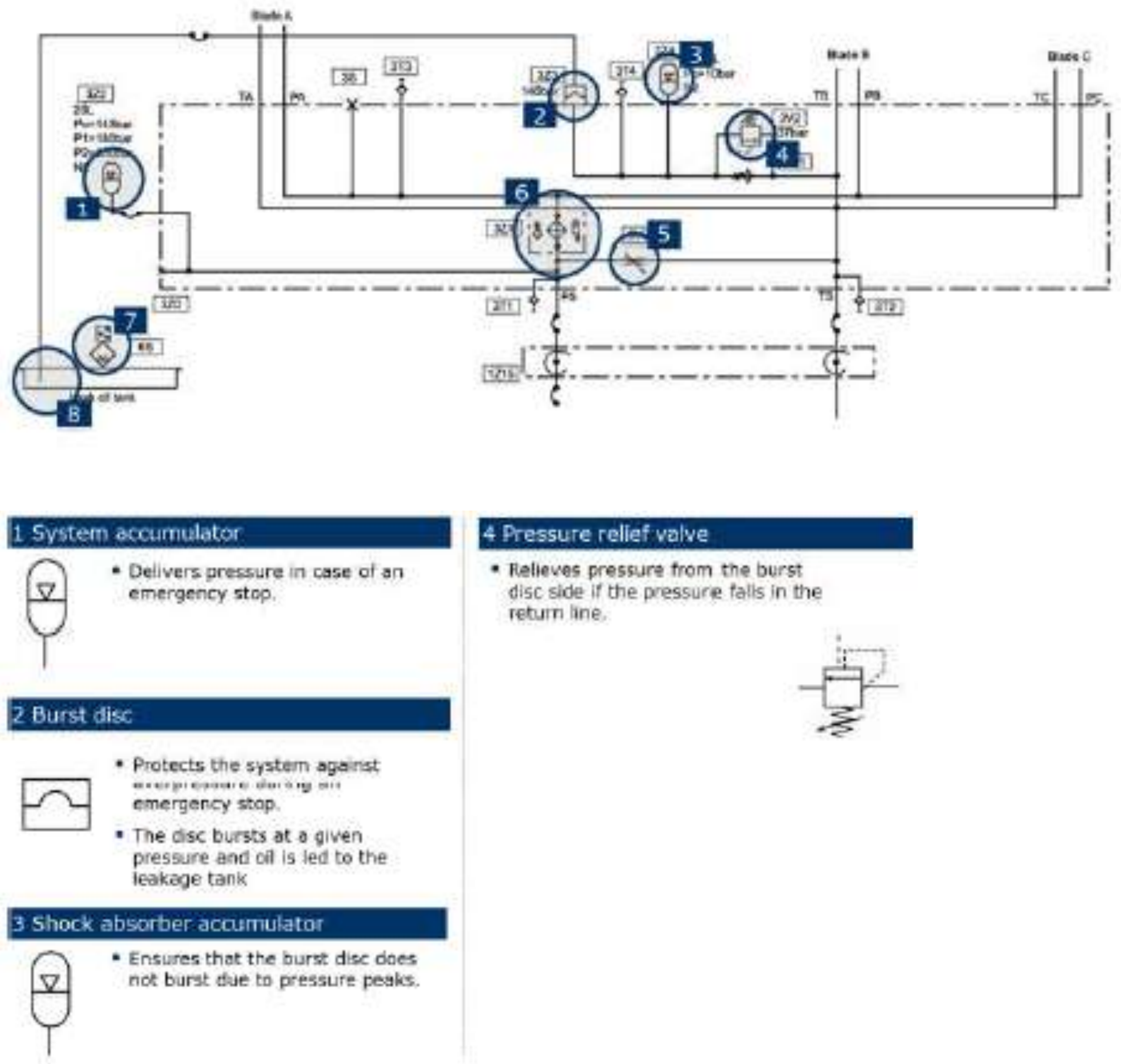


Figure 105. Hydraulic diagram components and sensors

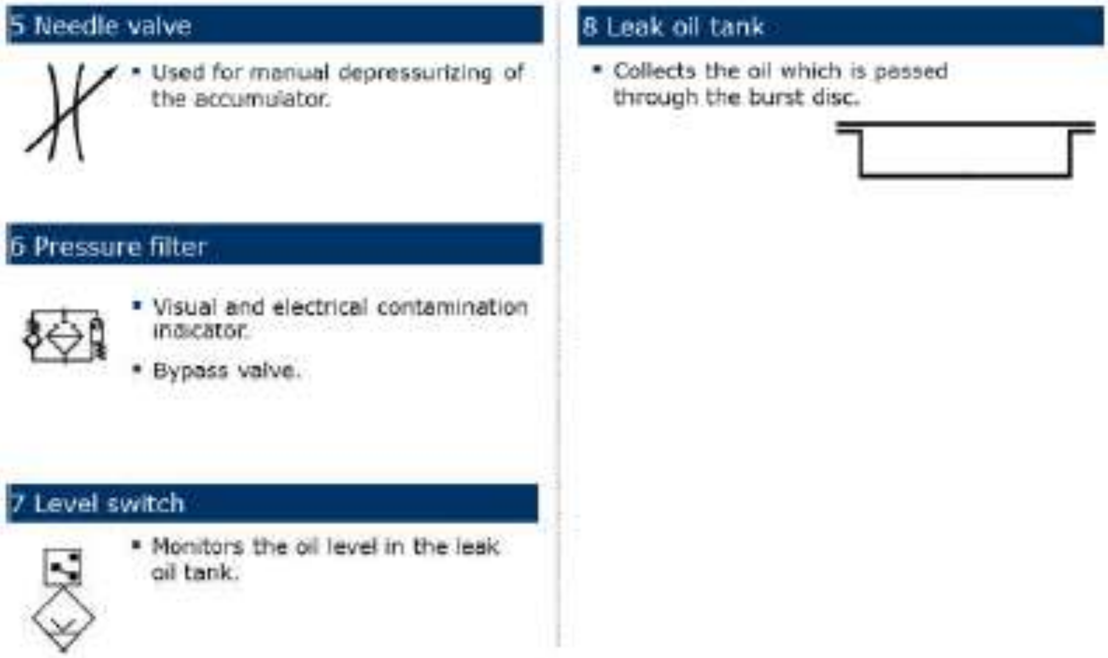


Figure 106. Hydraulic diagram components and sensors

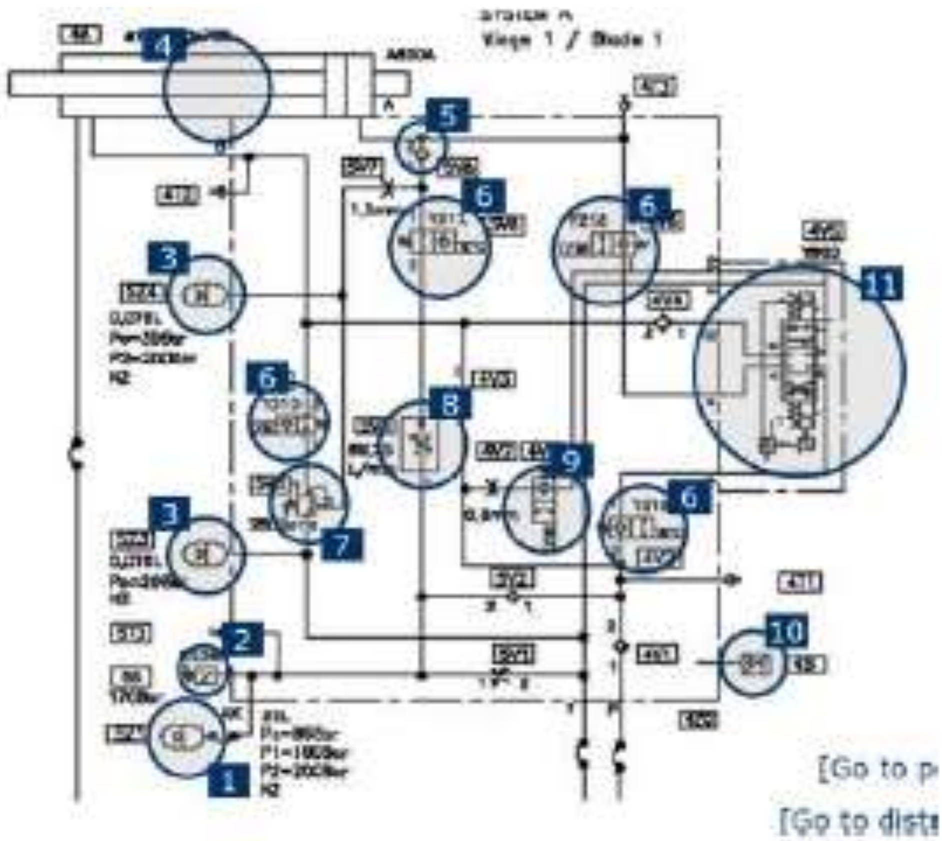


Figure 107. Hydraulic system diagram

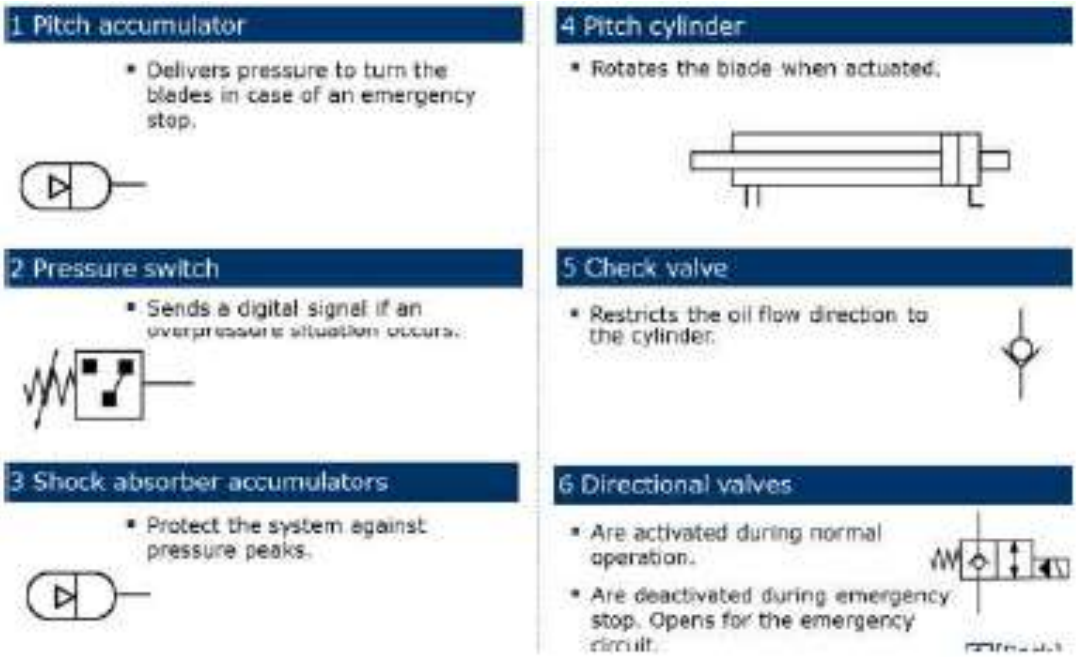


Figure 108. Hydraulic diagram components and sensors

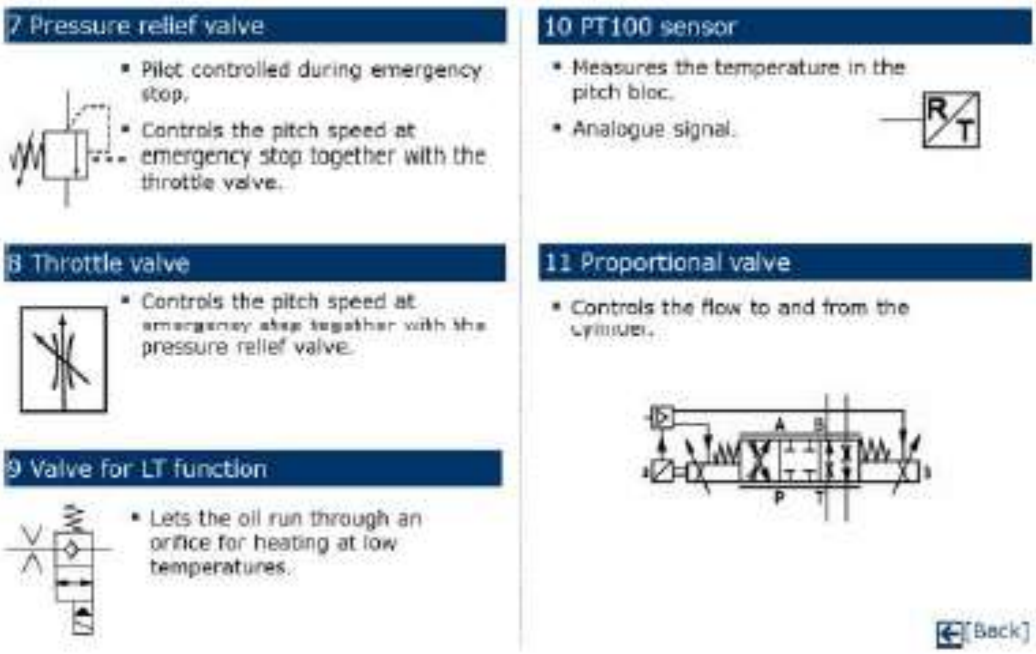


Figure 109. Hydraulic diagram components and sensors

Electric diagrams:

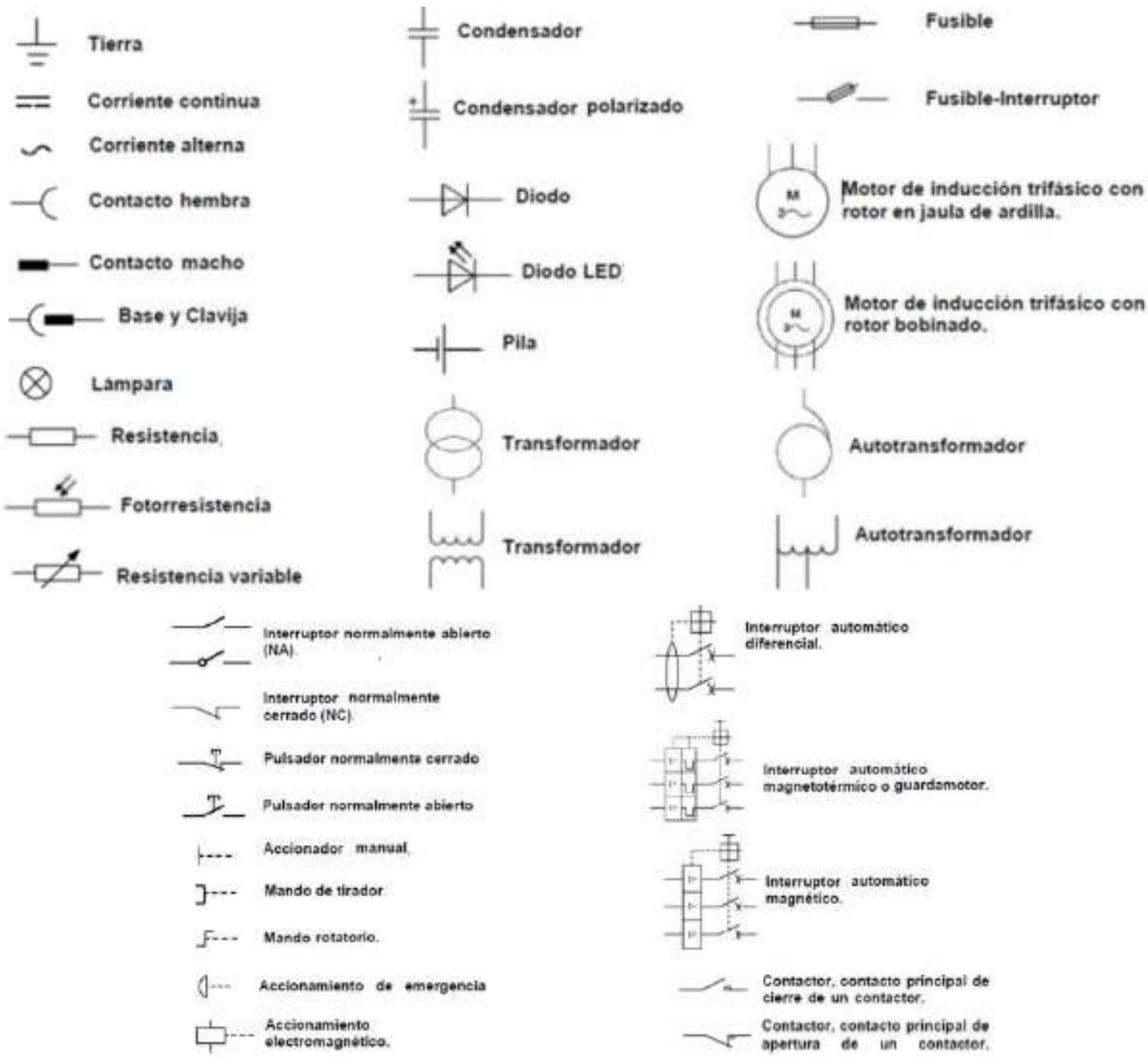


Figure 110. Electrical diagram components

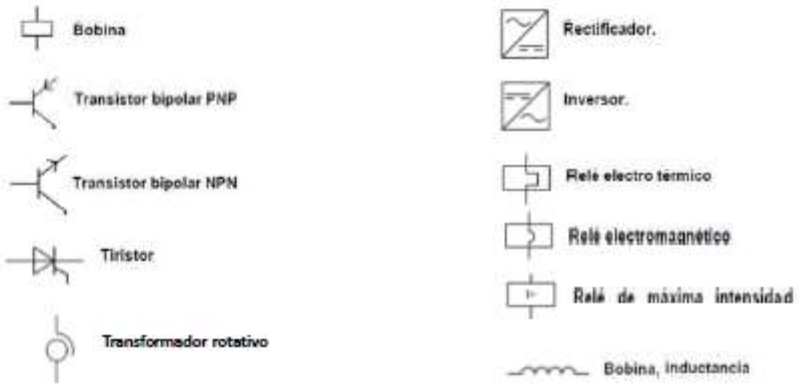


Figure 111. Electrical diagram components

0.1.3. Availability definitions

There are different kinds of presenting the availability of either a WTG or a WF, it is important to keep in mind that this definition will have contractual implications for both the user and the supplier of hardware or maintenance services.

- **Energy availability:**

It is calculated from the curve of the Wind Farm, theoretical value dividing the actually measured values for the availability percentage.

$$\boldsymbol{Energy\ availability} = \frac{\textbf{Energy produced in the period}}{\textbf{producible energy in the period}}$$

In the following figure a typical graphic representation of the availability is presented, comparing the theoretical with the actual power generation as well as the loss of power generation. Once this value is known, it is important to evaluate reasons of this deviation.

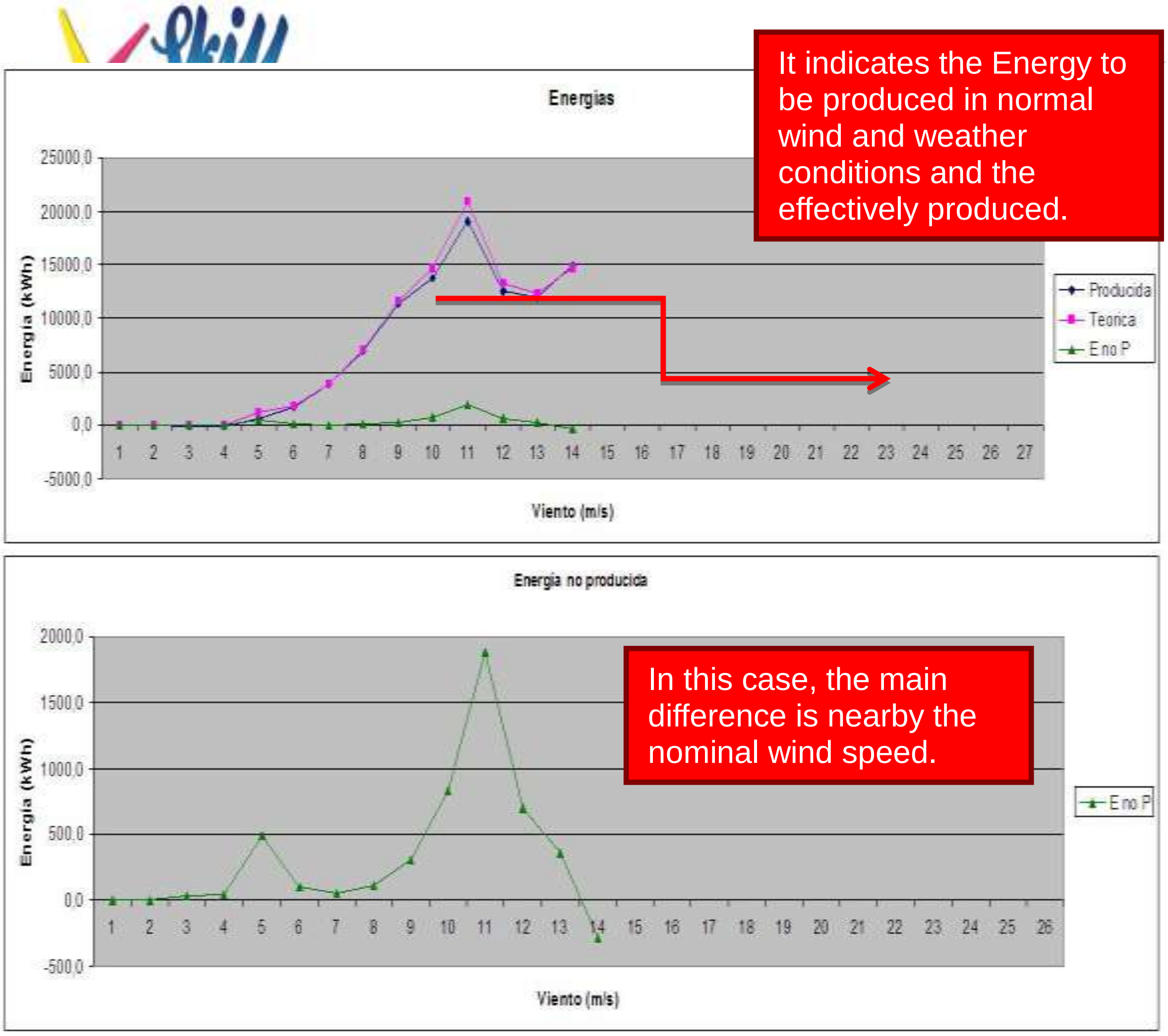


Figure 112. Therical power, generated power and non-generated power

- **<u>Availability time:</u>**

To calculate the time in which wind turbines are available is necessary the register the number of hours of actual operation of the WF as a whole:

$$\boldsymbol{Time\ availability = \frac{1}{N}\sum_{i}\frac{\text{Available time}}{Total\ time - Excluding\ time}}$$

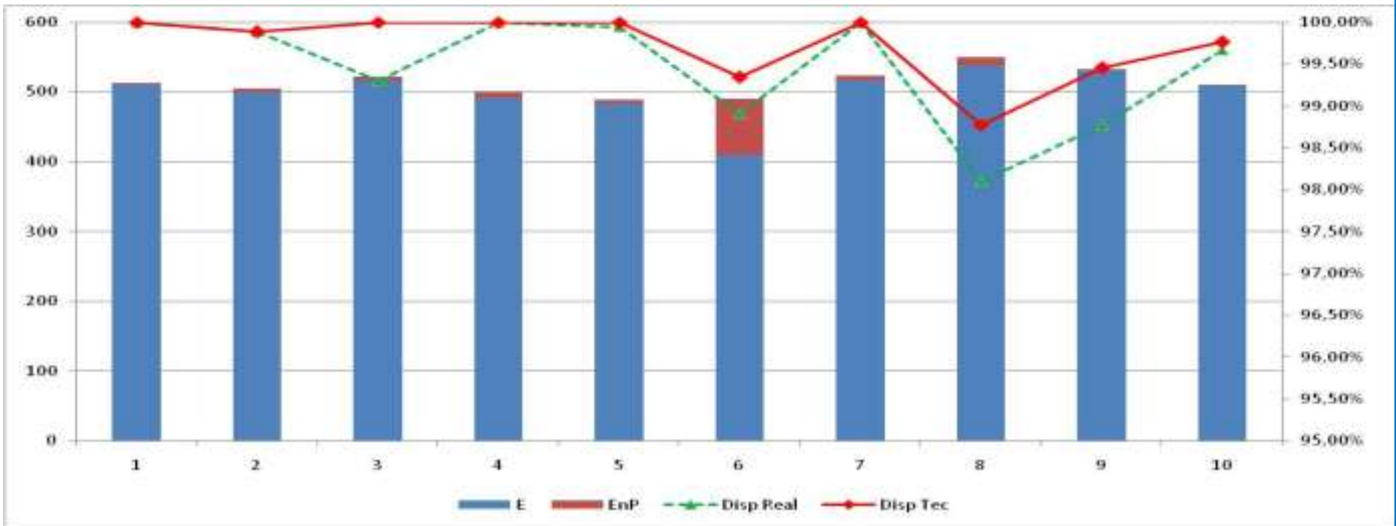
- N: Number of wind turbines.
- Available time: It is added during the period in which each turbine is producing or capable of producing, minus the preventive maintenance hours up to 24 hours per year time.
- Total time: Total duration of the period.
- Excluding time: Hours in which there have been no operation caused by several reasons beyond the reasonable control of the provider.

The guaranteed availability could have a Bonus / Malus which will be calculated annually and reconciled by the parties. In case of breach of that availability warranty, the supplier wouldl pay the customer a penalty equivalent to the loss of revenue caused by such compliance.

The availability gives an idea of the overall efficiency of maintenance, which is not detailed enough to assess the operational efficiency of the service or the company responsible for wind farm maintenance. Therefore, availability is only a target, not an indicator of support management. In this sense there are two options:

- Actual availability: taking into consideration all the registered alarms, independently of their reason or origin.
- Contractual or technical availability : taking only into consideration the alarms related to the technology itself or in other words, those alarms which are OEM's responsibility.

In the following gigure it is shown the actual power generation by the WTGs of a WF as well as the non produced electricity, following the available wind resource. The technical and contractual availabilities are also included.



E: Theoretical generation EnP: Energy lost Disp. Real: actual availability Dis. Tec: Technical avialbility

Figure 113. Energy generation and losses vs Real and technical avaialbility

Thus, during the life of the turbine if detected, for instance, an assembly problem, manufacturing or design problem of the components, which affects only a precise production serie, or assembly, it would be known in which position are placed the affected wind turbines and if it is necessary, any repairing or replacement it could be planned in advance.

All this serves to define the technical availability for a wind farm according

In this sens it is important to keep information on the WTGs availability:

Wind farm generation and technical availability

Position	Identification number	Generation	Technical availability
AEG 1	724019001	278.873 kwh	99,77 %
AEG 2	724019002	283.915 kwh	100,00 %
AEG 3	724019003	235.541 kwh	94,80 %
AEG 4	724019004	274.460 kwh	100,00 %
AEG 5	724019005	281.612 kwh	98,65 %
AEG 6	724019006	263.810 kwh	95,93 %
AEG 7	724019007	267.734 kwh	100,00 %
AEG 8	724019008	317.922 kwh	99,66 %
AEG 9	724019009	302.350 kwh	97,00 %
AEG 10	724019010	295.057 kwh	98,43 %
AEG 11	724019011	294.854 kwh	99,98 %
AEG 12	724019012	291.713 kwh	99,88 %
AEG 13	724019013	288.709 kwh	99,80 %
AEG 14	724019014	289.632 kwh	99,86 %
AEG 15	724019015	274.629 kwh	94,99 %
AEG 16	724019016	296.307 kwh	100,00 %
AEG 17	724019017	305.463 kwh	98,25 %

AEG 18	724019018	304.229 kwh	99,96 %
AEG 19	724019019	290.654 kwh	99,98 %
AEG 20	724019020	290.234 kwh	99,59 %
AEG 21	724019021	272.479 kwh	99,94 %
AEG 22	724019022	253.884 kwh	96,80 %
AEG 23	724019023	281.683 kwh	99,59 %
AEG 24	724019024	259.607 kwh	97,17 %
AEG 25	724019025	289.528 kwh	99,61 %
AEG 26	724019026	298.072 kwh	99,98 %
AEG 27	724019027	301.200 kwh	99,18 %
AEG 28	724019028	284.965 kwh	100,00 %
AEG 29	724019029	285.584 kwh	97,99 %
AEG 30	724019030	307.555 kwh	100,00 %
AEG 31	724019031	308.074 kwh	99,76 %
AEG 32	724019032	295.519 kwh	97,58 %
AEG 33	724019033	339.896 kwh	99,99 %

Chart 3.Availability and production per machine

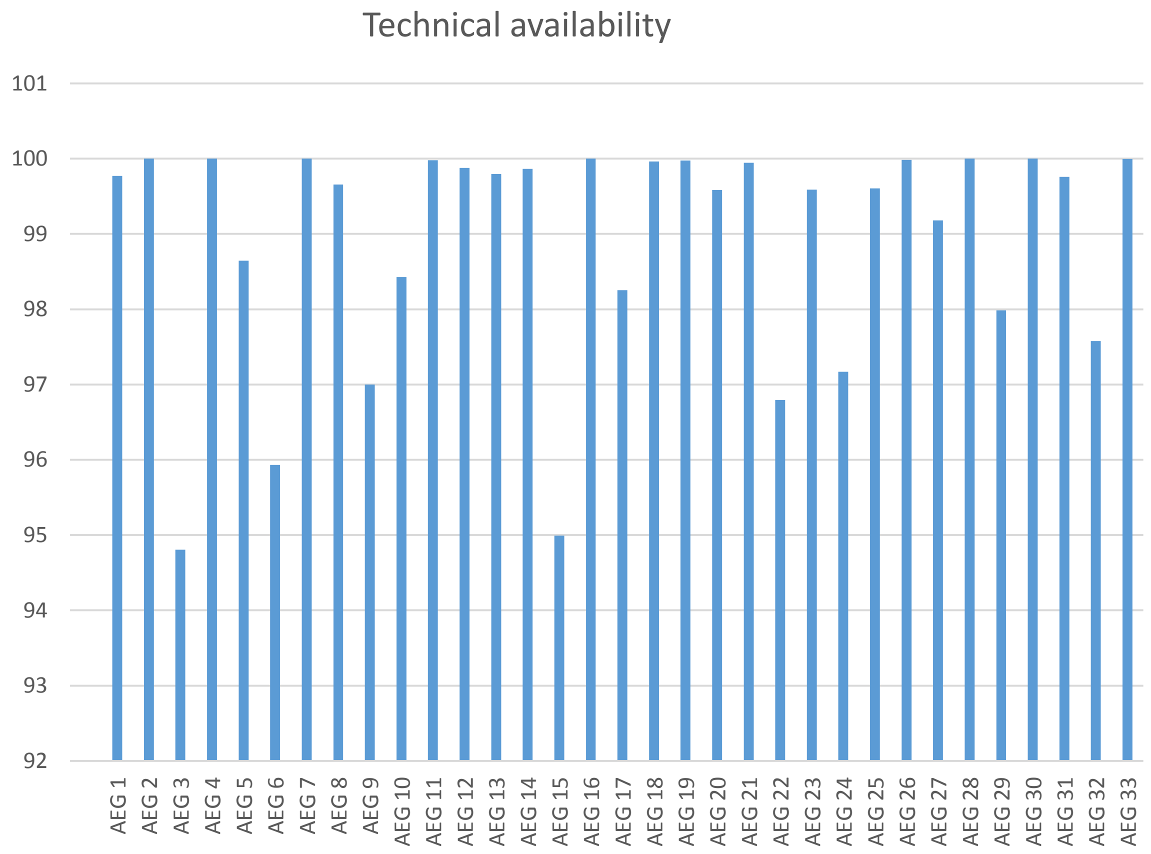


Figure 114. Technical availability per machine

0.1.4. Faults and downtime per components

Faults

To initiate the course it is important to understand the operation of a wind farm as well as the faults per component and the average downtime, because small components break down more often but have a lesser impact in the loss of profit. In the following figures it can be observed the faults per component.

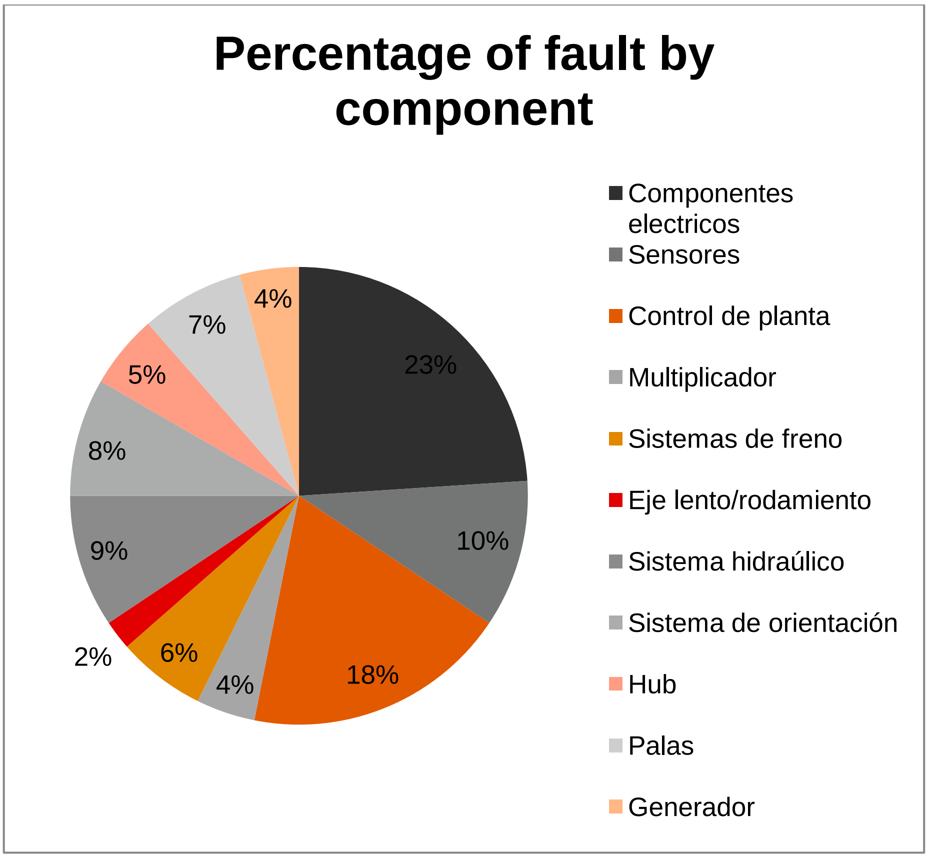


Figure 115. Percentage of fault by component

It is also important to keep in mind that some components have more faults in high wind conditions as it can be observed in the following figure:

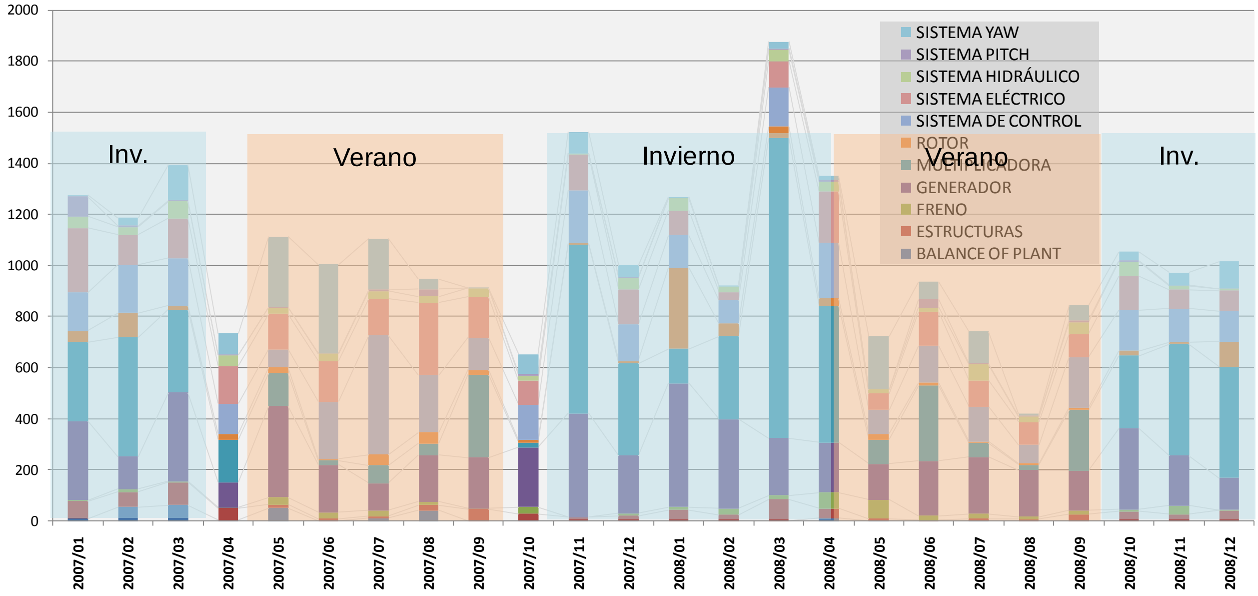


Figure 116. Component failure stationaly

In the following figure it can be observed the number of failures and their incidence in the down time, concluding that small faults have a low impact in the total downtime

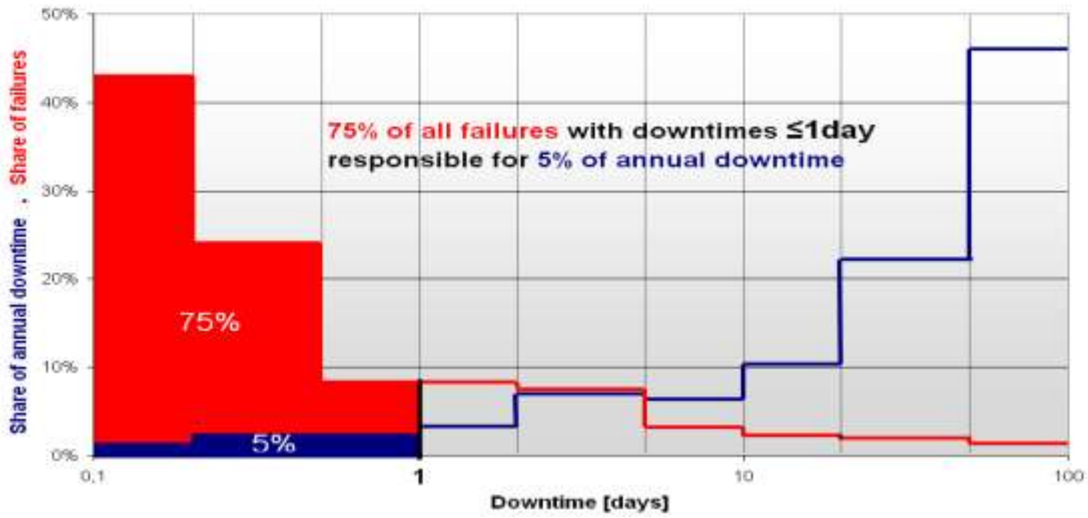


Figure 117. Failure down time

Therefore, it is clear that the failures are more often in small components but they have a reduced impact.

Downtime

In the following figure is presented the downtime per component:

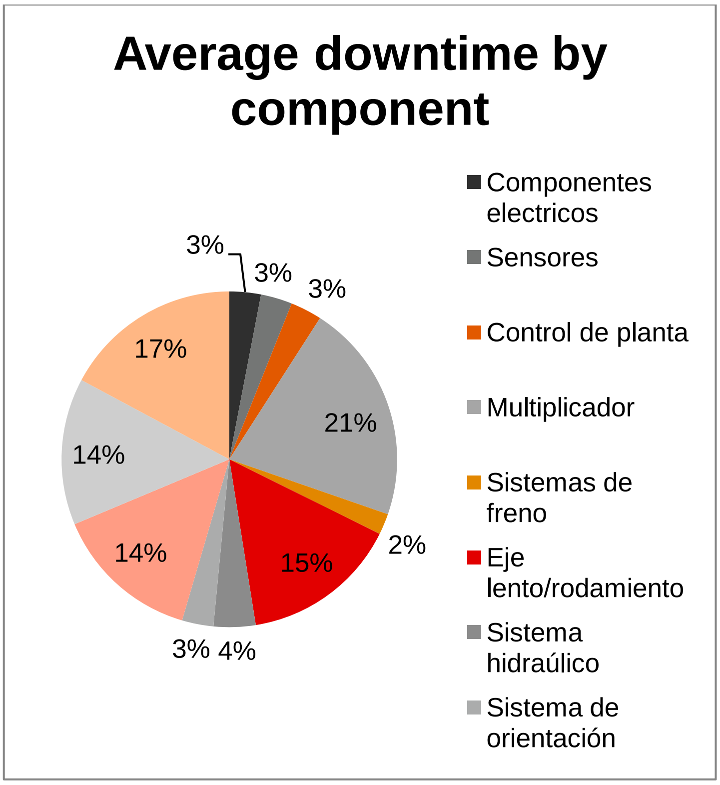


Figure 118. Average downtime by component

To enter into the detail of the down time we can see the following figure:

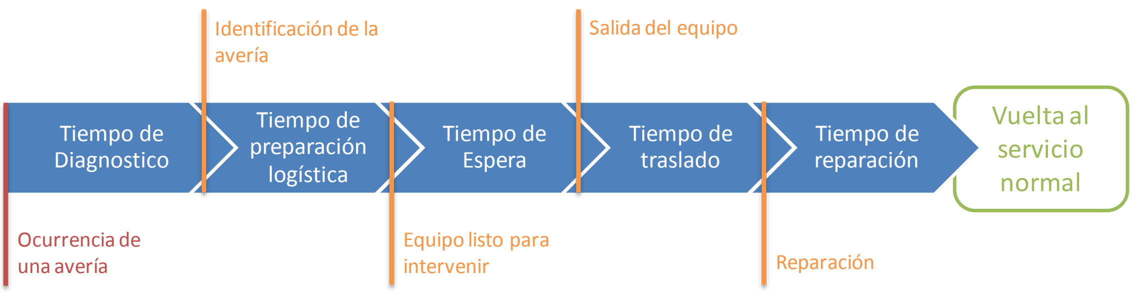


Figure 119. Downtime detail

But it is also important to evaluate the down time of a turbine more in detail due to planned and un-planned activities. In the following diagram are organized the different activities with implications in the turbine down time.

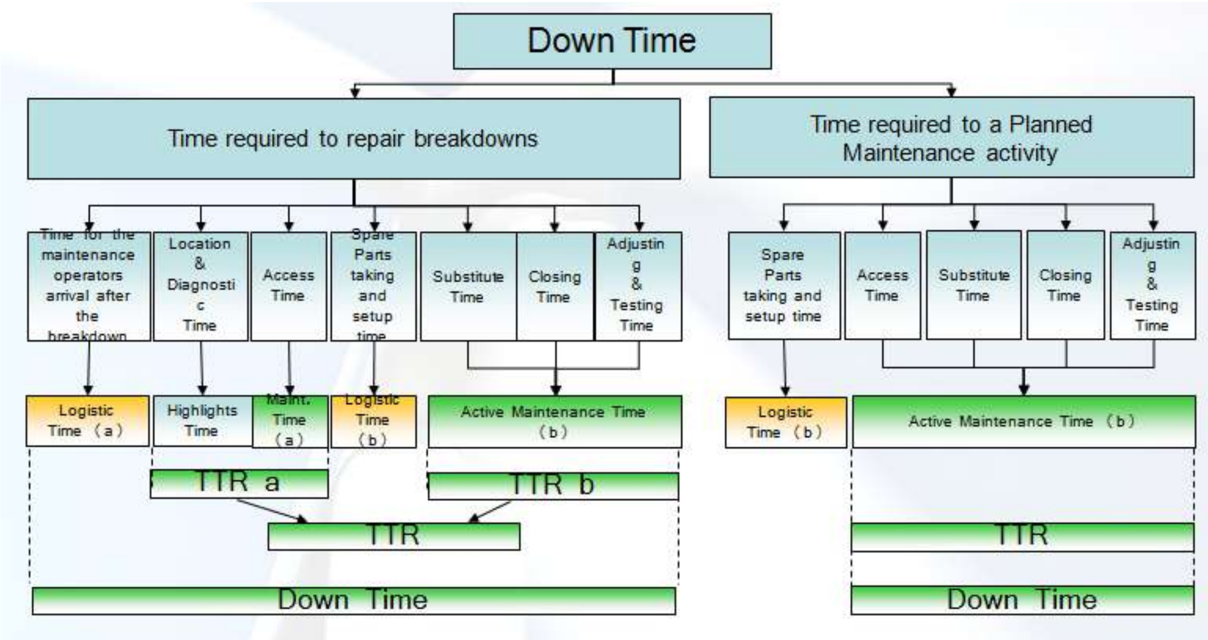


Figure 120. Down Time activities

Unplanned activities, which are represented on the left of the picture, have large uncertainties due to the nature of the events that are not provided.

A logistics time is needed to mobilize maintenance equipment, since fault happens until the equipments arrive could be quite long. The way to reduce this time is to have a computer available near the turbine storing data 24 hours a day. This time of mobilization is given the name a) in the figure.

The time required for fault diagnosis can be shortened with improved training and provision of facilities for the maintenace teams.

The access time is the time required for the maintenance team to access the fault. We should note that certain faults could be prolonged in time if they are located in parts such as the pitch.

The sum of these times (location and access) is what is called TTR (time to repair). Once accessed the fault, the time needed to supply the spare parts, is the time called logistics b).

It is important to distinguish these times because their reduction is relatively easy with investment, but as seen in certain cases investment is not sufficient or cost exceeds the benefit.

Continuing with the repair operation, the time of replacement or repair itself has to be regarded . By adding the closing time of the wind turbine generator after replacing the component in which the fault appeared and the adjustment and testing times gives us the other side of TTR (time to repair)

Two parts of TTR are distinguished because these two values and the overall value give a very different information. One is the analysis and troubleshooting while the other part is the skill of workers to repair or replace those damaged components.

The first part is the most difficult to attack because it is not only with training but experience and provision of more sophisticated tools that the time required for troubleshooting could be attempt to be reduced.

It has to be taken into account that scheduled tasks are easier to optimize. These tasks can be divided into different sub-actions such as:

- Time required for access: which includes the time since the machine stops until the component or sector in which to intervene is accessed.
- Replacement Time: it is the proper time of the maintenance action.
- Closing time: it is the time required to collect and complete the action before the commissioning of the machine.

– Time adjustment and testing is considered necessary in order to check the time before the machine can be launched.

All the time periods commented before are considered the active or real maintenance time. The amount of time these activities take is included in what is called MTTR (Mean Time To Repair)

It would fail to include the time needed for logistics, that is, the time needed to organize all resources (both human and material ones) to carry out the activity.

Having all these maintenance times divided is really helpful for the optimization of maintenance operations in a wind farm.

Failure rate

Failure rate, λ, indicates how many times per unit time that a component fails. MTBF indicates how long a time passes between each failure. The relation between these is

therefore:

$$\lambda = \frac{1}{MTBF}$$

Mean Time Between Failure is the most common way to determine a maintenance interval. It indicates the time from a components failure to its next failure. This time include MDT (Mean Down Time) and MTTF (Mean Time To Failure).

MTBF = MDT + MTTF

FMEA

FMEA, Failure Mode and Effect Analysis, is used in reliability analysis and with this method the connection between possible failure modes for a construction and the failure effects that these give rise to can be determined [31]. The method was introduced by the aircraft manufacturer Boeing in 1957. The method was developed during the fast technical development in 1940-1960.

The purpose of the method is to find all the ways that the product can fail. Three questions are answered, these are:

1. What failures/events could appear?
2. What are the effects of the failures/events?
3. What are the causes of the failures/events?

Then the failures probability, seriousness and possibility of discovery should be estimated. To perform this the system is being divided into several sub systems. When the three questions have been answered the frequency with which the failure can occur is indicated with a number between e.g. 1 and 10. Then a number indicates the seriousness of the consequence. Finally a number indicates the probability for discovery. These numbers are multiplied into a combined index number, for which a higher value indicates a worse failure. This number is called risk priority number. This gives a ranking list for the failures, from which using the size of the risk priority number one can make an estimation of the seriousness of the failures and then make a measurement.

3.1.1. Indicators

Fault diagnosis, so far is one of the greatest difficulties. The software supplied by wind turbine manufacturers allows a first approach to a component failure and indicates that a sensor has an abnormality in its current analysis and introduces a management system adapted to new technologies. It is no longer unusual to find a CMMS (Maintenance Management Computer assisted) in a tablet. These applications allows working with a guide in troubleshooting as through inspection of a tree of activities that help to reach the focus of the fault.The most advanced computer systems allow to learn from the activities and to improve the diagnosis of faults, and to analyze similar failures occurring in the same machines to propose a solution.

In the text bellow, we can see some indicators, which are used in maintenance tasks:

- **MTBF** (Mean Time between Failure): mean time between failures corresponds to the expected frequency of a breakdown. It allows to know the reliability of a component and to plann obsolescence. Both very useful to program the need of replacement thereof.

- **Standardization of time** to perform maintenance tasks: it is assumed that each corrective maintenance task has to be performed in a given time, depending on the complexity of the task and the need for machinery/spare parts for its fulfillment. Breaking down this time period, it can identified which phase of the repair can be improved and with what means. To do this, technicians must record the detailed timing of each phase of repair calls.

In the following chart is presented the Accumulated dead time for different alarms as well as several indicators induding the lost energy. It is clear in this case that there is an excess of temperature in the nacelle and it is convenient to install an air conditioning system. This alarms will determine then the activities not initially foreseen.

Estadística de Alarmas						
Descripción	T. acumulado	Veces	MTBF	MTTR	T. Indisp.	E no P
›ient temperature high: 29°C	55:06:20	81	1:46:40	0:40:49	60:18:08	8259,5
ting nacelle and gear oil	0:16:16	10	14:24:00	0:01:38	0:16:16	0,4
rmoerror IGBT fan F5492	1:41:10	9	16:00:00	0:11:14	1:41:10	1102,0
many ArcNet reconf. 10	1:21:45	9	16:00:00	0:09:05	1:21:45	436,3
r. temperature high: 65°C	4:46:35	7	20:34:17	0:40:56	0:34:47	81,8
dback = 1, Brake	6:07:32	7	20:34:17	0:52:30	1:53:14	513,3
rmoerror Int.Gen.Fan F513A	1:35:46	7	20:34:17	0:13:41	1:35:46	380,9
t auto-outyawing CCW	3:30:44	7	20:34:17	0:30:06	3:30:44	292,9
:rl: 8.10V P.Vel: 6.2°/s	0:04:29	4	36:00:00	0:01:07	0:04:29	2,4
:rlV.STD 7.004V MEAN 4.076V	0:10:36	4	36:00:00	0:02:39	0:10:36	0,0
rmoerr. oil pump F410/ 51°C	0:33:51	3	48:00:00	0:11:17	0:33:51	60,0
rmoerror Ext.Gen.Fan F 509	0:20:56	2	72:00:00	0:10:28	0:20:56	283,3
se pressed on keyboard	1:55:55	2	72:00:00	0:57:58	1:55:39	0,0
eme yawerror 13.2m/s 62.9°	0:01:50	1	144:00:00	0:01:50	0:01:50	20,5
rmoerror Int. VCS Fan F 546	0:10:10	1	144:00:00	0:10:10	0:10:10	19,3
tdown timeout Stop Slow	0:10:00	1	144:00:00	0:10:00	0:00:00	0,0

Chart 4 Alarms and indicators through time

3.1.2. Check list example

The maintenance check lists were created with the idea of ensuring the proper functioning of preventive maintenance, to provide a guide to perform inspections for maintenance teams attending the machine. If an anomaly is found in these check list it would be marked for the preventive maintenance team in order to proceed with the corrective action corresponding to the machine marked in the chart. Often this list is provided for personnel to perform other preventive maintenance tasks such as the bolts tighting up. Thus, it facilitates subsequent proceedings.

Nº	**Inspection**	**Frequency (months)**	**Change**	**Frequency (months)**	**Quantity**	**Unit**	**Observations**
1.10	To check doors and entrances in gondola	6	-	-	-	-	
1.20	To check safety line	12	-	-	-	-	

Nº	Inspection	Frequency (months)	Change	Frequency (months)	Quantity	Unit	Observations
1.30	To check absence of abnormal noise or vibration in tower	12	-	-	-	-	Following the torque chart
1.40	To retighten screws	6 (12)	-	-	-	-	
1.50	To check no damage layer corrosión protection	12	-	-	-	-	
1.60	To check absence of displacemnts in structural components	12	-	-	-	-	
1.70	To clean the nacelle	12	-	-	-	-	

Chart 5 Preventive maintenance check list

Initial Bibliography:

- *INGETEAM TRAINING HANDBOOKS*
- *AEE: Maintenance Training course, background document*
- *Manual de Energía Eólica (Desarrollo de Proyectos e Instalaciones). Salvador Cuco. Universitat Politecnica de Valencia*
- *AEMER Guidelines for WTG/WF diagnosis and evaluation. GDES-COMSA contribution*
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