# windEXT

## Advanced maintenance, lifetime extension and repowering of wind farms supported by advanced digital tools

### Project nº 612424-EPP-1-2019-1-ES-EPPKA2-KA

# Summary of Deliverable R5.1.

# Types of Maintenance Strategies

## WP5

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# 1  Work Package Description

This document presents a **public summary** of the development carried out as part of WP5 of the WINDEXT Project (M3 – M24) lead by UCLM, corresponding to the development of "Module C: Maintenance" of the course from M3 – M12. For that, UCLM have gathered training material on maintenance activities, supported by AEE, 8.2, DP2i, INESCTEC, TESICNOR, TUDELFT and UTEC.

Module C covers all aspects of maintenance of wind turbines. First, the introduction to the different maintenance strategies and a comprehensive description for each of them will be presented, these being preventive, corrective and predictive maintenance.

Then, each type of maintenance will be broken down per wind turbine component, covering the main critical components and common faults in wind turbines. This part will cover inspection, reparation and monitoring of blades, gearboxes, mechanical transmission system, electric components, power electronics and foundation. It will include theoretical information and example case studies. The integration of preventive, corrective and predictive actions will also be developed.

The specificities of offshore maintenance will be addressed separately, covering specific maintenance offshore and manpower and logistics.

Finally, improvement of business for independent service providers (ISP) and new business opportunities in this field will be analysed: main lessons learned, business plans, follow up and feedback, etc.

UCLM will lead the integration and adequation of the different parts of this module. In this regard, the expected outcome and results of Module C are divided in two parts:

R5.1: The first part due in M12 (the present deliverable) will focus on the types of maintenance. Hence, this result will cover the introduction to the different maintenance strategies, and a comprehensive description for each of them (preventive, corrective and predictive maintenance), including theoretical information as well as practical case studies.

R5.2: The second part, due in M24, will cover Condition and Health Monitoring (including commercial systems), the specificities of offshore maintenance and business opportunities. R5.2 will also include the assessment of R5.1, where any necessary improvements or upgrades will be addressed.

## 2  Learning Objectives of the Maintenance Module

The main objective of Module C is to develop advanced training material for the students to acquire the knowledge covering all aspects of maintenance of wind turbines. Particularly, the objectives are:

- To learn the different maintenance strategies, target and scope.
- To learn preventive actions (common inspections) of the main components of a wind turbine.
- To learn corrective actions (common reparations) of the main components of a wind turbine.
- To acquire knowledge in condition monitoring and structural health monitoring, different techniques and learning through case studies.
- To understand the integration of the different maintenance strategies.
- To acquire specific knowledge for offshore maintenance.

The contents developed in WP5 will be integrated in the digital/simulator tools developed as part of WP3 lead by TESICNOR.

# 3   Structure of the Maintenance Training Material

The structure used to develop the training material for Module C is depicted in the following diagram:
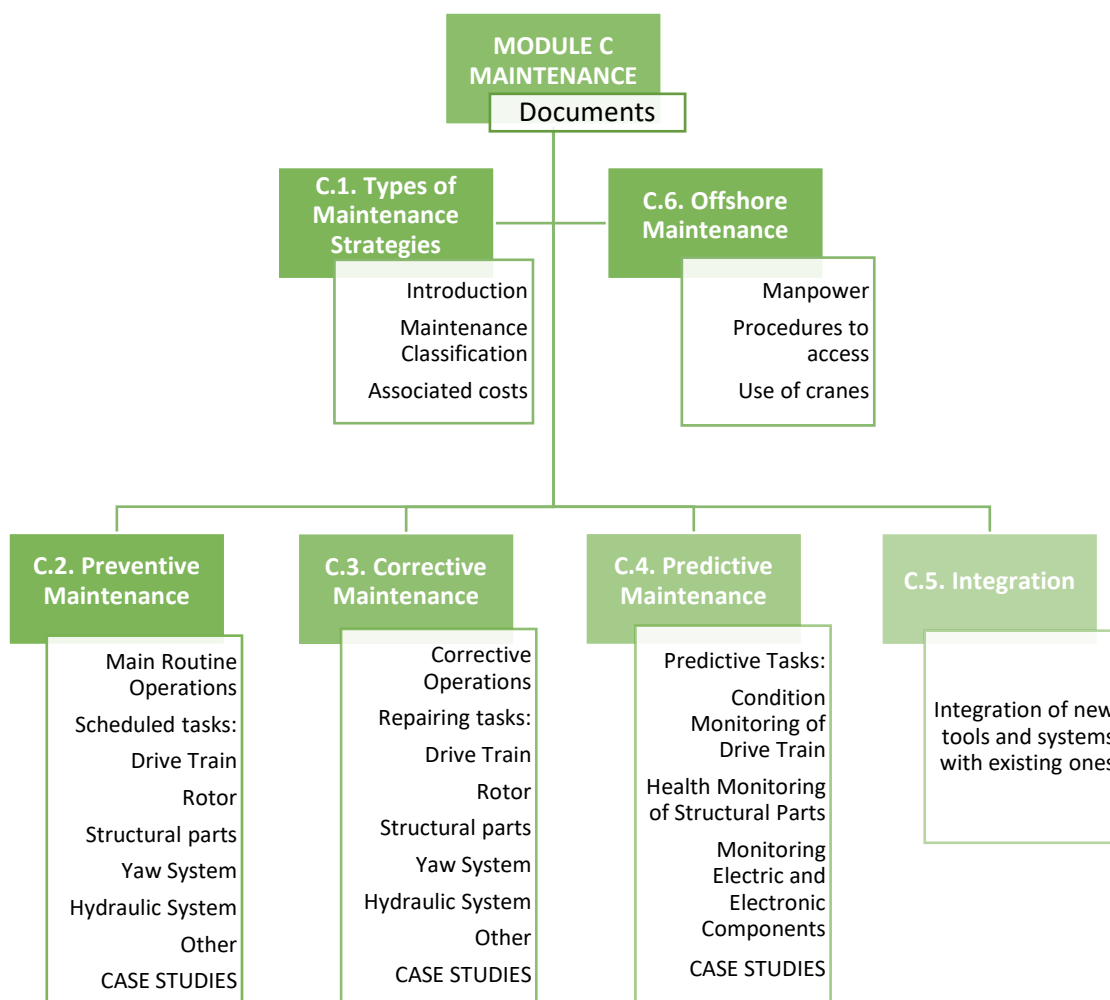


As explained in Section 1, the present deliverable (R5.2) covers the types of maintenance strategies, thus documents C.1 to C.4. The rest of the documents (C.5 and C.6) will be presented in R5.2 (M24). As mentioned, R5.2 will also cover the *Business Opportunities*, including:

- Commercial condition monitoring systems.
- Improvement of business for ISP.
- Methods to create new opportunities in the maintenance field.

# 4    Content of the Training Material

## 4.1    Types of maintenance strategies (C.1)

Operations and Maintenance (O&M) costs represent between 25% and 35% of the total expenditure for onshore and offshore wind farms, respectively. It is therefore clear that reducing these costs is highly beneficial for wind farm operators and owners.

According to the European Standard "*EN 13306:2018 Maintenance - Maintenance Terminology*", maintenance is classified in two main groups depending on whether the maintenance tasks are carried out before failure or after failure, these being preventive and corrective, respectively, see Figure 1. Preventive Maintenance is then classified in two sub-groups: Predetermined Maintenance, traditionally called Scheduled Maintenance, which is periodic and independent on the component's condition, and Condition Based Maintenance, comprising Predictive Maintenance within. Corrective maintenance is classified in another two sub-groups: Immediate Corrective Maintenance and Deferred Corrective Maintenance, depending if the maintenance tasks are carried out immediately after identifying a functional failure, or if these tasks can be programmed and executed as a scheduled task (but being the consequence of a failure).
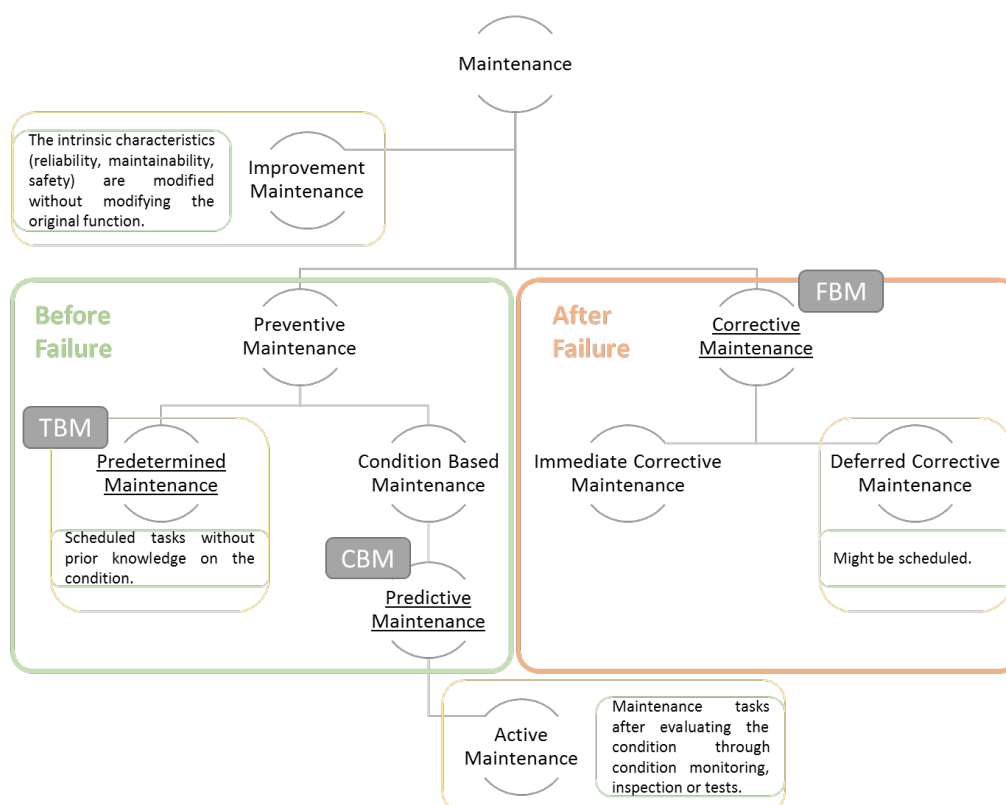


**Figure 1.** Maintenance classification according to European Standard EN 13306: 2017.

Besides, Improvement Maintenance might be applicable when the maintenance tasks are designed to create a positive change in any of the intrinsic characteristics (within the design of a specific component) but it does not affect the functionality of the component.

Another important concept is Active Maintenance, which implies the development of a work order (this being preventive or corrective) after evaluating the condition of a component.

In the wind energy sector, maintenance is commonly classified in three main groups, as labelled in Figure 1, these being: time-based (TBM), failure-based (FBM) and condition-based (CBM). TBM is formed by preventive tasks, also referred to as scheduled maintenance, and it is carried out regardless of the health state of the wind turbine. FBM involves corrective actions, only performed after a critical failure has taken place, thus usually causing long downtime periods. CBM (predictive maintenance) takes place only when there is a need but before a critical failure occurs, with the consequent saving in resources and downtime, thus achieving the optimum strategy.

In the present document, the different maintenance types have been defined as it is colloquially found in the wind energy sector: Preventive (TBM – Predetermined Maintenance), Corrective (FBM) and Predictive (CBM). It is important to highlight that, in this document, Preventive Maintenance refers exclusively to TBM (Predetermined or Scheduled Maintenance), although Predictive Maintenance (CBM) is a type of preventive maintenance, as illustrated in Figure 1. The number of failures vs costs for the different maintenance strategies are illustrated in Figure 2.
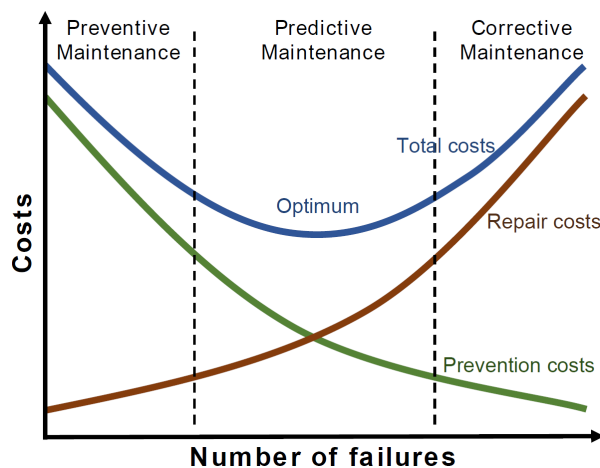


**Figure 2.** Maintenance strategies, number of failure vs costs.

Traditionally, a combination of Preventive and Corrective Maintenance has been the preferred option among wind farm operators. Lately, however, the trends are shifting towards Predictive Maintenance, which is performed through appropriate condition monitoring (CM), recognised in the field as the key for optimised reliability and availability of wind turbines while achieving cost reduction in O&M. The diagram in Figure 3 presents the differences among them, and the advantages and disadvantages comparing them are highlighted in the table below.
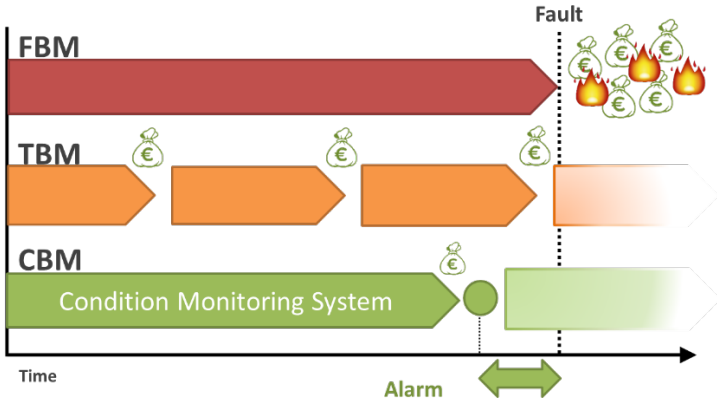
**Figure 3.** Main types of WT Maintenance.

| | ADVANTAGES | DISADVANTAGES |
|---|---|---|
| **FBM** | Simple, does not require advanced resources or specialised personnel* to be implemented and managed. | Likely to cause long downtime periods and high collateral damages. |
| **TBM** | It requires of a small investment in order to establish and implement the maintenance plan. After the initial investment and implementation, it becomes simple and does not require advanced resources or specialised personnel*. | Likely to cause very frequent interventions at high costs. It can also incur in late interventions causing full failure development, thus resulting in long downtime periods and high collateral damages (as in FBM). |
| **CBM** | It allows for sufficient time to plan the maintenance task associated to a developing failure before the failure becomes critical, as a result downtime and resources are minimised. Collateral damages are also minimised. | Medium-high complexity, requiring of advanced resources and qualified personnel, with their associated extra costs. |

*(It will require, of course, specialised personnel to carry out the maintenance tasks at the WT).

## 4.2 Preventive maintenance (C.2)

It is not always possible to anticipate a fault. When a specific type of fault cannot be anticipated (or predicted) and, thus, CBM cannot be implemented, preventive maintenance becomes critical in order to avoid or minimise corrective maintenance. Preventive Maintenance is carried out as indicated by the manufacturer.

The following diagram (in Figure 4) presents the logic behind predictable and non-predictable failures, explained with examples.
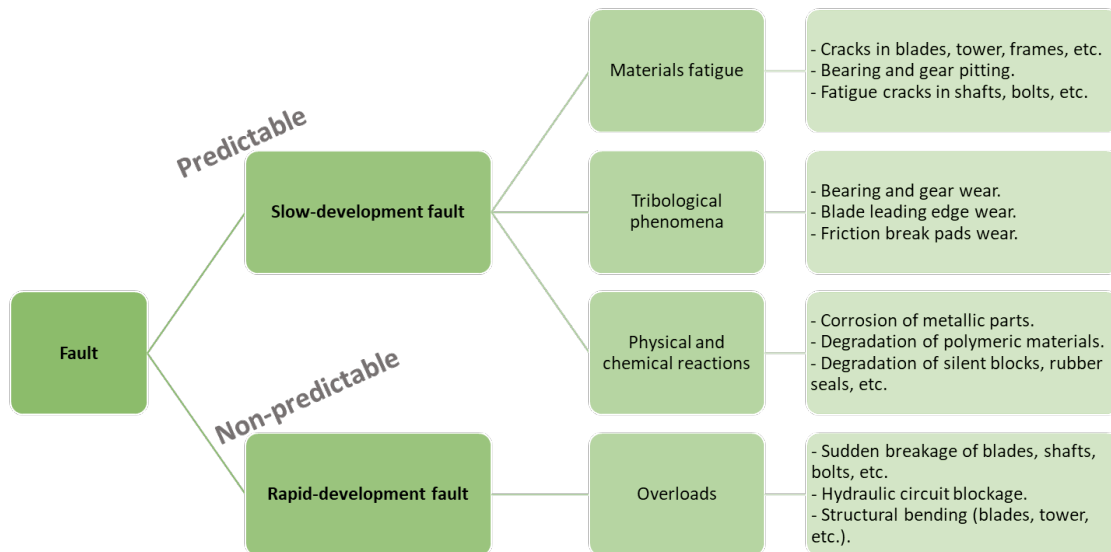


**Figure 4.** Faults classification.

It is possible to anticipate predictable faults, i.e. it is possible to implement CBM in those cases. However, it is not possible to predict those faults classified as non-predictable. In these cases, corrective maintenance can only be avoided through appropriate preventive maintenance.
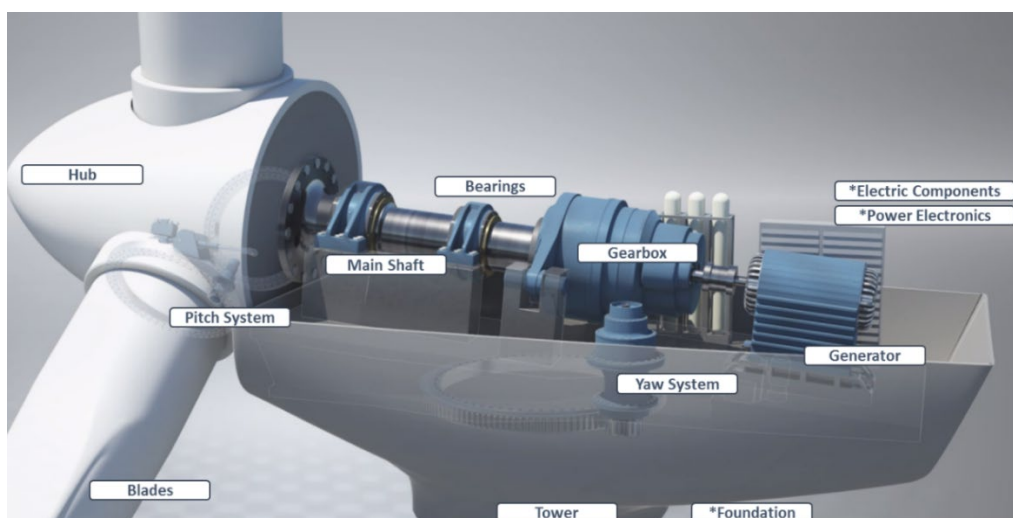


**Figure 5.** Main components of a wind turbine.
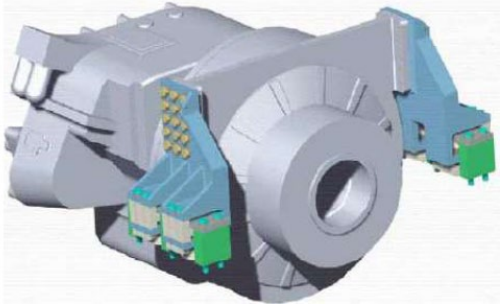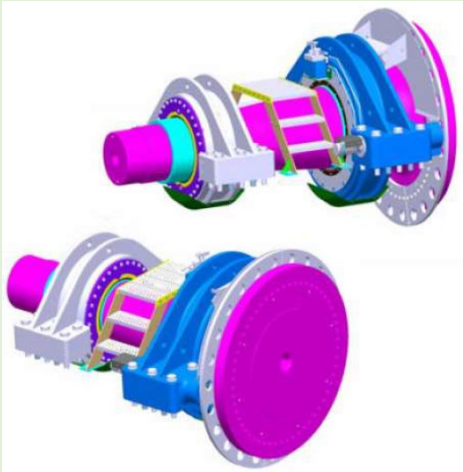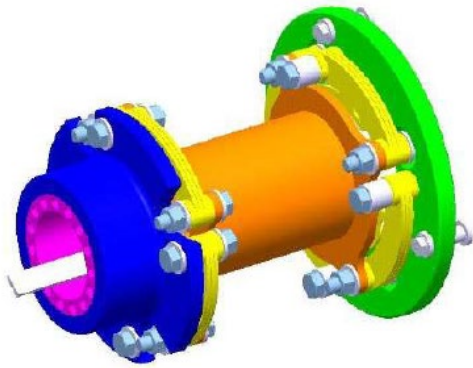
Wind turbines, as any other type of machinery, are formed by different individual components, see Figure 5. These components deteriorate in time, thus needing maintenance. Preventive Maintenance aims at restoring the characteristics of a component to a state similar to that at its beginning, so that its operational functionality does not get diminished. To this end, a Preventive Maintenance Plan is established, based on the indications of the WT manufacturer.
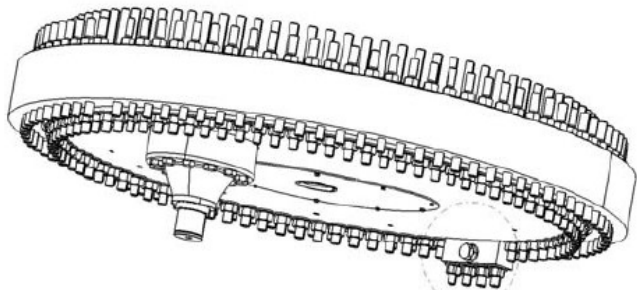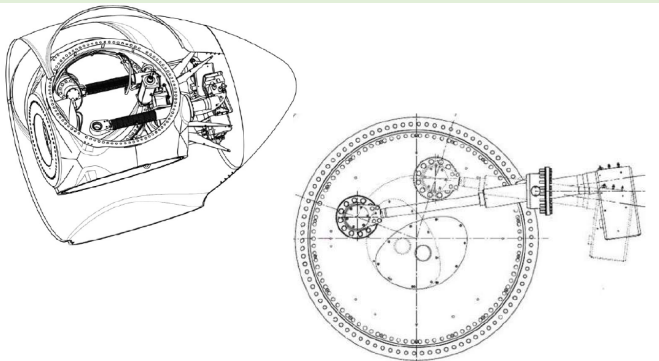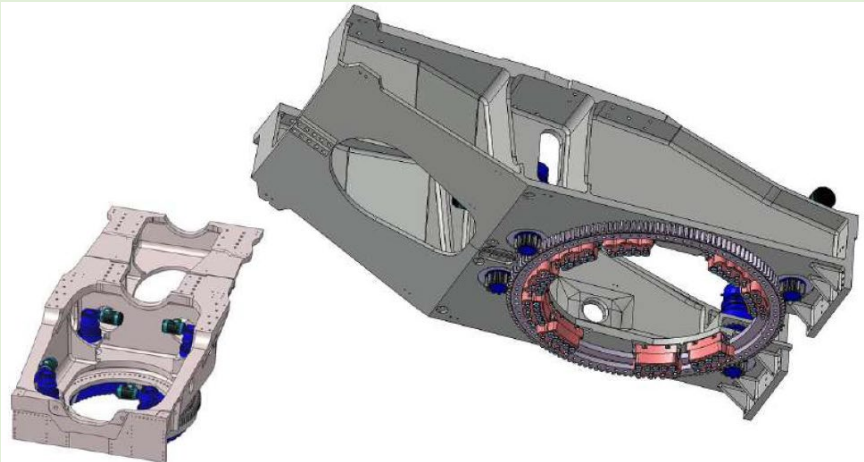
The diagram in Figure 6 illustrates the most common routine inspections and maintenance operations according to the type of task, rather than the specific target component, and are briefly explained. As follows in this section, the most important tasks, these being the lubrication and tightening of bolted joints tasks, are further developed, including examples on specific components.
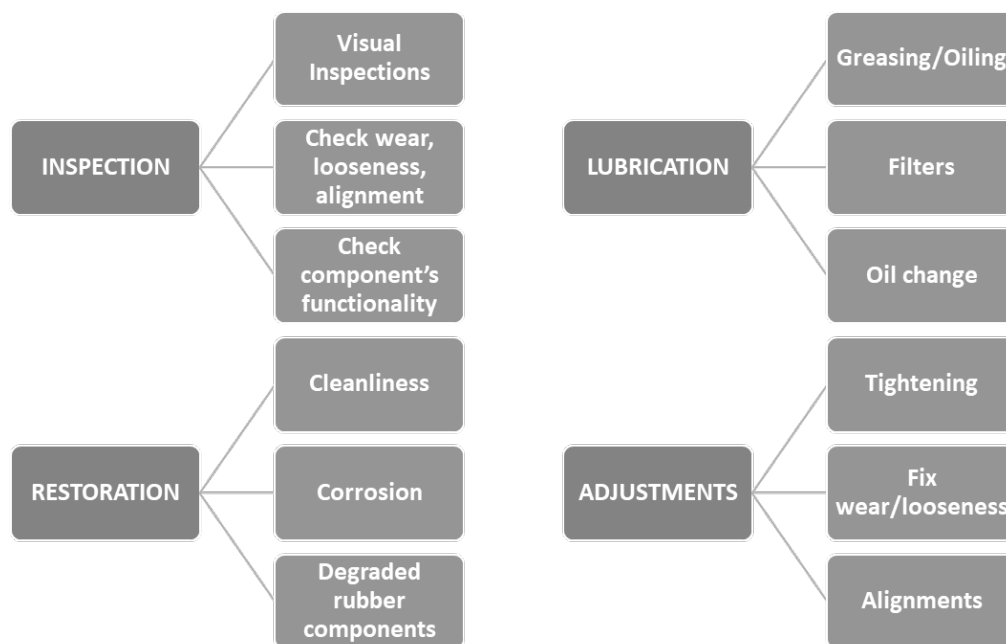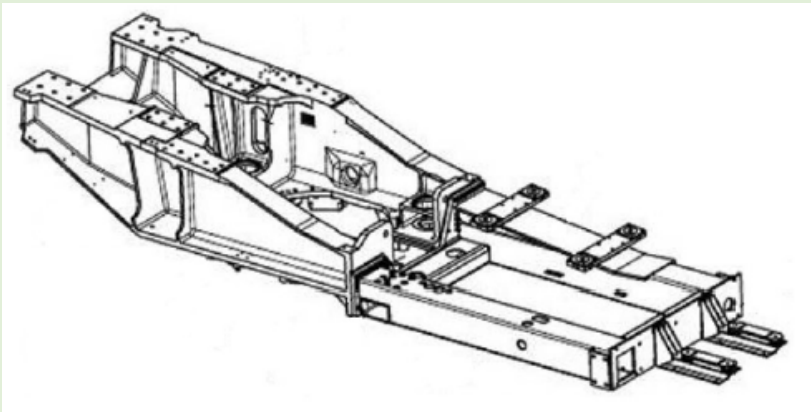
**Figure 6.** Common routine operations.

### 4.2.1   Case Studies

| CASE STUDY | Gearbox inspection |
|---|---|
| |  |
| CASE STUDY | Main shaft inspection |
| |  |
| CASE STUDY | High speed shaft inspection |
| |  |
| CASE STUDY | Generator inspection |
| |  |

| CASE STUDY | Blade bearing inspection |
|---|---|
| |  |
| CASE STUDY | Hydraulic Pitch System |
| |  |
| CASE STUDY | Electric Pitch System |
| |  |
| CASE STUDY | Yaw system inspection |
| |  |

| CASE STUDY | Hydraulic system inspection |
| --- | --- |
| |  |
| CASE STUDY | Bedplate inspection |
| |  |
| CASE STUDY | Tower inspection |
| |  |

| CASE STUDY | Foundation inspection |
|---|---|
| |  |

## 4.3   Corrective maintenance (C.3)

Corrective Maintenance involves corrective actions, performed after a critical failure has taken place, thus usually causing long downtime periods.

There are three main types of corrective actions depending on the severity of the fault:
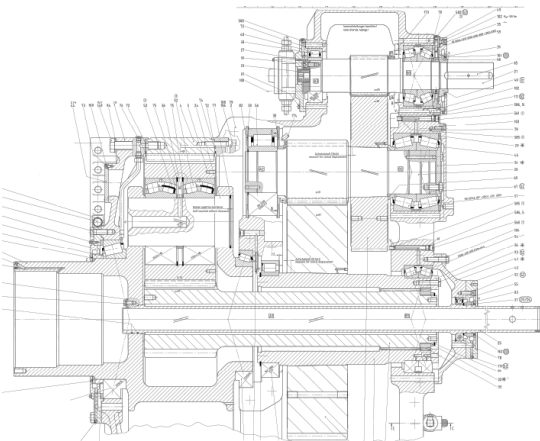
- Minor repair
- Major repair
- Replacement

Depending on the severity of the fault and the affected component, corrective maintenance can be carried out in different ways. For small and/or accessible components that have not suffered severe damage, it will take place on-field (e.g., minor repairs). When the affected components are critical components, such as the gearbox, generator, or main shaft, these will involve major repairs or component replacements.

Most corrective actions are in fact component replacements. For example, a fault in the gearbox caused by a bearing could be repaired by replacing the faulty bearing on-field. Thus, the actual corrective task is a bearing replacement, although the gearbox is being repaired on-field. Differently occurs with blades, where most if not all corrective tasks are indeed repair actions directly applied to the affected part of the blade.
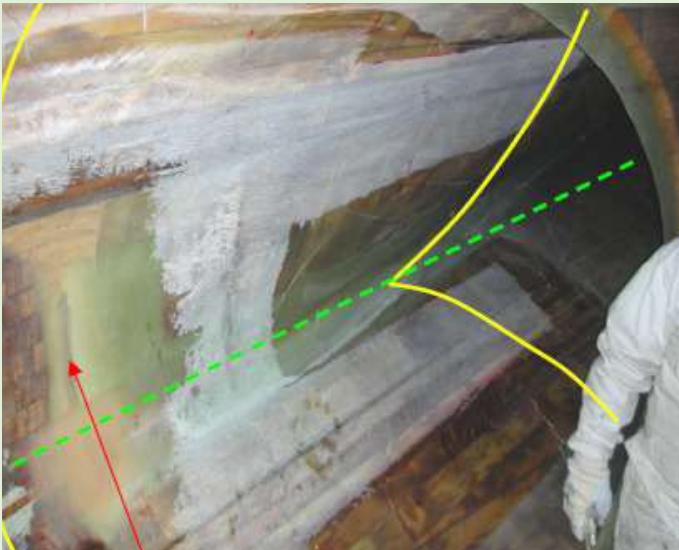
The difference between minor repair and major repair / replacements is the special equipment required to perform the corrective tasks, such as cranes, special loading lifts, specialised technicians, etc.
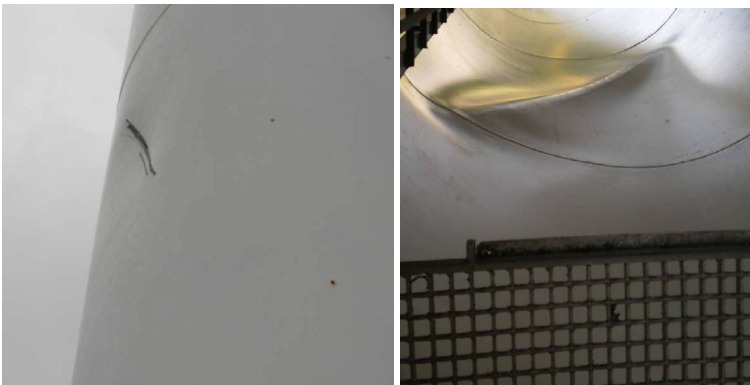
### 4.3.1 Case Studies

| CASE STUDY | Intermediate gearbox shaft replacement |
|---|---|
| |  |
| CASE STUDY | Gearbox replacement |
| |  |
| CASE STUDY | Main bearing and shaft Replacement |
| |  |

| CASE STUDY | High speed shaft replacement |
|---|---|
| |  |
| CASE STUDY | Generator replacement |
| |  |
| CASE STUDY | Minor Blade Repair |
| |  |

| CASE STUDY | Minor Blade Repair |
| --- | --- |
| |  |
| CASE STUDY | Major Blade Repair |
| |  |
| CASE STUDY | Major Blade Repair |
| |  |

| CASE STUDY | Major Blade Repair |
| --- | --- |
| |  |
| **CASE STUDY** | Major Rotor and Blades Replacement |
| |  |
| **CASE STUDY** | Major Tower Replacement |
| |  |

| CASE STUDY | Major Foundation Repair |
|---|---|
| |  |
| CASE STUDY | Major Foundation Repair |
| |  |

## 4.4    Predictive maintenance (C.4)

To reduce the cost of energy from WTs, there is a pressing need to improve the WT availability and reduce the O&M costs. Condition Monitoring Systems (CMS) have the ability of continuously monitor the performance of the wind turbine parts. Many faults can be detected while the defective component is still operational. Such early detection facilitates a proactive response, allowing the necessary repair actions to be planned in time, thus reducing and minimizing the wind turbine downtime and maintenance costs. Autonomous online condition monitoring systems with integrated fault detection algorithms allow early warnings of mechanical and electrical faults to prevent major component failures.

There are many techniques and tools available to monitor the condition of wind turbine components. These include sensors coupled with algorithms and architectures, allowing for efficient monitoring of the machine's condition. The different available techniques applied on the different WT components are introduced in the present section, followed by existing signal processing techniques. In order to provide diagnostic and prognostic of the WT's health, fault detection algorithms need to be applied after signal processing and feature extraction.

The wind industry currently uses CMS such as vibration, temperature, lubrication oil, and generator current analysis, developed from other rotating machine power generation industries where they have achieved success. However, despite their application in the wind industry, they have not yet proven their complete effectiveness due to the peculiarities of a WT, which has a slow speed and rapidly varying torque. Commercial WT CMSs mostly employ vibration-based techniques, which are sophisticated, and the sensors and cabling are costly. The technique is also not ideally suited to all WT types and faults. Lubrication oil analysis is popular for detecting gearbox tooth and bearing wear but cannot detect failures outside the gearbox. More advanced techniques, such as optical strain measurement, have been developed for monitoring WT blade integrity, also costly.

CM is defined as the collection and interpretation of the relevant parameters of a certain component for the purpose of the identification of any changes from normal conditions and trends of the health of the component under study. CM operates on the basis that "a significant change is indicative of a developing failure". Information on an incipient component failure can thus be obtained from the monitoring of these prognostic parameters.

CM can be divided in three main stages: data acquisition, signal processing and feature extraction. Data acquisition involves measuring the required variables (e.g., current, voltage, temperature, speed) and turning them into electronic signals. Judicious choice and placement of the right type and number of sensors is necessary to perform data acquisition effectively. Performing basic operations including amplification, filtering, linearization and modulation/demodulation (i.e., signal conditioning) may be necessary to reduce the susceptibility of the signals to interference. Signal processing comprises the use of algorithms and tools to analyse data for better understanding and interpretation of data. The procedure of extracting useful information from the processed signals is the so-called feature extraction.

There are numerous signal processing techniques and algorithms in the literature for diagnostics and prognostics of mechanical systems. Case-dependent knowledge and investigation are required to select appropriate signal processing tools among a number of possibilities.

For wind turbine monitoring, different authors make different classifications of CM Techniques depending on the component (or group of components) under study. Most agree on the differentiation between Structural Health Monitoring (SHM), Condition Monitoring (CM) of rotating parts, and Electric and Electronic components. The first targets structural components of the WT such as tower, blades and hub, and the objective is to monitor the structural integrity of those components. The second targets rotating equipment (bearings, gearboxes, etc.). Although the techniques employed (in terms of data acquisition, i.e. vibration) can be the same, the monitoring strategy is usually completely different. Monitoring electric and electronic components, however, is rather challenging due to the rapid development of faults that naturally happen in these components.

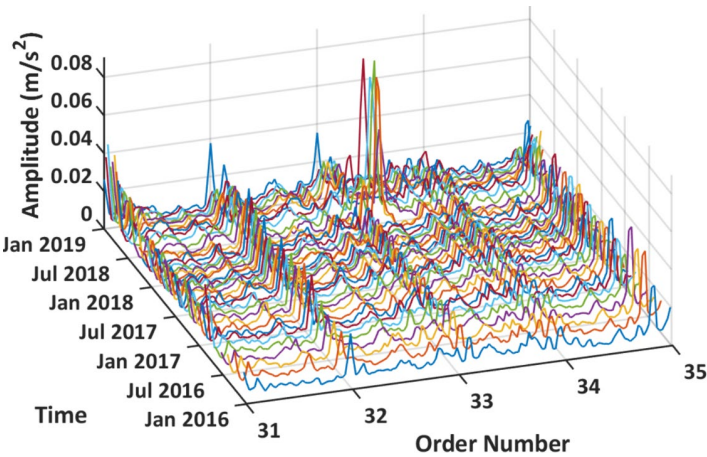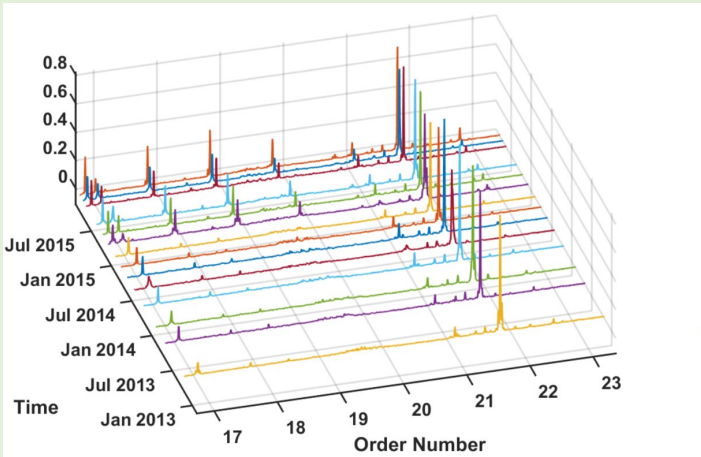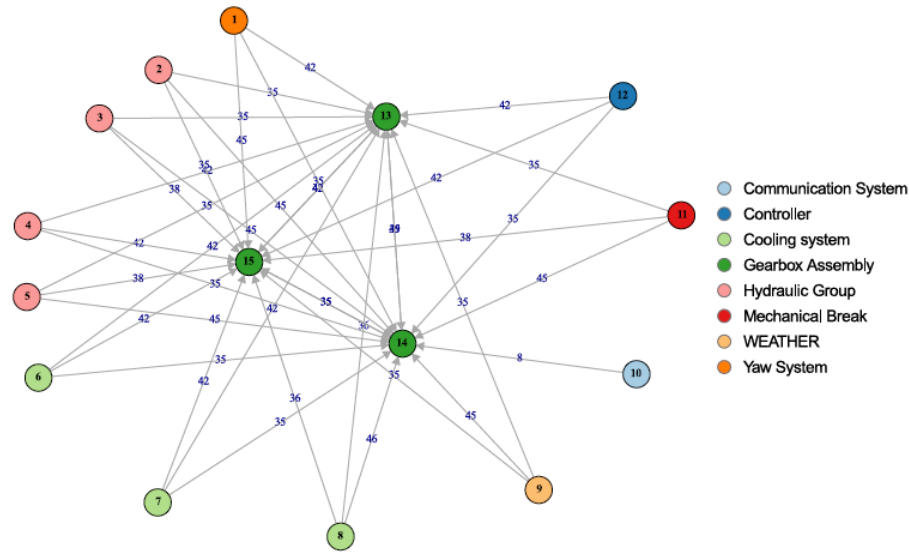| CM Type | Subassembly |
|---|---|
| SHM | Tower |
| | Blades/Hub |
| CM | Bearing(s) |
| | Gearbox |
| | Yaw system |
| | Pitch system |
| | Generator |
| Electric / Electronic | Electric/Electronic Components |
| | Power Converter |

**Table 1:** Classification of wind turbine monitoring.

Another differentiation between CM Techniques falls between subsystem (or single component) monitoring and global system monitoring. The first type monitors the condition of a single component through data acquisition (typically signals, i.e. waveforms) while the second uses parametric information from several subsystems that are combined form a global system (e.g. SCADA data).

Many different CM Techniques can be applied to different wind turbine components, summarised in Table 2.

| Component | CM Technique |
|---|---|
| Gearbox and Bearings | Vibration |
| | Oil Analysis |
| | Thermography |
| | Shock Pulse |
| | Current and Power Signals |
| | Torque |
| | Acoustic Emissions |
| Tower, Blades, Pitch Control | Vibration |
| | Ultrasounds |
| | Radiography |
| | Strain |
| | Torque |
| | Physical Conditions |
| | Acoustic Emissions |
| Generator | Current Signature Analysis |
| | Power Signal |
| | Shaft Torque-Speed |
| Electric Control and Power Electronics | Thermography Own Parameters |

**Table 2:** Techniques for wind turbine monitoring.

### 4.4.1 Case studies

| CASE STUDY | Vibration Analysis |
|---|---|
| |  |
| CASE STUDY | Vibration Analysis |
| |  |
| CASE STUDY | Time-sequence analysis of SCADA data |
| |  |

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| CASE STUDY | Current Signature Analysis |
|---|---|
| |  |
| CASE STUDY | Current Signature Analysis |
| |  |
| CASE STUDY | Current Signature Analysis |
| |  |