Purchase and installation of

Used wind energy converters

A manual for potential investors

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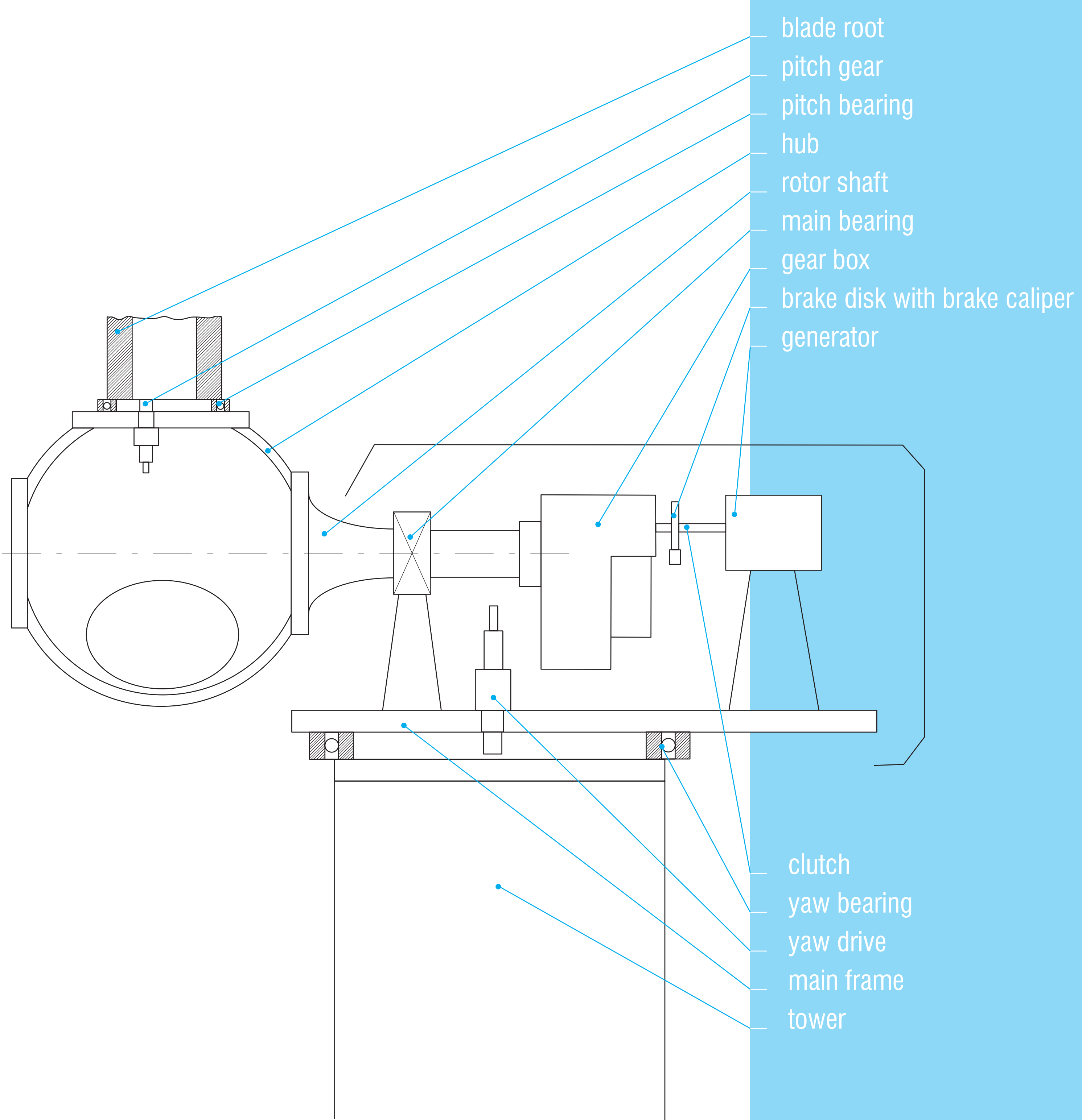

Typical WEC: general overview

IMPRINT

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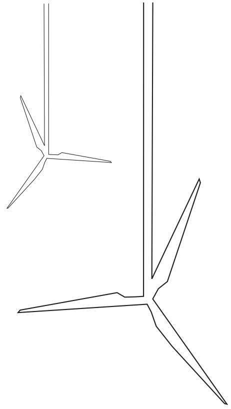


Foreword

The study on hand is one output of the InterregIIIb-project „Wind energy in the BSR", which has united 29 partners in wind-energy-related co-operations from 2003 on. As much as the project itself, the study intents to contribute to a further stimulation of the European wind energy market.

Despite of: it should be read as a document written by German authors as a lot of the practical hints and information have been gained by Norbert Schulz and Peter Dierken during many years of work within the German wind energy branch.
The heterogeneity of the wind energy market has to be considered as well: many types of wind energy converters (WEC) produced by various manufacturers exist - a study as this one will be only able to take the most common ones, those that were installed most often, into account.

Aiming to help investors and project managers of potential „second-hand" wind farms or turbine sites to plan and to carry out the project, the study on hand can be a compendium but cannot claim to be exhaustive as this is nearly impossible. Though, the longtime branch experience of the authors, mentioned before, ensures that it is a valuable guide that, hopefully, will be able to accompany many new „used turbine projects" on their way to a successful commissioning and operation.

Rostock, August 2005 Dr Kristina Koebe, Project manager

Content

About this study

For the „classic wind energy countries", which already look back to a long tradition of wind energy converter installation, the issue of „second-hand wind energy converters" or „used wind energy converters" has become more and more important over the past years. Due to the lack of new sites available in countries like Germany and Denmark, smaller wind energy converters (WEC) are more and more replaced by converters with a considerably higher rated output. However, the dismantled plants have very often a residual life expectancy of more than ten years, thus offering a good opportunity for „second-hand purchasers", who can buy the plants to a reasonable price and, thanks to the low investment costs, are able to ensure a profitable further operation on new sites.

Actually, this trend can only be welcomed as it goes along with a certain „democratisation" of the wind market. Now even potential WEC-operators with less investment capital will be able to realise wind farm projects - an opportunity for individual operators and also for countries, where the establishment of wind energy is only slowly developing due to a lack of capital base. These facts give reason to expect that the coming years will face a further upward trend on the „second-hand market" for wind energy converters.

For the project planning of a wind farm or an individual WEC with used wind energy converters, it is vital to know the performance and, first of all, the technical condition of a plant, because finally the technical condition is the criterion for the financial success of the project. A plant that is permanently generating costs can be hardly profitable. Therefore, it is recommended to verify the technical condition already before the purchase, preferably before the dismantling on the original site has started. All aspects to be taken into consideration are summarized in the chapter „Expertises".

What can this study achieve?

The present study is designed to serve as guideline for individuals and institutions with the intention to purchase a „second-hand wind energy converter”.

It is the main objective to outline the extent of technical inspections for used wind energy converters and to reveal possible risks and consequences. This includes the technical condition of WEC components and also the documentation, performed maintenance work, possible repairs, the assembly & disassembly and the transport of the WEC. Further aspects are life expectancy estimations of individual components and the entire plant, a possible plant optimization and the investigation of regional conditions.

Naturally, the present study can not cover all problematic issues, as the individual plants can widely differ in terms of construction and technology. Therefore, we have focused on aspects with a certain universality. Differentiations are made were it seemed generally sensible: for instance, plants with a rigid rotor blade-hub-connection, so called „stall turbines“, require different considerations than pitch turbines, that are able to adjust their rotor blades according to the aerodynamic requirements.

Summarizing: The study gives support for an initial orientation, however can and must not replace an expert inspection of the plant, because on-site many details can be revealed that are not covered by a general description.

For whom is the study designed?

This study addresses persons, who intend to purchase or re-install a used wind energy plant on a new site. We will point out possible problems and describe solutions, that enable new owners to operate their new-old wind energy plant successfully and profitably.

The study serves in the preparation phase of a project with used wind energy plants, it displays to the parties involved the possible scope of issues and gives assistance to ask the right questions in the planning phase. However, the statements in the study make no pretence to completeness. An exhaustive guidebook can not be provided facing the variety of plants being on the market and various obstacles in the implementation of projects.

The requirements of insurers or certification institutes, technical prerequisites etc. must be generally re-inquired at the companies.

Expertises

What is an expertise?

An expertise is designed to survey and examine the entire wind energy converter by an independent expert. Depending on the kind of expertise the extent of investigations may widely differ. For instance, after commissioning it is sufficient to inspect the converter, a status-oriented inspection may require oil samples, comprehensive measurements at the drive train, endoscopying or ultra sonic expertises at the blades. The inspection results are summarized in a document. This document should meet a number of minimum requirements, partly specifications may exist that must be complied with in the implementation and text edition.

What is an expert?

The terms „expert” and „surveyor” are not protected, basically everybody can characterize himself as „competent”. However, there exists a number of criteria, from which you should specify a competent expert. The three most significant criteria are shortly listed below:

- A preferably comprehensive professional experience; the ideal case: long occupation in the wind energy branch,
- Membership in a corresponding association, for instance in the advisory board of the „Bundesverband Windenergie Deutschland” (German Windenergy Association),
- The certification „Officially appointed and sworn-in expert” - these persons passed an examination to furnish proof of their expertise and professional competence at the Chamber of Commerce. Only this „official appointment” gives authorisation to bear the certification.

An expert must be independent in his work. An employee of the manufacturer can not furnish an impartial expertise for the customer. That also applies vice-versa: All parties involved in the project to be surveyed must be in the position to accept the observations and conclusions of the expert, from which his totally neutral position is automatically arising. Any connections to one of the partners must be notified beforehand. In doing so, the other parties have the opportunity to make a decision, whether the connection can be accepted.

Under certain conditions, depending on the requirements of certification bodies, building authorities or building departments, experts must be either accredited or approved by these bodies. Most countries provide a list, where all accredited experts and surveyors are listed. In Germany, for instance, such a list can be obtained from the German Windenergy Association (BWE).

Summary: There exists a number of criteria, from which an expert should be selected, including professional experience and accreditation by a Chamber of Commerce or a professional association.
The selected expert must be independent. A list of independent and accredited experts can be obtained from the Chambers of Commerce or branch associations.

Damage evaluations

Modern wind energy converters are complex technical constructions, which consist of many mechanical and electric components. The production of these components includes some manufacturing tolerances and, under certain circumstances, even hidden manufacturing deficiencies. The installation of a turbine or improper storage may also cause damages. There are no one-hundred-percent damage-free wind energy converters.

The competence of a specialist is required to evaluate the damage potential, i.e. the possible consequential damages, which may arise from a deficiency. Naturally the corrosion damage at a sensor fitting remains without any consequences whereas a rusting welding seam at the main frame or tower may lead to the destruction of the complete installation.

The turbines are designed to meet the technical requirements for 20 years. This is a task to be fulfilled. In this respect it is vital to realize the consequences of a damage on time and, where required, introduce measures to ensure that the planned life expectancy will be achieved.

Different occasions - different kinds of expertises. An overview.

Expertise after commissioning

At the time of the WEC commissioning the operator arranges for an expertise which is designed to analyse the condition of the newly installed WEC in total. At the same time, possible rework and residual work are specified, release for payment is issued etc.

Expertise prior to expiry of guarantee period

Prior to the expiry of the guarantee period of a WEC, many operators arrange for a profound inspection of the overall condition. The purpose is to specify which work has to be completed by the manufacturer before he can be released from his liability for the turbine.

Investigation of damages (Survey report)

Any damages of a wind energy converter require that an expert is called in to investigate the extent of the damage and its repairability.

Recurring investigation

The periodically recurring investigations are required by the certification body and the competent building department (in Germany every 2 to 4 years). These investigations are designed to verify the safety installations and the structural integrity.

Status-oriented investigation

These periodically recurring investigation (every 1, 2, or 4 years) are required by the insurer of the wind energy converter. It is designed to identify so-called initial damages and avoid consequential damages.

Summary:

There are no one-hundred-percent damage-free wind energy converters.
It is the objective to keep the number of deficiencies low, identify and eliminate existing damages on time. Timely introduced measures ensure a maximum life expectancy of the turbine.
The actual damage potential of a deficiency can only be evaluated by specialists.
There are different kinds of expertises, their implementation and extent arise from the occasion of the expertise. Before the purchase of a used wind energy converter it is recommended to carry out a Status-oriented Survey of the WEC.

What kind of documentation is required for a WEC expertise?

The evaluation of a WEC also includes the review of the available documentation, which is designed to give a complete overview of the structure, the operation and history of the turbine. As a minimum, the following documents must be available:

- Building permission
- Operating instructions
- Circuit diagrams and hydraulic diagrams
- Commissioning record
- Results of former oil analyses
- Maintenance specification including all maintenance and service reports
- Logbook with all the service team calls

In addition, it may be required to view the documentation related to type testing or the inspection and experience reports of converter components or replaced parts. If, for instance, the rotorblades of the turbine have already been replaced, the newly installed rotorblades must be included in the type testing. If this is not the case, it is mandatory to perform a subsequent certification of this component related to the specified wind energy converter. This procedure must be documented in a corresponding certification report.

However, not compulsory but very helpful may be documentation from previous expertises. They may give information about the operation breakdown of the service department responsible for the WEC and the work quality of the on-site service team.
This documentation and the service reports of the employees provide the following information to the expert:

- How much time did it take to eliminate the damages?
- Was the service rendered by the manufacturer or by external companies?
- Were all damages eliminated?
- After own inspection of the repairs: With which capability was the work done?

A long period of time between reporting the damage and its elimination may be an indication that the service team was not capable. Certain damages, for instance a low oil level inside the gearboxes or insufficient lubrication of the toothing of blade bearings and yaw bearings, can, if tolerated over a long period, lead to so-called initial damages. A promptly operating service of the manufacturer is normally regarded as a guarantor for a WEC with a low damage potential

Summary: The documentation related to the WEC must be viewed under any circumstances to evaluate the condition of the turbine. The following minimum information must be available: building permission, operation instructions, circuit diagrams, hydraulic diagrams, commissioning record, results of former oil analyses and maintenance certification with all maintenance & service records and the logbook with all service team calls.
In addition, ask for the documentation related to type testing and test & certification reports, where applicable, also previous expertises of the WEC.

What are the prerequisites for the expertise of a WEC?

The turbine must be accessible: The access must be neither blocked nor swampy. Larger animals on the site - in particular bulls - must be removed before the expert starts his work.

Any person, who intends to climb a wind energy converter, must obtain a complete set of protective equipment. Generally, it consists of the following parts:

- Harness (please note the instruction for fastening the harness!)
- Climbing protection (normally a guide rail runner or rope runner)
- Safety rope with pipe hook
- Safety helmet
- Sturdy footwear

Very often the experts dispose of their own equipment - in case of doubt inquire the information beforehand.

Before climbing the WEC - notes on safety

Emergency switch

In compliance with the valid safety regulations, every WEC is equipped with one or more emergency switches, which are marked with the corresponding symbols. They are designed to immediately switch-off the WEC in emergency cases by interrupting the power supply.

Please find out where is/are the emergency switch/es before you climb the turbine!

Fire protection equipment

Depending on the national fire protection regulations the WEC is equipped with fire distinguishers. In most cases in the tower foundation as well as inside and below the nacelle. The escape routes inside the WEC must not be obstructed.

Please find out where the fire distinguishers are located and how to handle them before you climb the WEC!

Please note! The protection of persons is the highest priority! If there may be the danger, that the fire cannot be extinguished with the existing equipment (fire distinguisher) the following rules of conduct will apply:

- Leave the turbine as soon as possible!
- Call the fire department!
- Help injured or needy persons!
- Do not stay under the WEC!
- Leave opposite to the wind direction!
- In case of burning cables: Do not inhale the smoke (contains hydroclorid acid)!

Weather conditions

Climbing the WEC should only be considered at good weather conditions. Never climb a turbine, if a thunderstorm is approaching. Always leave the turbine immediately, if a thunderstorm is approaching - there is particular danger to life when you stay in the nacelle!

The same applies to storm, high wind speeds and other adverse weather conditions. Under all these conditions do not climb the WEC or leave the turbine without delay. Do not stay under the WEC at high wind speeds.

Before climbing the WEC, always find out the position and handling of emergency switches and fire distinguishers. Only climb the WEC at good weather conditions: thunderstorm and high wind speeds can be dangerous to life!

Please note! Every WEC has further, turbine-specific safety regulations. Make the necessary inquiries BEFORE CLIMBING THE TURBINE - normally the operating manual or service manual contains such information. Please pay particular attention to the safety instructions for climbing the nacelle or hub. Any work at the turbine's electric and electronic installation must only be performed by qualified service personnel!

During the expertise

In either case, a qualified service engineer should accompany the expertise, preferably a technician of the team, who was in charge of the surveyed turbine. His tasks are, depending on the scope of the required expertise:

- Answering the questions or giving explanations to the questions of the expert
- The operation of turbine control and locks
- The disassembly of the covers, cover of the fast shaft between gearbox and generator or opening the inspection hatch of the gearbox
- Inspecting the tightening torques of the screw joints

Please note! Mechanical work at the turbine is not part of the expert's tasks. Generally he is not qualified for this kind of work and also not insured in this respect. For instance, a small washer dropped accidentally by him into the gear may cause considerable financial damage …

The expertise of rotorblades - different options

Roping from the blade

The expertise of rotorblades can be performed in different ways. Some specialists are roping from the blade downwards along the blade and work in direct contact with the surface. Although this seems to be a relatively simple way, not everybody would prefer that.

Pulling down the blades in the „man basket"

Pulling down the blade by means of a basket hanging from a crane rope, the so-called „man basket" is relatively inexpensive for smaller turbines. However, the disadvantage is the wind vulnerability of the basket and the permanent risk of colliding with the blade. Contact with the crane operator is kept via walkie talkie.

Working platforms

Self-climbing working platforms are fastened with steel ropes upward in the nacelle and are often supporting at the tower. Assemble and disassemble of the equipment requires slightly more time than other methods. The operating panel is situated directly at the working platform.

Use of lift platforms

The best way to carry out on-site inspections are lift platforms The operating panel is also part of the working platform, which can be independently moved to all interesting spots. The hourly rates are slightly higher than for other methods.

Please note! It is of great significance that for all expertises of rotorblades the wind speed is not higher than 10m/sec otherwise the blades may be damaged. Even short gusts of wind lead to a deflecting of the blade tip up to one meter. And a lift platform, for instance, can be easily pushed aside by the wind one meter at a height of 70 meters!

Further expert work - an overview

Work with crane and lift platform

All activities performed with a crane or lift platform require sufficiently solid ground around the wind energy converter.

Measurement of grounding resistance and coating thickness

The grounding resistance and the coating thickness of the coatings are measured with special equipment.

Vibration measurements of the drive train

Measurements for a vibration diagnosis of the drive train are carried out with acoustic sensors which are connected to a data logger. The applied sensors are fastened by means of magnetic bases at the spot used and marked for the first measurement. In doing so, the comparability can be ensured in terms of recorded values in comparison to previously measured data.

Checking the tightening torques

Calibrated torque spanners have to be used for checking the tightening torques. The value to be checked should not range in the full-scale points of the tools.

Oil analysis

Oil analysis is carried out by external laboratories. The laboratories sell together with the analysis complete sampling sets with special sample containers.

Gear inspection by means of an endoscope

The gear toothing and gear bearings that are not visible through the inspection holes are checked by means of flexible endoscopes. Apart from the conventional endoscopes with optics, lamp and adaptor for a miniature camera, currently digital systems are more frequently used, the images of which can be easily integrated into the reports.

What do the different expertises cover?

Expertise after commissioning

The purchaser of a wind energy converter arranges for the inspection of the following:

- Assembly faults
- Completeness of the wind energy converter
- Compliance with type testing (used components, components features, WEC operation, labelling...)
- Compliance with building permission requirements
- Operatibility of all components
- Compliance with safety regulations guidelines

Generally, the expertise is carried out either directly after commissioning or after appr. 500 operating hours. The earlier point of time has the advantage that major assembly faults can be identified and eliminated by the service team thus avoiding damage to the installation.

An expertise after some days of operation can also reveal nonconformities of the turbine that arise from the motion of the components (galling of cables, bearing damages, leakages in the hydraulic system etc.).

The expertise after commissioning is only designed as visual inspection of the transformer station, the foundation, the safety installations, tower, nacelle and hub. An inspection of the rotorblades from a lift platform is not compulsory, the visual inspection of the blade roots and the evaluation of blade noise during turbine operation are sufficient. The expert should have the opportunity to receive an acoustic impression of the operating turbine inside the nacelle. Furthermore, the sensor operation must be checked.

The expertise should contain the denominations, manufacturers and serial numbers of the major components read out by the expert at the corresponding parts.

Expertise prior to expiry of guarantee period

In order to ensure the guarantee claims towards the manufacturer, the owner of the WEC arranges for an expertise that results in a residual work to be done. In some cases, it may lead to an extension of the guarantee period for replaced components.

The extent of inspections is similar to the first expertise after commissioning. However, it should be extended by the following items:

- Inspection of all documentations of maintenance and service work
- Inspection of the rotorblades (see chapter of the same title)
- Temperatures listed in the control system, if possible
- Visual inspection of the gearbox toothing
- Analysis of the gearbox oil

Investigation of damages (Survey report)

An investigation of damages is limited exclusively to the occurred damage and its direct environment. No statements are made for the remaining wind energy converter.
An investigation of damages can not replace the other expertises described in the study.

Recurring inspection

The type testing or building permission can contain requirements for periodically recurring inspections. Normally, the time intervals are 2 years, a corresponding maintenance contract can include 4-year intervals during the first 14 years of operation.

If the specified deadlines are not observed, the building permission can be cancelled and the type certificate for the wind energy converter will no longer be valid. This results also to a loss of the insurance coverage for the turbine and provides a risk to all other contracts based on the building permission.

The objective of the Recurring Inspection is the check of safety installations and the structural integrity of the construction. The tasks comply with the expertise prior to the expiry of the guarantee period, however, must be extended by the following inspections:

- Random sampling of tightening torques of screw joints at the major components (blade, blade bearing, hub, shaft, gear, generator, main frame, azimuth system, tower, foundation)
- Measuring the continuity of the lightning protection and the ground electrode

Status-oriented survey

It is common knowledge, that insurers have a vital interest in contracting wind energy converters with a low damage potential. After the bitter years at the beginning of this century the emergency brake was pulled and a surveillance systems was included in the insurance contracts that is aimed at an early damage detection.

The reason: If a component failure can be detected at an early stage, immediately introduced repair measures can considerably limit the extent of the failure, including time & financial expenses. In the ideal case the teams fulfil their tasks in just one day, if it is a warm long summer day with low wind speeds and well-negotiated crane fares. In contrast to that, a sudden breakdown at high wind speeds in autumn may take weeks to eliminate the failure and can cause high expenses, including the loss of earnings due to the standstill.

The recurring inspections are regularly arranged, the time intervals are graded according to the performance:

| Wind energy converters less than 300 kW: every 4 years
| Wind energy converters with 300 kW up to less than 1500 kW: every 2 years
| Wind energy converters with 1500 kW and more: annual

The extent of inspections complies with the expertise prior to the expiry of the guarantee period, however, contains a number of additional items:

| Vibration diagnosis of the drive train
| Endoscopying of all equal gearings
| Temperature check in the cooling system
| Check of the maintenance contract
| Check of the Annual Report related to the technical operation of the turbine

Please note! The results of the performed Recurring Inspections must be taken into account for the evaluation of a used wind energy converter.

Vibration diagnosis of the drive train

Some wind energy converters are already equipped with stationary measuring systems for the vibration analysis of the drive train, the results of which can be used for evaluation. If such a measuring system is missing, the vibrations must be measured at the casings of the drive train components, i.e. main bearing, gear and generator, in the course of the expertise. For gearless turbines, the measuring tasks are limited to the recording of vibrations at the rotor bearings.

Background for the measurements and the analysis based on them is that the rolling motion of the rolling body in the bearings and the relative movements of the theeth in the gear generate vibrations, which can be measured with acceleration sensors as structure-born noise at the casings.

If all diameters, the number of teeth of a gearwheel and the number of rolling bodies in the respective bearings are known, the measured vibrations can be allocated to the individual bearings and equal gearings. If the „regular" intensity of vibrations from a bearing or an equal gearing is also known, than even a statement can be made, whether the component shows a an appearing damage. The measurements are carried out during the operation of the turbine, the wind speed should be sufficient to achieve the fractional load range.

For the vibration diagnosis the complete cinematic data from the main bearing, the gear and the generator are required:

- Gear drawing
- Number of teeth of the toothing
- Data of all bearings
- Speed range of the wind energy converter
- Interference frequencies of all secondary installations, e.g. azimuth drives, hydraulic units etc.

The interference frequencies are required to evaluate individual, unexpected signals and frequencies. An azimuth drive, which suddenly starts operating during the measurements, sends an initial strong impulse when the engine brake has been opened. In addition, the whole frequency range consisting of drive engine and gear levels must be taken into consideration. Afterwards, the yaw drive, again generating a strong impulse, puts on abruptly the engine brake located behind the drive engine. These effects must be known to provide a correct evaluation of results, as they are reflected in the measurement.

Some manufacturers still claim that the number of teeth of the equal gearing and the type denominations of the bearings are confidential insider knowledge. However, these components are only purchased parts, which can be easily obtained by any customer. Even the number of teeth can be easily identified by simply counting the teeth. Before purchasing a used turbine, always clarify whether the manufacturer is ready to cooperate.

The written expertise - how should it look like?

The written expertise, that the surveyor hands out to you after compiling the expertise should contain at least the following items:

| Type and serial number of the wind energy converter
| Location and wind farm ID
| Date of on-site inspection
| Names of the persons attending the expertise
| Weather conditions under which the expertise took place
| Previous operating hours and total yield of the wind turbine
| Description of the inspection task and its scope
| Result of the inspection, where applicable, with picture documentation

The written expertise must be handed out to the customer as hard copy bearing the signature of the expert. If more than one expert have been involved in the inspection, all individual reports are integrated into the documentation and signed by the expert being in charge for the entire expertise.

What can an expertise achieve?

An expertise specifies already existing faults, from which arise corresponding repairs or guarantee claims. If the manufacturer is not inclined to accept these claims, even if it is a guarantee claim, he will arrange for a counter expertise.

The documented errors can relate to the engineering, electrical engineering, control engineering, corrosion protection and building technology. A detected fault may have the „usual" causes, for instance assembly or operating faults, but can also arise from design shortcomings. In this case the owner of the wind farm will be enabled through the expertise to require a permanent solution of the problems from the manufacturer or other specialized companies. In addition, expertises throw light upon the quality of the wind energy farm - an aspect, which is primarily interesting for insurance agencies. But also manufacturers attach increasing importance to expertises. They regard expertises not only as an annoying element causing work but rather as a source from which many information is given about the product manufactured by them.

What can not be achieved by an expertise?

An expertise can never determine all faults. The expert can only identify obvious errors - a complete detection of all faults would require the entire disassembly of the WEC. However, that goes beyond the economic acceptable limit. The same applies to some other inspections, for instance X-ray of all welding seams.

In some place, an insight can be given of otherwise invisible parts, for instance by removing the shaft casing or other covered components. Nevertheless, there will be always areas, that can not be inspected without comprehensive work or expensive technical equipment. Furthermore, in some cases, pollutions may obstruct the visual inspection of components. Surfaces covered with grease or areas filled with leak oil can not generally be cleaned on mere suspicion.

The list of the faults included in the documentation applies exclusively for the time of onsite inspection. Some weeks later, further nonconformities may become visible at the farm. A good condition described in an expertise is as up-to-date as the expertise itself.

Information received by the WEC control, like for instance error indexes, maximum temperatures, performance curves and pitch angle tables must be regarded with special care.

Please note! Very often nothing is said from which date the values are applicable or how long the last „Reset" of the index dates back. Other values are inapplicable due to technical problems. That applies for instance to a listed gear oil temperature of more than 200°C resulting from malfunctions of the control in the event of grid breakdown.

The majority of lists filed in the controls can be manually modified, if the password is known. Therefore, even a „dressing up" of values can not be excluded.

What else can be measured?

There are some measurements, that are not required by an expertise. However, they give additional significant conclusions about the condition of the WEC:

Temperature of individual components

Maximum temperatures exist for the majority of components, like gear, generators, drive engines, engine breaks, switchboards, accumulator sets, hydraulic systems and, in particular, for all bearings. These temperatures must not be exceeded. If they are exceeded, this may be an indication for erroneous components acting as a heat source or components, which fail at too high temperatures, like shaft seals, which may cause gear damages due to occurring leakages.

By most of the system controls the maximum values are measured and filed in indexes. For older wind energy converters, some series of measurement may be quite useful.

Insulation of generator windings

If the insulation value of the generator windings is too low over many years, there may be the risk of a sudden short circuit because of the resins ageing process - with possibly high consequential costs. Therefore, it is recommended to check the insulation condition at regular intervals.

Rotor imbalance

By measuring the accelerations in the nacelle, aerodynamic imbalances and mass imbalances at the rotor can be determined. If these problems occur, the loads resulting from the vibrations of the turbine head, and affecting the entire turbine including foundation, may be higher than assumed in the component calculations. That may cause premature fatigue of materials, which also impairs the life expectancy of the wind energy converter, so-called fatigue failures may occur.
If they are recognized in time, imbalances can be generally eliminated with compensating material or by removing loose residual resin from the blades.

Blade angle

If the blade angles of the blades do not coincide, so-called aerodynamic imbalances may occur (see also: rotor imbalance). In most cases, aerodynamic imbalances can be eliminated by correcting the blade angles.

Bending and torsion moments at tower, shafts and blades

By means of strain gauges, transmission units like slip rings or radio paths and data logs the actual load of the major components can be determined.
If meteorological data after the installation of the turbine is measured over a longer period, estimations can be made, whether the loads affecting the turbine over the years will be higher or lower than predicted. However, these measurements are only useful, if the loads calculated for the components of the wind energy converter, are available for the purpose of comparisons. As a result of such investigations, estimations can be made regarding the residual life expectancy of the turbine or load reducing corrections of the aerodynamics

of the rotor. In addition, problems can be identified by this method, which can be eliminated or reduced by a modified operation mode. That applies, for instance to drive engine vibrations, that affect the WEC loads.

Alignment of generator and gear

At most turbine types, the gear and generator carrier are fastened with rubber vibration dampers on the main frame. That allows both components to move independently from each other, so that the distance between both components is varying.

That permanent varying of the distance, called relative motion, may exceed 10 mm in some cases - a condition, which must be compensated during the transmission of the torque from the gear to the generator shaft.

The compensating is performed by cardan shafts of various types. However, even their mobility is limited: if the operating range is exceeded, damages may occur. To prevent damages, the horizontal and vertical misalignment and the angularity of gear shaft and generator shaft must be specified. This can be determined by dial gauges or laser measuring systems.

The expertise of used wind energy converters

Progression and explanatory power of a used WEC expertise depend on the condition of the WEC to be purchased: The optimum would be the inspection by a surveyor, when the turbine is assembled and ready for operation. Only at this point, operation faults can be detected. If the WEC subjected to expertise is assembled but not ready for operation or even dismantled, the expert can only give limited statements on the situation. But even for this case, certain recommendations can be given.

Detailed information about the individual components to be inspected can be referenced in the chapters about the individual components of the WEC. However, the reading of this passages does not replace the knowledge, you and a surveyor get from own inspections.

Evaluation of assembled, operative WECs

In the ideal case, the purchaser is offered an assembled, operating wind energy converter. The plant can be inspected, measured and dimensioned while in operation. In the course of disassembly further spots will be accessible, that can normally not be reached. In addition, a supervision of the dismantling can identify damages that have occurred due to in-

appropriate work and may have been not detected otherwise.
An inspection of the entire documentation is the minimum work, a purchaser should do.
A status-oriented inspection will provide the best foundation for the purchaser to evaluate the efforts to be expected until the plant is re-commissioned.

Evaluation of assembled, non-operative WECs

The previous specifications of the individual characteristics of an expert have shown that many evaluations can only be made while the wind energy converter is in operation. If the WEC is non-operative, the most important information of all will be to find out the reason for the standstill. Is the information about the standstill plausible? What are the explanations and proof given for the condition? In case of doubt, a competent person should make a survey report at that point.

Further crucial items:

- How long did the turbine stand still?
- Why was the damage not eliminated by the seller himself?
- Can the rotor move freely or is it locked? The locking of the rotor over a longer period can quickly lead to bearing damages, as the rolling bodies constantly remain in the same position, displace the lubricating film and thus causing corrosion at the runway. The same applies to blade bearings and the azimuth bearing, that need to be set in motion from time to time.
  Many turbines must only be locked up to specified wind speeds, higher wind speeds may cause damages to this component.
- Is the turbine still connected to the grid? If confirmed, error- and temperature indexes of the control may be inspected. If not confirmed, switchboards can become damp or even start to molder in adverse weather conditions. Switchboards must be always kept dry!

Evaluation of dismantled WECs

If the wind energy converter is already dismantled, statements on the condition of the turbine are even more difficult to make than for a defective idling turbine. On the other hand, components like for instance the blades, the tower and the nacelle casing are easy accessible and can be well inspected. Even here, it is crucial that the switchboards are stored in a dry location - the best would be to heat them via an external power source. The drive engine and the bearings of the blades and the nacelle adjustment must be set in motion from time to time. However, this is practically impossible.

Expert support of a re-installation project

To give optimal support for the purchase of a used wind energy converter, a so-called second-hand WEC, the following tasks should be fulfilled:

- Expertise of the installed turbine on the original site (basis for the purchase decision)
- Surveillance of the dismantling (recording disassembly damages)
- Expertise of dismantled components (inspection of spots which are usually not accessible)
- Surveillance of the installation (recording assembly damages)
- Surveillance of the commissioning (check of the system settings)
- Status-oriented inspection of the re-assembled turbine (contract basis for insurers)

The actual extent of the support depends mainly on the experience and competence of the project leader.

However, an expertise before purchasing a turbine can not be replaced by any other inspection. After re-commissioning a status-oriented inspection is compulsory, because otherwise no insurance agency will be ready to conclude a contract.

On what you should pay attention - initial selection criteria for a used WEC:

Select an insurance company before launching the project and clarify which requirements must be complied with.

In case of doubt, cooperate with a competent, independent consultant.

Inquire also smallest details and matter of courses.

Request an insight into the documentation and check it for completeness.

Check, whether individual components had to be frequently replaced.

Request the documentation regarding the yield of the turbine.

If the turbine is part of a wind farm, also request the documentation of the yields of the other wind energy converters.

Pay attention that promised features and possible damages were named accurately and form part of the concluded contract.

Contact other operators of the same turbine type and ask for their experience.

Make sure that the documentation associated to the wind energy converter is complete. Check all available documents for their completeness by way of the following list:

| Type testing or individual testing
| Certificate of conformity
| Building permission
| Maintenance requirements specification
| Maintenance contract

| Installation and assembly record
| Commissioning record
| Soil expertise
| Grounding record

| Logbook of the turbine (usually a blotter with handwritten entries)
| Reports of all service and maintenance work
| Reports of all oil analyses

| Operating manual of the turbine
| Electrical circuit diagrams
| Hydraulic diagrams
| Kinematic data of the drive train
| Operating instructions and test log of the crane installation
| Operating instructions and test log of the climbing protection
| Operating instructions and test log of the passenger lift (where applicable)
| All expertises and inspection records
| Repair reports

The individual components of the WEC

General remarks

A wind energy converter consists of many different components - mechanical and electrical, that are designed, selected and assembled for an optimal interaction. The result of this interaction is based on years of development by experienced engineers. Therefore, a non-conforming assembly, even of „unimportant" components, can lead to consequential damages of other, much more important components.
It is therefore recommended to exercise reasonable care not only at the time of the first assembly, but also at the time of the WEC re-assembly in order not to delay the commissioning and avoid future damages. The same applies naturally also for future maintenance and repair work.

The following chapters are focused on the individual components of a wind energy converter. It is intended to give a deeper insight into its design, thus enabling a competent and professional handling of each individual component.

At first, some general remarks should be made: Naturally, even with due care and professional handling, the life expectancy of all components is limited. That applies also to the large power transmitting components, i.e. rotor hub, bearing casing, rotor shaft, gear, main frame and tower. It is generally recognized that the life expectancy of a wind energy converter amounts to twenty years. A possible further operation after this period depends also on the more or less optimal „external conditions", for instance the turbine site, just to name one. In either case, the further operation of the wind energy converter after expiration of the „regular" life expectancy should be duly considered for every individual case and coordinated with the permission body.

In order to ensure an adequate operation of the wind energy converter, the individual components must be maintained at regular intervals. This includes for instance, that the

pre-load of the screw joints is regularly checked. The length of the intervals depends on the component and the age of the WEC - further details can be referenced in the maintenance and service manual of the WEC.
With the assembly and re-installation of a WEC all power-transmitting screw joints must be newly pre-loaded, afterwards checked and possibly pre-loaded at regular maintenance intervals.

Lubricants and supplies

All lubricants and supplies must be substituted before the WEC is re-commissioned.
Lubricants:

- Grease in the blade bearings, in the main bearings, in the yaw bearing and the generator bearings
- Gear oil in the main gear
- Gear oil in the pitch and yaw gearbox

Supplies:

- Hydraulic oil

The set-up of a wind energy converter

The figure on the interior of the cover page shows the general set-up of a wind energy converter. Naturally, the implementation of this structure by individual manufacturers may widely differ. However, there are some statements that generally apply. The figure shows the most important major components, which can be found at almost all wind energy converters:

- Rotorblades
- Hub
- Blade adjusting system (for pitch and ActiveStall turbines)
- Rotor shaft
- Main bearing
- Main frame
- Nacelle cover
- Gear with clamping set
- Coupling
- Generator
- Rotor break

- Azimuth system (yaw bearing, gear, breaks)
- Cooling system
- Switchboards
- Tower
- Foundation

If you intend to purchase a second-hand gearless wind energy converter, currently only turbines made by Enercon can be recommended. These turbines are provided with rotor and generator on one „shaft" and run with equal rotation speed. Enercon wind energy converters are not only gearless but also pitch-controlled and have variable rotational speed, i.e. the angle at which the wind is hitting the blade can be adjusted by a pivoted blade and a corresponding setting of the rotor speed according to the respective operating situation. The generator is designed as a ring generator with several pole pairs. The electrical energy of these turbines is fed to the grid by a frequency converter.

Control and operation of wind energy converters

The operation and control of a wind energy converter is performed by a computer equipped with corresponding software. The basis forms the recording of current operating and environmental conditions (wind direction, wind speed, outside temperature etc.). For this purpose, the WEC is equipped with an anemometer for measuring the wind speed on the roof of the nacelle.

On the basis of the measuring results, the measuring and control software activates the different operating conditions, e.g.:

- Starting the WEC as soon as the switch-in wind speed is achieved
- Switching-off the WEC as soon as the maximum operating wind speed is exceeded
- Pitch control in relation to the respective wind speed
- Initiating an emergency stop in case of damage
- Yawing at changes of the wind direction

There are different concepts for the control and operation of wind energy converters:

- Stall-controlled wind energy converters
- ActiveStall-controlled wind energy converters
- Pitch-controlled wind energy converters
- Wind energy converters with constant rotational speed
- Wind energy converters with variable rotational speed

Stall-controlled wind energy converters

At stall-controlled wind energy converters the rotor blades are rigdly connected with the hub. The aerodynamic profile of the blades is designed in a way that the performance is limited by blade stall. A performance optimisation can only be achieved to a certain extent: via long holes in the blade flanges of the hub the angle of incidence can be re-adjusted.

In order to achieve a performance optimisation, the rotor blade can be equipped with stall-strips or Vortex generators (see glossary).

To avoid damaging of the Vortex generators, the disassembly, transport and installation of the rotor or blades must be performed with reasonable care. Even light damages can impair its positive effect. See also explanations in the glossary. Damaged Vortex generators can be easily removed, as they were subsequently affixed to the rotor blade. If you require new Vortex generators, make sure to inquire the former operator of the blade manufacturer for the respective supplier.

For turbines of this type the performance of the WEC is limited, if the wind speeds at the turbine reach 13 to 15 m/s. If the 10-minute-average value ranges around or beyond 25 m/s, the wind energy converter is switched off via the blade-tip breaks to avoid overload. The rotation speed of stall-controlled turbines is equal and is specified by the mains frequency, the pole pair number of the generator (see also chapter „Generator") and the rotor blades. The gear transmission is adjusted on the basis of this specification.

All in all, most of the stall-controlled wind energy converters are provided with 2 rotation speeds: the speed is changed by a pole-switching in the generator. The second speed, the smaller of the two, is switched in to achieve an optimal performance at lower wind speeds and thus achieving the best possible energy yield.

Stall-controlled wind energy converters are provided with a rigid rotor-blade-hub connection. The performance limit starts at 13 to 15 m/s by aerodynamic effects. The rotation speed of the WEC is continuous - depending on the wind speed, however, there is the selection between two rotation speeds.

ActiveStall-controlled wind energy converters

For ActiveStall-controlled wind energy converters, the connection between rotor blade and hub is no longer rigid: the rotor blades can be rotated alongside their longitudinal axis.

This mobility of the blades allows a better balancing of larger variations of the wind speed than for stall-controlled turbines.
If the performances of the WEC must be limited due to high wind speeds, the fore edge of the rotor blade must be turned from the wind. This provides a wider angle of incidence at the rotor blade and the stall is appropriately controlled. ActiveStall turbines are also operating with continuous rotation speed.

If the upper performance limit, the so-called rated output of the WEC is achieved, the turbine control ensures that, even at rising wind speeds, the output is kept on a permanent level. This can also be achieved by changing the pitch. A output limit of this kind is necessarily required, as the WEC may be damaged by high loads.

ActiveStall turbines are provided with a movable connection between rotorblade and hub, which ensures an improved balancing of wind speed variations. The output limit is provided by a wider angle of incidence - the blades are respectively turned from the wind.

Pitch-controlled wind energy converters with variable rotation speed

Pitch-controlled WECs are able to change their pitch and thus the position of the rotorblade towards the wind in a way that, even at changing wind speeds, an optimal performance can be achieved.

If the turbines are provided with variable rotation speed, their generator or rotor speed can be adjusted in a way that the generator can be operated in its optimal characteristic curve at all times.

For pitch-controlled wind energy converters with variable rotation speed, 2 operating modes are distinguished:

1| the fractional load range
2| achieving the rated output

Part-load operational range

In the so-called fractional load range, the wind energy converters are operated with less than the maximum output (rated output). This is provided through controlling the output via the generator speed.

The pitch is adjusted in a way that the drive engine generates the highest possible drive torque.

Achieving the rated output

When the WEC achieves the so-called rated output during operation, the performance limit is provided by a corresponding adjusting of the rotor blades (and speed control, if applicable) in order to maintain the output level and prevent damaging the WEC.
For pitch-controlled turbines, the fore edge of the rotor blade is turned towards the wind. Turbines with variable speed are provided with a generator, which is connected with the grid by a frequency converter. This reduces the feedback between WEC and grid to the largest possible extent.

For wind energy converters with blade adjustment, 2 concepts are distinguished:

1| single blade adjustment
2| uniform adjustment of all three rotor blades

The single blade adjustment allows an independent adjustment of each individual blade. For the second concept, the blades are adjusted together by the same angle each.

With the single blade adjustment blades can be operated as redundant brake system (see chapter „Rotor brake”). The second concept requires a sufficiently dimensioned mechanical rotor brake.

Please note! Extent and structure of the control and operation of wind energy converters may widely differ depending on the turbine type. Therefore, always refer to the respective manuals, that are to be provided together with the WEC.

Rotorblades

The rotorblades of a wind energy converter are the most significant components in terms of the energy transformation of wind energy into mechanical rotation energy. Naturally, this component has a considerable influence on the mechanical behaviour and the life expectancy of the entire wind energy converter. Therefore, nature and structural condition of the rotorblades will considerable influence the yield and thus the economic success of your wind energy project.

Function

The rotor blades cover two tasks:

1| They transform wind energy into mechanical rotation energy.
2| They are designed as aerodynamic brake. Its specific structure and function depends on the control and regulation principle of the wind energy converter.

Material

Rotorblades are made of GFP (Glass Fibre-reinforced Plastics = GFP or Carbon Fibre-reinforced Plastics = CFP). The shaft between blade tip and rotorblade, which can be found in stalled turbines, is mostly made of CFK for blades with blade tip brake, because this material is best suitable to stand high loads.

Plastic composite is hygroscopic (i.e. it is able to absorb moisture from the environment) and is sensitive to ultraviolet radiation. Therefore, the outer surface of the rotorblades is applied with a UV-protection layer, so-called gelcoat.

Pitch and stall turbines

Depending on the measurement and control principle provided on your WEC, two categories of wind energy converters can be distinguished:

1| turbines with blade adjustment (pitch, active stall)
2| turbines without blade adjustment (stall)

The blade adjustment of pitch and active stall turbines used both for the energy production and the brake system: The brake effect derives from the rotor blade rotation by 90°. Differences between pitch and active-stall blades are mainly referring to the aerodynamic profile.

Brake procedures by tip mechanism

Rotor blades for stall turbines are provided with a tip mechanism, which must be activated to introduce the brake procedure. In general, this mechanism consists of a spring, a tube with a nut drilled by 90°, a sleigh gliding inside it and a hydraulic cylinder. The tip-head is disengaged by the spring while turning the tip head by 90°. The hydraulic cylinder, located in the blade root and connected by a steel rope with the tip head, is designed to „recover" the tip head.

The tip mechanism is designed „fail-safe". That means, if no hydraulic pressure is available at the start of the WEC or the hydraulic pressure declines during operation, the aerodynamic brake (rotorblade brake) remains activated by the spring and the centrifugal force. That provides a fail-safe operation and prevents damage from the WEC.

Important issues to be taken into consideration for a used WEC

- the surface condition of the rotorblades

A damaged rotorblade surface reduces not only the energy yield, it may also lead to an additional material damage weakening the whole structure. For instance, the fibre plastic composite under the gelcoat layer may be impaired by UV radiation or intruding water. Deeper damages can occur due to the notch effect of locally increased tensions, which may lead to a premature fatigue. Unfortunately, these damages are relatively hard to identify - in case of doubt, always call in a surveyor.

Special attention should be taken to the following damages:

- pores
- holes
- cracks on bonding surfaces
- dissoluting Vortex generators
- loose lightning protection

Pores and holes up to a certain size can be relatively simple filled with suitable surfacer. Cracks on bonding surfaces should be eliminated with the kind of resin (epoxy or polyester) the rotorblades are made of. If the dissoluting Vortex generators are undamaged, the may be re-affixed to the rotor blade. Otherwise they must be replaced by new generators in order to achieve optimal flow conditions (see glossary). Loose lightning protection must be re-affixed to the rotorblade in order to ensure the required lightning protection.

Conclusions: Always perform a thorough visual inspection of the blade surface and blade root area. Possible damages should be eliminated before the re-assembly. Repairs on the assembled blade are only possible with extremely high technical effort.

- Functional testing of the tip brake for stall blades

Pay special attention to the smooth running of the entire tip mechanism in order to ensure the faultless brake operation of the wind energy converter. In worst-case scenarios a non-conforming tip mechanism may cause a brake operation failure. The consequences would be WEC operation with overspeed, which may then lead to the destruction of the wind energy converter.

The serviceability of the tip brake can be checked by lowering the hydraulic pressure inside the hydraulic cylinders of the rotorblade below the triggering value while the wind energy converter is standing still. In doing so, the tip brakes of the blades should be extended and activated. When checking the braking function of the WEC, the tip brakes should be activated, too, as the hydraulic pressure will be reduced at first.

- Checking the screw connections between rotorblade and hub
The rotorblades are connected with the hub by clamping bolts. The winding of the bolts should be running smoothly and be free of corrosion. Further information on the screw connections can be referenced in the homonymous chapter.

- Checking the anchorage of the blade's tension rod
The blade should be free of cracks and do not rove.

Rotor hub

The rotor blades are connected with the rotor hub by flange connections. Stall turbines are provided with a direct connection between rotor blades and hub. Pitch and ActiveStall turbines are provided with a blade bearing between blade and hub. Detailed information can be found in the homonymous chapter.

In general, rotor hubs are made of EN-GJS-400-18U-LT (GGG40.3) cast material. This material provides a sufficient strength and disposes of an appropriate tensibility and notch bar impact value. Rotor hubs are subject to normal material fatigue, although external wear is not recognizable.
However, maintenance work and renewed disassembly and assembly of wind energy converters can lead to coating damages (corrosion protection). Such damages can be easily eliminated by renewing the coating. In this respect, special attention must always be paid to the paint specification of the manufacturer, where available.

Stall turbines

Long holes for the pitch control are located in the hub flanges of the stall turbines. Its length effects the possible control range. Therefore, during assembly, special care must be taken on the correct position of the blades towards the hub. If the position is not-conforming, the optimal pitch can not be controlled. That may lead to a permanent low output or a frequent shut-off of the turbine due to overload at high wind speeds.

ActiveStall and pitch turbines

The setting range of the pitch for turbines with pitch-control amounts to 90° in most cases and is limited by end points. Therefore, these turbines require also reasonable care for the correct positioning of the blade during blade assembly.

The inner hub

The internal part of the hub can be reached via a hatch. This hatch is usually located opposite to the shaft fastening. Some WEC types are provided with a covered hatch.

The inner hub of wind energy converters without pitch control contain only the hydraulic distribution system for the hydraulic cylinders of the inner blade root. The hub of turbines with electric pitch control contains the actuators, the switch cabinets with the support and frame system and the standby- battery power supply (UPS). Wind energy converters with hydraulic pitch are provided with a hydraulic cylinder in the hub, the associated hydraulic accumulator, the mechanical actuator system and the control switchboards. The hydraulics is supplied via a distribution system from the nacelle.

The checking of used wind energy converters should also include inspection of internal structures for corrosion, leakages and functioning. Pay special attention to possible contact corrosion at the electrical connections! All screw joints should be checked and retightened, where applicable. Details can be referenced in the maintenance and service manual of the WEC. All rubber bearings should be replaced by new ones, if possible.

Pitch and ActiveStall systems

Pitch and ActiveStall systems have generally the same design, they vary only in the way of pitch control and actuating of the blades For easier reference, both versions are referred to as „pitch systems” in the following description.

Pitch systems may be either provided with electric or hydraulic pitch-control. Both systems have generally similar designs. They consist of the following components:

- Drive motor
- Gear and/or hydraulic cylinder with mechanic actuating system
- One or more switchboards
- Uninterrupted power supply (UPS) for electric systems and/or hydraulic accumulator for hydraulic systems
- Steel frame for fastening the individual components (optional)

Electric pitch

The rotorblades of turbines with electric pitch systems are adjusted by the toothing between pinion and blade-bearing. Always check the wear of the pinion: if the material fatigue is too high, this may impair the toothing, which causes enhanced wear and tear at the toothing. A further component of the pitch control is the transmission gear (multi-level planetary gear) and the drive engine with the control unit.

Hydraulic pitch

For hydraulic pitch systems, the clearance of the movable components must be regularly checked, where applicable, the clearance must be re-adjusted. In addition, the entire hydraulic system must be checked for leakages. The hydraulic accumulator must be inspected for a possible pressure decline. The vibration adsorbing elements, (made of rubber) must be replaced at regular intervals.

Uninterrupted power supply / hydraulic accumulator

The uninterrupted power supply and the hydraulic accumulator are designed to provide a so-called emergency operation in case of grid failure or errors of the turbine. During emergency operation the rotorblades can be turned to the „flag position" even without grid supply and the rotor is decelerated. In doing so, a safe operation mode is provided. For this reason the UPS and/or hydraulic accumulator are of great significance for the wind energy converter. Their breakdown can lead to overspeed, and in worst-case scenarios, to the destruction of the WEC. Therefore, both components must be regularly maintained and checked for their functioning. If batteries are used for the stand-by power supply, they should be replaced after one year.

Before the wind energy converter is dismantled, the entire pitch system should be chekked for its proper functioning. Possible non-conformities should be eliminated without delay or, at least, documented in detail. At least during maintenance the non-conformities of the wind energy converter should be eliminated in order not to delay the commissioning.

The set blade pitch adjusted by the pitch control is measured via a sensor. Before commissioning the blade pitch must be adjusted in compliance with the manufacturer's specification in order to ensure an optimal operation of the wind energy converter.

Blade bearing

So-called slowly-turning large roller bearings are designed as blade bearings. For electric pitch drives, the pinion of the drive bites into the inner toothing of the bearing ring. The outer bearing ring is connected with the hub via a screw joint. The same applies to the connection of inner bearing ring and blade.

During assembly, special attention must be taken to the correct tightening torque and tightening methods to be applied. For this purpose, each individual case must be referenced in the assembly and maintenance manuals.

The blade bearings are sealed with grease to reduce the friction and provide a sealing and prevent corrosion. The grease coating must be replaced regularly. Make sure that during re-lubricating a so-called „grease collar" of new grease establishes alongside the entire bearing gap and/or alongside of all seal rings. The lubrication intervals can be referenced in the maintenance manuals of the wind energy converter.

Rotor bearing

For rotor bearings, different concepts exist:

1| the 3-point bearing
2| the rotor bearing on two main bearings
3| the integration of the bearing into the gear

The 3-point bearing

In the so-called 3-point bearing, the rotor shaft rests on a rotor bearing and the torque reaction bar of the gear. In this case, the rotor bearing is a so-called self-aligning roller bearing, which is located relatively close to the shaft flange. The rotor bearing is placed in a casing that is supported on the engine carrier.

Self-aligning roller bearings are designed for very high axial and radial loads. They consist of 2 rows of symmetric barrel rollers and a hollow-spherical runway of the outer ring. This allows turning around their radial axes and prevents power transmission from bending or torsion. The rotor thrust is completely absorbed by the main bearing.

The bearing of the planet carrier is located inside the torque reaction bar of the gear. Through the elastic bearing of the torque reaction bar, the rotor shaft is resting in a way that torsions up to a certain level can be ensured. This mobility reduces the forces applied

on the torque reaction bar and thus the impact on the components.
However, the disadvantage of this kind of bearing is, that bending moments must be provided at the entrance area of the gear.

The rotor bearing on 2 main bearings

The version is designed in a way that the rotor shaft rests on two main bearing, to that the bending moments from the rotor can be absorbed by the two main bearings. Only the drive torque is transmitted to the gear - a significant advantage of this type. Similar to the 3-point bearing, the bearings are designed as self-aligning roller bearings. The rotor thrust can be either absorbed by the fore or aft bearing. The rotor bearings can be either individually or together mounted in the bearing casing.

The integration of the bearing into the gear

The 3rd version is the integration of the bearing into the gear. This allows to completely omit the rotor shaft. Similar to the 3-point bearing, the bending moments in the gear imply an adverse effect. Due to the relatively high bending moments, this type of bearing can only be implemented for smaller turbines.

Bearings of used wind energy converters

To determine the condition of a used wind energy converter, the condition of the bearings must be subject to an extensive inspection, in order to perform a possible replacement prior to re-assembly or during maintenance. The dismantling and assembly of a rotor blade requires a complete dismantling of the power train on the slow shaft. This procedure is much easier to perform in a workshop or prior to installing the machine house on the tower than at a completely installed WEC.

Inspection of the bearing condition of used WECs

The condition of the bearings can be either checked by visual inspection or condition monitoring. The condition monitoring allows an inspection of the assembled bearing and can be performed during operation of the wind energy converter. It specifies approaching or occurring damages and wear. As the condition monitoring requires an exact knowledge of technical and geometrical data of the bearing and, therefore, much experience, it should only be performed by professional engineering staff.

Lubrication of the rotor bearing

In general, rotor bearings are lubricated with grease. While installing and re-assembling a WEC the bearings must be re-lubricated. The re-lubrication is carried out via the lubricating nipples. Lubricating nipples are small cups that can be filled by a grease gun with grease. The further lubrication of the rotor bearing should be carried out in compliance with the maintenance intervals - details can be referenced in the chapter „Documentation", and, in the first line, also in the maintenance and service manual for your wind energy converter.

Some wind energy converters are provided with an automatic re-lubrication. In this case, it is sufficient to provide an adequate amount of grease for re-lubrication purposes. This work forms also an integral part of the maintenance specified and described in the respective manuals.

A new mounting of the rotor bearing, requires full compliance with the assembly instructions of the manufacturer. If the shaft is fitted tightly into the rotor bearing (press fit), the inner bearing ring must be warmed. The material extension allows an assembly without damaging the seat of the bearing.

The rotor shaft

The rotor shaft connects the hub with the gear (respectively, for gearless turbines, with the generator). Rotor shafts are mostly made of heat-treated steel, in individual cases materials like spheroidal cast iron (EN-GJS-400-18U-LT) or cast steel are used.

Under adequate operating conditions of the wind energy converter, the rotor shaft is only subject to the load caused by the rotor, so that, apart from normal material fatigue, no wear and tear should occur.

A possibly problematic case

Under certain conditions it may occur that the rotor shaft may distort towards the gear entrance shaft. Such a „distortion" may either lead to a seizing of the joint or result in a large, i.e. too large, clearance.
If such a condition has occurred for the relevant WEC, it should have been documented by the maintenance personnel or must be documented in the course of an expertise.
Always make sure that, while mounting the rotor shaft to the gear, the contact surfaces between rotor shaft and entrance hub of the gear are grease- and oil free. Only then the transmission of the drive torque is ensured. In addition, it reduces the risk of „distortion"

(see previous passage). It must be ensured that the shrink disc can be tightened „smoothly".

The thread and the head bearing area of the rotor shaft must be sufficiently lubricated (see chapter „Screw connections"), in order to ensure that the shrink disc can safely transmit the drive torque. If the friction below the head surface areas and the thread is too high, the clamping torque of the screws will be achieved, but the shrink disc is not sufficiently tightened. The transmitted torque of the shrink disc depends on the pre-load of the screws and is additionally reduced by the transmission of bending moments (3-point bearing).

The inner rotor shaft is hollow, that allows to lead the piping (hydraulics) and electric cables from the gearing to the hub.

The dismantling of a rotor bearing in the course of a service call or re-installation should include the inspection of the bearing seats. If the wind energy converter operated appropriately, no wear or tear can be expected at the bearing seats.

The gearbox

The gearbox of the wind energy converters is one of the most important components of the WEC and requires special care. Usually, the operating time of Second-hand-WECs is elapsed to at least 50%, so that the risk of a gear damage or failure increases continuously.

Due to the fact, that such a failure or even the repair may cause considerable costs, the profitability of the wind energy project can be significantly impaired. Therefore, even in the event of smaller failures, considerations should be made, whether a replacement of the gear would be sensible in the course of the re-installation.
Combined planetary and spur gear units are used in most of the wind energy converters. Here, the planetary level is located at the gear entrance whereas the outlet is provided with two spur levels. The advantage of the planetary level is that a very high transmission is achieved with only one level.

Depending on the year of manufacturing of the gearbox, the toothed wheels gear straightly or helically towards each other. Modern wheels with helical toothing enable a smoother operation as the gearing and releasing of the teeth happens gradually and more teeth lay within the gearing area at the same time. Because of this, the helical teeth are more suitable for higher rotational speeds and can be stressed harder than straight toothed wheels of the same size. In addition, the smoother operation reduces the noise level of the gearbox. The disadvantage: additional axial forces occur due to the helical toothing at the toothed wheels - they have to be absorbed by the bearings and shafts.

Cables and wires that lead into the hub have to be wired coaxially towards the rotor through gearbox and rotor shaft in any case. All required connections (rotational feedthrough of the hydraulic oil, slip ring runner for electric cables) are located at the „backside" of the gearbox. The coaxially positioned axes and shafts inside the gearbox are hollow. At this gearbox, the sensor for rotational speed control of the slow shaft can be installed comparatively easy.

High temperatures occur during the operation of the wind energy converter - they are monitored with special sensors. In case the oil temperature exceeds a certain limit, the oil looses gradually his lubrication characteristics. It matures fast and looses its viscosity.

For wind energy converters that are operated in colder regions, an appropriate operation temperature is extraordinarily important. In case the WEC has longer standstill periods at very low temperatures, the oil becomes cool and thickens. Such an oil cannot reach the most important lubrication spots of the bearings which might cause bearing damages. For these conditions, the gearbox oil of such „cold climate versions" is preheated. In this respect, it is important to ensure a good circulation at the heating as otherwise parts of the oil might be heated too much and „burn".

The inspection of the gearbox of used plants

An inspection of the gearbox should be carried out prior to the disassembly or during a maintenance, if possible. Special attendance should be given to a detailed documentation here, as this is helpful for further maintenances and possible later repairs. For a gearbox inspection, oil samples will be taken and analysed.

If the toothings are accessible via the housing cover, its status should be inspected and documented with photographs. Possible damages are:

- Tooth fracture as a results of bending strain at the tooth bottom
- Tooth flank fatigue (pitting) as a result of material fatigue
- „Seizure" due to combined occurrence of compression and sliding speed

Tooth fracture

Tooth fracture require, that the gearbox be disassembled and repaired. Such a problem is caused by exceeding the highest tolerable strain: the tooth breaks at the bottom. The appearance of this tooth breaking provides information about possible reasons of the damage (violence or fatigue fracture).

Tooth flank fatigue

Material fatigue occurs due to permanent loading and unloading of the tooth flanks. In case the tolerable compression of the gearing teeth is exceeded, items dissolve out of the tooth flanks. After a certain amount of overruns, pittings occur. Tooth flank fatigue is only problematic if these pitting gets worse during unmodified operation.

„Seizure"

The so-called „Seizure" occurs if the lubrication film between the tooth flanks is interrupted and metallic surfaces ream directly against each other. This can lead to momentary local welding of the tooth flanks. Stripe-shaped, roughened ribbons occur, mostly pronounced at the tooth bottom and tooth head. Due to a temperature rise during too high sliding speed with simultaneous compression, the so called „warm seizure" occurs. If the compression is too high while the sliding speed is low, „cold seizure" occurs.

One of the main reasons for the „seizure" is the use of unsuitable lubricants. However, this can be almost avoided by careful maintenance and lubrication of the gearbox.
If one of the above mentioned damages occurs, an expert should be consulted regarding the remaining life-time of the component.

Options of bearing inspection

A careful inspection of the bearing should be carried out as well as far as this is possible with the appropriate method and the condition monitoring system. Consider: a bearing damage that draws attention to itself only during further operation, results often into complete assembly of the gearbox, high repair costs and a loss of yield.

The sensors for gearbox monitoring should be inspected for proper operation. Defect sensors have to be exchanged, where necessary.

The oil level can be checked via the gauge glass.

All oil filters that are necessary for the gearbox (coarse and fine-mesh filter) should be exchanged as well as the gearbox oil. Gearbox oils must never be mixed. If an oil exchange shall be carried out, the gearbox has to be flushed with the new oil completely several times. Consult the gearbox manufacturer and the oil manufacturer under any circumstances, if the oil type shall be modified.

Rotorbrake

The rotorbrake is divided into two systems: an aerodynamic and a mechanical brake that operate independent from each other.

Aerodynamic brake

The aerodynamic brake shall decelerate the rotor until a complete stop. At pitch-controlled and ActiveStall-controlled wind energy converters, it consists of the entire blade. The blade will be turned by 90° towards the leading (flag-like position) and, thus, creates a very high drag. Depending on the design of the control system, the rotorblades can be operated independent from each other or as a unit, thus triggering the braking procedure.

Mechanical brake

At plants with three independent single-blade pitches, the mechanical brake has been designed as a parking brake. As every blade pitch is able to shut down the plant by itself, this is called a redundant braking system. If no single blade pitch exists, the mechanical brake is designed to brake the rotor as well.

Brake system of stall plants

At stall blades that are rigidly screwed with the rotorhub, the aerodynamic rotorbrake consists of a movable tip brake that moves 90° towards the leaning direction if the braking function has been triggered. The drag created by this is high enough to decelerate the rotor to low rotational speed.
On this low rotational speed level, the mechanical rotorbrake is used: It brakes the wind energy converter until complete shutdown.
Even with stall-controlled wind energy converters, aerodynamic and mechanical brake form a redundant system: in case of emergency, the rotor should be braked to shutdown with the mechanical brake.

The aerodynamic brake is designed fail-safe. This means: If no hydraulic pressure is put on when the WEC is started or it trails during production operation, the aerodynamic brake (deceleration by appropriate turning of the rotorblades) remains active or gets active via a spring and centrifugal force - the WEC passes on into a fail-safe operation mode.

The construction of the mechanical rotorbrake

The mechanical rotorbrake is a disc brake. It is located, depending on the wind energy converter, on the slow shaft (within the flux in front of the gearbox) and/or on the fast shaft (within the flux behind the gearbox). Either active or passive brakes are used here. Passive brakes are so called „fail-safe brakes", i.e. they can only be opened if hydraulic pressure is put on. The required brake torque is adjusted by regulating the hydraulic pressure - it depends on the operation situation of the wind energy converter: In an emergency situation, the brake is operated with maximum brake torque. In other situations, the brake torque is kept as low as possible to minimize the stress on the WEC and the components to the lowest possible extent.

Inspection of the brakes

Carry out a functional test of the mechanical brake. In addition, the brake linings have to be inspected: the brake lining must be designed with a prescribed minimum thickness. If this is not the case, the linings have to be exchanged.
Some brake types are equipped with an abrasion sensor - here, it has to be inspected if the display corresponds with the real status of the lining.

During the braking procedure, brake disc and brake linings are exposed to high temperatures that are an additional stress of the material. It has to be ensured that no deeper score marks are on the brake linings that, as well as an increased impact of the disc, result into an uneven and enhanced abrasion of the brake linings.

In addition, attention has to be paid to possible discolouration of the brake disc as they might result from a malfunction of the brake.

The braking procedure of the wind energy converter is monitored via rotational speed control: it determines how strong the WEC has been braked within a certain period of time.

Generator coupling

The generator coupling has to compensate the axis and shaft angle displacement between gearbox output and generator input shaft. If the displacement is too high, the stress of the flexible components becomes too high and the coupling tends to fail earlier. Thus, it is possible to inspect the axis and shaft angle displacement (misalignment) during the assembly of gearbox and/or generator and to correct it, if necessary, via the adjustable generator feet.

In most of the cases, the generator coupling is assembled together with the brake disc at the gearbox side. Some plants are provided with an additional safety coupling located at the generator side between coupling and generator shaft, mostly designed as slip clutch. It serves to limit the maximum torque.

In wind energy converters, different forms of generator couplings are used:

- multiple-disc clutch (steel lamellas, plastic lamellas)
- curved-tooth gear coupling
- CENTALINK
- CENTAFLEX

Multiple-disc clutch

Multiple-disc clutches have one or more flexible lamellas at both ends that allow a radial and angular misalignment of the connected shafts. In case of plastic lamellas (mostly fibre-plastic-bonding) one lamella is used at every side. If the lamellas consists of metal, there are several thin lamellas on every side of the clutch.

Lamella clutches operate wearless and noiseless. The maintenance efforts are low: it has only to be inspected for mechanical damages.

Curved-tooth gear coupling

Curved-tooth gear couplings are shaft connections with a positive transmission of forces. The curved-tooth gear principle allows edge compression at the toothing with radial and angular shifting. Because of this, the clutches work nearly wearless. The positive effects of the rigid toothing allow a transmission of high torques and high rotational speeds.

With curved-tooth gear couplings, it has to be checked regularly whether the toothings are lubricated sufficiently during operation - this is only the case if a certain radial and angular shifting exists that allows the relative motion between the teeth.

Design-related, curved-tooth gear couplings are operated with more noise than lamella couplings as they have less vibration-damping characteristics. Curved-tooth gear couplings are characterized by a relatively compact construction.

CENTALINK-coupling

The CENTALINK-coupling is a simple, highly elastic and connecting coupling, easy to assemble and with rubber-like bushings. The coupling allows a compensation of large axial, radial and angular shiftings. The CENTALINK-coupling is a torsion-rigid, zero-backlash coupling that work noiseless.

CENTAFLEX-coupling

The CENTAFLEX-coupling is a simple rubber coupling that work maintenance-free and quiet. It is set up similar to the lamella coupling.

Maintenance and inspection of the generator coupling

The flexible components of the generator coupling are exposed to a maximum of stress. Because of this, they should get special attendance during the maintenance. Torn down coupling items might cause a remarkable damage of other components due to their high rotational speed (up to 1500 min^{-1}) and the high kinetic energy resulting from this. The imbalance from a torn-down coupling item must not be underestimated. Under certain conditions, the GFP-cover of the wind energy converter might be punctured by fragments.

Rubber items and items made of plastic should be inspected for possible cracks or material brittleness. Rubber items go beyond the normal wearout processes: inspect them for material fatigue. Possibly damaged components have to be exchanged. Consider that the costs that occur with an exchange of this item are much lower than those occurring with consequential damages and repairs.
Occasionally, a safety clutch can be located at the generator side - familiarize yourself with its functioning. In addition, the height of the release torque has to be checked or (in case of a new assembly re-adjusted. Apart from this, the safety clutch is operated wearless.

Generator

The generator is the last link of the WEC's drive train. It transfers mechanical energy into electric energy. Synchronous as well as asynchronous generators are used here.

In most cases, the generator is placed on adjustable generator feet, more or less flexible regarding level and height. The rubber of these feet is wearless apart from maturing. Further information about the rubber feet you get in chapter „Rubber feet".

The generator is either equipped with air or water cooling. Further information can be found in the chapter „Cooling system".

Synchronous generators

Synchronous generators are used for pitch-controlled WEC with variable rotational speed. They are connected to the grid via a static converter. It prevents that occurring po-

wer fluctuations are directly transmitted to the grid.
Synchronous generators are provided with a better coefficient of efficiency than asynchronous generators. On the other side, losses of up to 5 percent occur while the current is converted to grid frequency.

Asynchronous generators

In general, asynchronous generators with two different pole-pair figures are used with stall-controlled wind energy converters. This allows to equip the generator with two different power levels and to operate the wind energy converter at two rotational speed levels. The rotational speeds of the generator amount to 1500 min^{-1} (4 pole pairs) for high capacity ranges and 1000 min^{-1} (6 pole pair) for low capacity ranges.

Asynchronous generators are cheap, sturdy and need little maintenance. They allow an easy synchronisation with the grid. Its coefficient of efficiency is lower than those of synchronous generators.

The generator level or the rotational speed the generator is working with depends on the wind speed. The values for switching from one generator level into the other are set by the manufacturer. They can be examined in the control system of the wind energy converter and adjusted there.
As a permanent alternation between the two generator levels due to frequently changing wind speed should be avoided, the switching values are taken as standard values: a real switching over takes place only after not just the value itself but also a preset tolerance zone has been exceeded.

Please note! Frequent changes of the generator level impair the service life of the drive train components, because relatively high stresses occur during this process.

Unlike other components, the mechanical stress of the generator remains low. During inspections of this component, particular attention should be drawn to the bearings and their lubrication. If the maintenances were carried out correctly, a proper functioning of the bearing over the entire life time of the wind energy converter can be expected.

The maintenance effort is limited to a regular lubrication of the bearing (regarding the intervals, please, consider the maintenance manual) that can be done via grease nipples in the easiest cases.

Double-fed asynchronous generators

Double-fed asynchronous generators are able to modify the rotational speed during operation within a certain tolerance zone. Thus, performance fluctuations can be compensated and structure loads can be reduced. Double-fed asynchronous generators can be easily connected to the grid. Compared to simple asynchronous generators, they are quite expensive and have a low coefficient of efficiency.

Main frame

The main frame is the basic frame of the wind energy converter. All other components are installed on it or attached to it. All forces and torques created at the rotor are transmitted via the rotor bearing, gearbox bearing and generator bearing over the main frame into the tower. As the main component of the nacelle, the main frame is of essential importance. If it fails at a critical spot, this can cause the destruction of the entire wind energy converter during further operation.

In general, two materials are used for main frame manufacturing:

1| a properly weldable structural steel (for instance S235)
2| the cast material EN-GJS-400-18U-LT as it is also used for rotor hubs

Both materials can be processed fairly good.

Main frame made of cast material

The advantage of the cast material is that it can be transformed into various forms. This allows softer connections between different thickness and an adaption of the main frame to any stress level. In addition, the material has good damping characteristics.

It is one disadvantage that holders, steps and other mounting facilities have to be screwed in. But as this was already done during the first assembly of the plant, it should be not relevant here.

Main frame made of structural steel

Main frames made of steel are welding constructions where mounting facilities, holders and steps can be assembled with comparatively low effort. The disadvantage is that they cannot be manufactured in every desired form.

Maintenance

Main frames are not exposed to further wear then those resulting from material fatigue as long as there is an appropriate corrosion protection. Nevertheless, the critical spots should be examined for cracks and damages (corrosion) within the regular maintenance intervals (detailed information on that you find in the maintenance manual).

Corrosion protection

The corrosion protection can be carried out differently, depending on the original material and the size of the main frame. Welding constructions up to certain size can be galvanized, which is a very good and lasting corrosion protection. For possible later welds, the corrosion protection has to be removed. The machined spots have to be protected against corrosion again, afterwards. If zinc spray is used, it should be additionally varnished.

If the melded main frame is too large for a galvanizing zinc coating bath, a multi-layer colour system can be put on as corrosion protection. If damages from assembly work or something similar have to be repaired, the relevant colour specification has to be considered.

Surfaces where the power transmitting component (rotor bearing, gearbox) is fixed with bolt connections, have to be metallically bare before the assembly is started. During transport or maintenance, these surfaces should get an easily removable corrosion protection as well.

It is possible that the seatings of the rotor bearing and the gearbox were treated with a zinc-silicate-layer. This layer is supposed to increase the coefficient of friction (see chapter „boltings" for this, too) - it must not be removed!
Main frames of cast material are generally protected against corrosion with a colour-layer-system. Damages of the colour layers can easily be repaired, considering the relevant colour specification.

Larger wind energy converters may have a two-piece main frame. The generator and possible control cabinets inside the nacelle are mostly located on the so called generator frame which is connected to the main frame via boltings. In such cases, the main frame and the generator frame may consist of casting or as a welding construction

Yaw system

The yaw system of the WEC consists of the yaw drives, the braking system and the yaw bearing, located between tower and nacelle. It adjusts the wind energy converter according to the current wind direction. Usually, the rotor is „turned into the wind", with high wind speeds (above the upper wind speed limit), the reverse process will be carried out to reduce the stress that effects on the wind energy converter.

Yaw bearing

Yaw bearings are slowly turning fourpoint large roller bearings with their toothings located at the inside or at the outside, depending on the arrangement of the yaw drives. If the wind direction changes, the wind energy converter will be newly adjusted via this toothings. In general, the yaw bearing is slightly preloaded.

If treated appropriately, the fourpoint bearing is only exposed to the operation-related wear that should remain within the limits. Particular attention should be drawn to a proper lubrication. Due to longer standstill periods, compression spots and corrosion at the bearing runways might occur as the lubricant between bearing runway and rolling element is pressed away. For this reason it is important that the yaw bearing is moved in regular interval with a motor or manually - this ensures that the relevant contact spots between runway and rolling element are provided with „fresh" lubricant.

The toothing yaw bearing - pinion has to be lubricated properly as well to prevent early wear through pitting at the toothing of the yaw bearing. „Pitting" is a form of material fatigue at the tooth flanks: pitting-like cavities at the surface. It might result into the release of tooth flank items if the compression that effects on the teeth exceeds a certain limit. The reason for this material fatigue is a permanent loading and unloading of the tooth flanks - but only problematic if these pitting grow further or the number increases during unmodified operation.
In general, pitting occurs at the toothing of the yaw bearing, as the toothing of the pinion consists of harder material. And a component with a much smaller number of teeth is overrun more often during the toothing procedure and, thus, experiences larger stress.

In case there is a „main wind direction" at the new installation site of the wind energy converter it should be examined whether the yaw bearing could be installed turned for 90° around the axis of revolution. In this case, the other areas of the bearing runways will be stressed more. In most cases, this should be possible because of the rotation symmetry. Take care that the possible assembly or disassembly boreholes remain accessible.
Because of the very large reduction ratio between pinion and yaw bearing, the yaw speed is extremely low.

The contact pattern of the toothing

The contact pattern provides information, how the teeth engage with each other. It can be found in those area of the tooth flank where the tooth flank contact and the transmission of forces take place. Its structure tells a lot about the quality of the toothing. Too large deviations from the ideal contact pattern cause an uneven transmission behaviour that reduces the lifetime of the toothing and increases the noise. Because of this, the contact pattern of the toothing should be examined over the entire periphery of the yaw bearing.

Yaw drive (Azimuth drive)

In most cases, two or more drives are used for the yaw system. The drives consist of a hydraulic or an electric motor, a gearbox and a drive pinion.

For the gear reduction of the large differences in rotational speed between drive and yaw system, a multi-stage epicyclic gear is the best option. The coaxial arrangement of the input and output shaft allows a very compact construction. The electric or hydraulic drive unit serves as the parking brake, too.
An additional spring-loaded brake is located behind the electric drive engine on a second shaft. It is ventilated during the yawing process. In general, no wearing of the brake occurs because of this second function as a parking brake.

With hydraulic drives, the braking effect is reached by switching off the hydraulic pump. The drive shaft of the pinion is eccentric towards the fixation flange of the yaw drive. This allows an adjustment of the tooth flange clearance between pinion and the toothing of the yaw bearing. For this, in many cases the entire drive can be turned within its bearing. The adjustment is done with the help of the bolt pattern. At some variants, the drive can be moved sidewards by turning the eccentric ring. The boreholes for the fixation bolts are designed appropriately large, then. The entire drive is attached to the main frame via a screw flange.

The adjustment of the tooth flank clearance does effects considerably the lifetime and the wearing of the toothing so that the manufacturer information about the tooth flank clearance should be followed absolutely. Especially regarding the wind energy converters that have already been operated for many years on a site with frequent changes of the wind direction, this aspect is very important to avoid that existing pitting cannot progress too much.

Brakes in the yaw system

In addition to the brakes of the yaw drives, there is a second braking system for yawing. It may consists of several active disc brakes that are spaced regularly along the yaw bearing.

Permanent braking system

Alternatively, a permanent braking system can be used. For this variant, several constructions exist, depending on the manufacturer. These brakes decelerate the yawing of the WEC to avoid strong vibrations which might be dangerous for the wind energy converter. In addition, these brakes are able to lock the yaw system, in case it shall not be activated when the wind direction changes (during WEC-standstill, during maintenance and service work etc.)

Cooling system

High temperatures occur within the gearbox and the generator during the operation of the wind energy converter - they require a cooling of these components.

Gearbox cooling

The cooling of the gearbox is done with gearbox oil which, again, is cooled by a heat exchanger. As with the gearbox, the temperature of the bearing is monitored by appropriate sensors.

Generator cooling

Depending on manufacturer and design, the generator can be cooled with air or water.

With a water cooling, the cooling circuit of the water can be connected to the heat exchanger for the gearbox oil. The water again is cooled by a heat exchanger with outside air.
An air-cooled generator uses outside air for cooling. The airflow needed for this is produced by a fan located on the generator axis.

The cooling system should be inspected regularly - the intervals are defined in the maintenance manual of the WEC. Although the movable components of the cooling system (pumps, fans etc.) are not exposed to excessive stress, they should be inspected regularly. Possible faults of the cooling system are recorded by the temperature sensors. To ignore these error messages or nonconformity reports, might cause severe and expensive damages.

Nacelle

The nacelle is the cover of the wind energy converter towards outside. It can be opened and is accessible via one or more hatches. The opening of the nacelle is mostly done by the hydraulic system. As no rainwater must get into the closed nacelle when the nacelle is closed, the air exchange with the outside is exclusively done via the fan or openings in the nacelle wall. They allow a heat exchange and reduce the formation of condensate.

Nacelles made of GFP

Usually, nacelles are made of glass-fibre reinforced plastics (GFP). The GFP-cover is reinforced by a steel frame. This steel frame consists of galvanized square and pipe outlines that are laminated with GFP. The nacelle is connected with the main frame at several spots via vibration damping elements. At the outside, the GFP is covered with a gel coat layer that protects it against UV radiation and humidity. The interior is usually covered with a layer of painting. The interfaces of the GFP-cover should be sealed because of its hygroscopic quality as humidity might get into the laminate at these spots which would damage the material.

Scorings of the GFP-cover that can, for instance, be caused during transport or assembly, can be repaired relatively easy.

Nacelles made of sheet steel

Instead of the GFP-cover, steel sheets can be used. They have to be protected against corrosion in the usual way. Possible damages of the layers have to be repaired according to the colour specification - details are specified in the maintenance manual of the plant.

For some energy converters a part of the nacelle is formed by the main frame.

The nacelle interlock

To open and close the nacelle without problems, hinges and possibly existing interlocking systems have to be inspected regularly. In case the interlock does not work without problems, the hatch might get open at high wind speed and get damaged. Worst case would be that the nacelle hatch or even the nacelle cover is torn down.

Tower

3 types of tower are used for the installation of wind energy converters:

- Segmented conical steel towers, screwed via flange connections
- Lattice tower
- Ferroconcrete tower

The disadvantage of concrete tower is that they generally cannot be used again (see chapter „Disassembly of wind energy converters"). Lattice and conical steel towers can be disassembled into segments and re-installed on the new site.

Conical steel tower

Depending on its length and diameter, the conical steel tower is divided into two or more segments that are screwed via a flange connection. Another flange connection attaches the tower to the foundation and the nacelle to the tower. Platforms which are needed for the assembly of the flange connections are assembled between the segments. Later they serve as the prescribed rest places for the mechanics. The climb-through hatches in the platforms are covered by lids.

The hatch lids have to be closed after every passing as falling items and/or tools during maintenance work at the wind energy converter are stopped by the next platform below.

Please note! Every falling item can harm persons who follows behind!

A ladder is assembled at the tower wall for climbings into the nacelle. It is equipped with an additional safety rope or runner-system for personal safety.

The control cabinet at the tower bottom contains the operation unit of the wind energy converter. The current and control cables run along the tower wall up to the control cabinet inside the nacelle. Before reaching the nacelle, they form a long, hanging loop. This loop provides the clearance for several possible turns of the nacelle around the tower axis and into one direction („twisting"). This twisting is monitored by a sensor. After the maximum cable twist has been reached, the WEC-control system triggers a de-twisting-process. Because of the very high reduction ratio, this process will take some time.
The conical steel tower can be entered via a lockable door.

Lattice tower

Unlike conical steel towers, the lattice tower does not provide any protection against environmental influences. The same applies to tower ascents and descents towards and from the nacelle of the wind energy converter. Due to this open construction, all components „inside" the tower have to be protected against environmental influences separately.

The single tower segments are connected with bolts, which means that the assembly effort is very high. The boltings have to be checked at regular intervals - for details about that, please, consult the maintenance manual of the WEC. At first, only a certain amount of bolts will be checked. If this check shows that the tightening torque is too low at a certain percentage of bolts, all boltings of this segment connection have to be checked.

An adaptor is located between tower and nacelle (yaw bearing) that connects the steel profiles of the lattice tower with the yaw system. It provides an access to the nacelle of the wind energy converter.

A ladder for the nacelle access is attached to the lattice elements of the tower as well as the cables that lead from the control cabinet into the nacelle. The cables form a loop that provides clearance for several turns of the nacelle in the same direction. The ladder is equipped with an additional safety rope.

Concrete tower

As concrete towers have to be built newly on every new wind turbine site, no former details about their consistency, functionality and maintenance are given here. Where appropriate, concrete towers could be replaced by conical steel towers, in case conical steel towers are available for the same WEC-type.

Please note! WEC-towers are designed according to the behaviour and operation of a certain wind energy converter which means that the tower geometry plays an important role. In case you consider to change the type of tower, for instance from concrete to lattice tower, this should be based on extensive information from the manufacturer.

Boltings

Numerous boltings of different sizes are used at wind energy converters - they connect and fix the single components. Boltings allow a relatively simple assembly and disassembly of the components that consist of different materials very often. At flange connections between the force transmitting components, comparatively many bolts can be used even for one single connection.

Some of the bolting of wind energy converters have to transmit very high forces and torques. Because of this, exclusively high-strength bolts are used. The most usual strength class is 10.9, sometimes strength class 8.8 is used for smaller boltings. Bolts with strength class 12.9 are used in exceptional cases only.

Please note! The higher the bolt strength the more brittle is the material. Because of this, high-strength bolts (especially strength class 12.9) cannot stretch very much and are more endangered to break due to overload.

To enable them to transmit forces and torques, the bolts have to be tightened up to a certain „preload force". This preload force will already be taken into consideration when the boltings are designed, i.e. during the planning and development period.

Please note! The higher the preload force the higher the force that can be transmitted by the bolting. The same applies to the lifetime of the bolting: the higher the preload force, the longer the lifetime.

The preload force can be applied to the bolts with various pick-up procedures [see guideline VDI 2230]:

1| with a torque wrench („torque-controlled tightening")
2| rotation angle-controlled pick-up procedure
3| yieldstress-controlled pick-up procedure

Torque-controlled tightening

This procedure is the most frequently used. The bolts are brought to the prescribed pick-up with a certain preload force - both data can be found in the maintenance and service manual of the WEC.
When turning the bolt, friction forces occur at the thread and below the bolt head. They have to be taken into consideration when adjusting the required pick-up torque - otherwise the connection might not get preloaded sufficiently or the bolt might get overstretched. In every case, the transmission of forces and torques would get obstructed and the durability of the bolting would decrease.
In addition, the bolt is twisted a lot if too high friction occurs during the torque-controlled procedure. This additional stress has to be absorbed by the material of the bolt. For this reason, the threads and bearing surfaces of the bolt head and bolt nut have to be lubricated with an appropriate lubricant. Lubricants based on molybdenum disulfide (MoS2), plumbago and Teflon (PTFE) reach extraordinary low friction coefficients. During torque-controlled tightening, the bolt is usually tightened up to 90% of its yield strength, i.e. the material does still remain within the elastic range.

Rotation angle controlled pick-up procedure

With this procedure, the bolt is tightened up to a certain pick-up and turned around for a pre-determined angle afterwards - by this, the appropriate preload force is brought on. For this, a preloading up to the overelastic range is possible. When preloading into the overelastic range, small, hardly noticeable distortions occur. The bolt remains fully elastic. For this procedure, the friction inside the thread and below the bearing surfaces has to be kept low as well, to keep the bolt twist as low as possible.

Yieldstress-controlled pick-up procedure

With this procedure, the entire elastic limit of the bolt will be used. During the procedure, the ratio of pick-up torque and pick-up angle of rotation are measured continuously - the process will be finished as soon as this ratio is reduced. The thread and the bearing surfaces have to be lubricated well during this procedure, too. The preload force can also be applied via elongating (pulling into the length, twist-free stretching) the bolt until the elastic limit has been reached. The friction is not relevant for this procedure.

All pick-up procedures are subject to certain scatterings when the preload force is applied. These scatterings result from friction and/or the elastic limit. To consider this scattering appropriately, a so-called „tightening factor" has to be integrated even into the calculation of the bolting. This tightening factor is lower with yield stress-controlled or rotation angle-controlled tightening than with torque-controlled tightening.

Some of the boltings are exposed to very strong dynamic stress. Because of the vibrating operating force, bolts of purely elastically preloaded boltings can get loose gradually. Thus, the thightening torques of torque-controlled preloaded bolts that use up to 90% of their elastic limit for pick-up, have to be inspected regularly - about the detailed maintenance intervals, please, consult the maintenance and service manual of the WEC. With elastic limit-preloaded bolts (preload up to the overelastic range), the preload force cannot be increased further as this only results in a further plastic deformation of the material.

Which pick-up procedure shall be used?

During the assembly of the wind energy converter, attention should be paid to which tightening procedure was recommended by the manufacturer for every single bolting. In case single or all bolts of one connection have to be exchanged, the strength class of the bolts has to be considered in addition.
Yieldstrength-controlled preloaded bolts must not be used again for a re-installation of the wind energy converter - all bolts have to be replaced by new ones, here. With torque-

controlled preloaded boltings, at least the highly dynamically stressed, force-transmitting bolts have to be exchanged due to material fatigue.

Important force-transmitting boltings are:

- Blade-hub-connections (the connections blade - pitch bearing and pitch bearing - hub included)
- Hub - shaft connection
- Shrinkable disc connection shaft - gearbox
- Boltings of the gearbox with the main frame
- Both boltings of the yaw bearing
- The flange bolting inside the tower
- Boltings of the brake calliper
- Bolting of the generator coupling

All surfaces of the connected components have to be metallically bare, clean and free of grease before the assembly can be started to enable the required coefficient of friction. The corrosion protection put on for transport and storage has to be removed before connecting them. In some cases, a zinc-silicate-layer can be put on the surfaces, that serves an increase of the friction coefficient. This layer must not be removed as otherwise relative motions of the connected components might occur.

Bolts have to be protected against corrosion, too. Because of this, HV-bolts are zinc-galvanized or hot-dip galvanized. Hot-dip galvanization provides better corrosion protection than galvanizing with zinc but can be used up to a certain strength of material (M30) and a certain strength class (10.9) only. With larger diameters and strength classes, the phenomenon of so-called „hydrogen embrittlement" occurs: a certain period of time after tightening the bolts, the bolt heads are torn down. This might happen very suddenly and even endanger persons as the bolt head is shot like a bullet out of the connection. Other disadvantages of hot-dip galvanized bolts are the larger undersize during fabrication (these bolts are smaller than others before the zinc-layer is applied) and the gliding behaviour of the zinc layer during the bolt tightening which is determined to be bad. In case of doubt, black bolts should be taken for the high-strength boltings - for bolts with strength class 12.9 there is not alternative for this! The corrosion protection is done by applying a colour-varnish.

Please note! When buying high-solid bolts, you have to regard that every bolt or thread rot should be marked with a manufacturer identification and solidity class. Otherwise the bolts should be returned directly to the manufacturer / supplier. High-strength galvanized bolts should only be ordered as complete sets.

Rubber bearings

Rubber bearings are supposed to absorb vibrations and shocks. In general, they are used at the following components:

- Gearbox
- Generator
- Control cabinet which are installed inside the nacelle
- Control cabinets inside the hub (for pitch- and ActiveStall-controlled plants)
- Hydraulic aggregate

The rubber elements at gearbox and generator are often adapted to their specific geometries and stresses. With the other components, „standard elements" can be used.
Apart from the stress caused by component vibration, the rubber is subject to the normal maturing processes caused by heat, oxygen and sunlight. If rubber elements are damaged (porous or with torn-off metal-rubber-connections), the standard items can be replaced comparatively fast and cheap and independent from the manufacturer. For the rubber bearings of generator and gearbox, the geometry should be considered as well as the spring stiffness and spring characteristic. If these information cannot be taken clearly from the delivered documentation, only the manufacturer is able to provide the required spare part.

Please note! Porous and/or torn-off rubber items should be exchanged in any case. A tilted control cabinet or a torn-off control box inside the hub causes much higher damages and repair costs than a new purchase of damaged rubber bearings.

Sensor system

There are several different sensors at the wind energy converter that monitor the operation and the environmental conditions. The most important ones are:

- Anemometer to measure the wind speed
- Wind flag to measure the wind direction
- Sensors to measure the electric capacity, the rotational speed, the temperature at several different spots, the gearbox, the generator and the outside temperature
- Sensor to measure the hydraulic pressure
- Acceleration absorber to investigate the moves of the nacelle

Anemometer and Wind speed measuring device

In most cases, cup anemometers are used as anemometers, in some cases it can be ultrasonic anemometers as well. The wind speed measuring device is usually the classical wind flag combined with an ultrasonic anemometer or, sometimes, an ultrasonic sensor.

The proper operation of both sensors is regularly tested by the control system as these measuring values are of enormous importance. If the wind flag fails, the plant cannot react on changes of the wind direction. The yaw system is not activated, the blades remain in an angle of incidence and thus, unintentionally high loads occur.

If the anemometer fails, overload and, worst case, destruction of the wind energy converter might happen at wind speeds that exceed the shutdown limit. In case one of the two problems occurs, the control system of the WEC has to record this as an error and report it so that repair work can be started immediately.

Please note! Anemometer and wind flag might freeze in cold regions if they are not heated appropriately. After this has been done, the wind energy should only be started after its serviceability has been re-established again.

Sensor for rotational speed monitoring

With this sensor, critical overspeed can be recognized. If such an overspeed occurs, the rotor will be braked and brought into a safe operation mode again. A monitoring of the rotational speed is needed for a controlled braking and the recognition of WEC-shutdowns, too.

Sensor for temperature monitoring

To record the temperature of the components which heat up during operation, temperature sensors assembled in appropriate positions are necessary. The most important things are the temperature control at gearbox and generator as a heating can cause a damage of the components here even faster than with others (see chapter „gearbox" as well). High temperatures at the generator might damage the insulation and, possibly, cause a short circuit. In addition, the lubrication grease inside the generator bearing might get liquefied and run out of the bearings.

Documentation

The documentation papers of the WEC are an indispensable basis for the professional installation, commissioning, operation, maintenance and, if necessary, repair of the turbine. Because of this, you should really pay attention that the following documents are available and complete when buying the WEC:

- Operation manual of the WEC and the control system
- Service and maintenance manual
- Assembly instruction (for hall assembly and installation, with the corresponding records)
- Commissioning instruction (with commissioning records)
- Circuit diagrams
- Type test
- Technical drawings

Operation manual of the WEC and control system

Here, the operation of the wind energy converter is explained in detail. Absolutely essential are information about the turbine safety, the operation of the plan in general and in certain (emergency) situations and a detailed description of the control software. Nowadays, many plants can be monitored from the distance: Take care that you get not only the necessary technical requirements for such a remote control (software, where appropriate with special devices) but also the corresponding operation manuals.

Service and maintenance manual

The maintenance manual should describe in detail which maintenances have to be carried out at what time and which working steps have to be executed at every single maintenance - after all the assigned mechanics have to execute the service and maintenance work based on this documents. In most cases, a record pattern or check list belongs to this manual: it lists all necessary working steps and has to be „ticked off" by the responsible mechanic. After filling it in, he files this records in the WEC-file which enables to recall without problems when which work was carried out last.

Please note! Pay attention that all information about required consumption materials are provided to you, such as a list of all lubricants and greases with a detailed designation (manufacturer information) of all components and items that have to be exchanged at regular intervals.

Assembly instruction

Some manufacturers differentiate between instructions for the „hall assembly" of the single components and the installation of the wind energy converter on the future site. The installation manual is the most important document for the re-installation of a used wind energy converter, nevertheless both documents should be handed over to you. There will usually be a checklist, record or something similar to document the installation process, too - it has to be filled in, signed and filed in the plant file by the executing mechanic.

Commissioning instruction and commissioning record

Here, all working steps that belong to the proper commissioning of the wind energy converter are described. Therefore, this document is very important for the commissioning of a used wind energy converter as well. It serves as a clear base for possible later discussion in case problems or faults occur as all working steps of the (re-)commissioning are recorded during the execution in the commissioning record. This record has to be signed by all participants and filed in the WEC-file.

Circuit diagram

For every wind energy converter, there are electrical and, if there are hydraulic components, also hydraulic circuit diagrams. They display the structure and operation of the electrical and hydraulic system, which is needed for maintenance and possibly occurring repair work. Because of this, pay attention that they are complete when buying a wind energy converter.

Type tests

The type test expires with the disassembly of the wind energy converter. Because of this, the extent and type of the new type test has to be agreed with the responsible approving authority at the location prior to every re-installation. In certain circumstances, a simplified permission procedure can be used, where only the fail-safety of the wind energy converter has to be proven.

Technical drawings

In general, no technical drawings of the components are delivered with the wind energy converter. But overview drawings of the WEC with a determination of every component should be available in any case.

Disassembly and transport of used wind energy converters

The influence of the differing designs and versions on transport and assembly

The different design characteristics of the different WEC designs require partly very individual solutions for transport and assembly.

For many versions, corresponding special devices have been developed:

- Transport devices for blades, hub, nacelle and tower segments
- Fixing devices for the main frame
- Crane crossbeams to hinge the fixing devices of the nacelle
- Fixing devices for every tower segment
- Devices for an assembly of the tower cables

Some wind energy converters need devices for craning the hub or the completely assembled rotor.

The assembly of a lattice tower requires totally different assembly procedures and periods than the installation of a conical steel tower. Possible tower versions are:

- Anchored steel mast
- Anchored lattice mast
- Lattice tower
- Conical steel tower
- Concrete tower consisting of segments

- Concrete tower cast at the construction site („site concrete”)
- Mixing variants of concrete and steel tube
- Conical steel towers on three legs

There are, among others, the following options for a rotor assembly:

- Assembly as „a star”: all three blades are assembled to the hub already on the ground. The rotor as a whole unit is lifted by the crane and assembled to the already-set nacelle (the easiest option for two-blade rotors)
- Single blade assembly at hub height: all three blades are lifted separately by the crane and assembled to the already-assembled hub
- Two blades are pre-assembled on the ground in V-position, the third blade is lifted with the crane separately afterwards and assembled to the already-assembled hub.

The following chapters describe some typical variants and conditions of the disassembly, transport and assembly of wind energy converters with three-blade rotors.

Availability of information and devices

Not only many different special devices but also special knowledge about the course of work will be needed for the disassembly, transport and assembly of a wind energy converter. If you do not plan to assign the manufacturer to carry out this project, it can be difficult to get all required information and tools, for various reasons.

Some of the older plant types face the problem that the manufacturer disappeared from the market due to insolvency or sale. In case of insolvency, documents as manuals, instructions and devices might get lost within the liquidation turmoil. If you are lucky, the essential documents could be found via the insolvency administrator, responsible for the sale of the assets and for archiving documents.

If the manufacturer was integrated into another company, it depends mainly on the new owner how he deals with the needs and requests of former customers. As the service for small turbines is not very profitable, this field is often neglected: the devices are rotten, the documents cannot be found. If the manufacturer is not assigned with the disassembly and assembly it is absolutely possible that he refuses any co-operation

For several plants installed in the 1990s, only carelessly kept documentation exists. The assemblies were managed by team members who's expert knowledge had never been recorded. In such a case it is essential to hire experienced persons that were involved into the installations.

If the required information can be obtained, it should be checked for safety reasons whether they fit with the purchased wind energy converter. Is the information valid for this version in general or does this wind energy converter have special peculiarities? With prototypes or series that were multiply changed during re-designs or where components from different manufacturers were assembled, larger deviations between documentation and construction might occur.

In case these information cannot be obtained, it should be clarified whether there is a service company that has experiences with this design.

If no transport and assembly devices are available, they can be designed newly by experienced design engineering offices and manufactured by mechanics.

Organisational matters

Regarding the working steps required for the installation and disassembly, the differences between smaller and larger wind energy converters are quite small. But in most cases, the larger plants are younger and, thus, have a higher technological standard. They are documented more detailed and much better and have special solutions for the installation and disassembly of the construction.

Please note! The weight of the WEC does not increase proportionately with the performance. The handling of the components becomes more difficult, the logistic aspects such as the rent and provision of large cranes are more problematic.

Not all assembly work can be carried out by every team member:

- Blastings of concrete towers must only be carried out by specialised companies. Lavish blocks and safety measures are necessary.
- The disconnection of the transformer from the grid has to be executed by a trained technician who has a medium voltage switching authorisation.
- For the disconnection of the transformer and all other work at the medium-voltage sided ground cables, the medium voltage cables of the wind energy converter have to be activated by the power authorities.

Disassembly of wind energy converters

Required information for the disassembly

Surroundings
Before cranes can be transported and installed, it has to be ensured that such vehicles can operate on the territory and where the heavy load bearing areas for the cranes are located. The gravelled areas were dismantled in some WEC sites and have to be constructed newly.

Is the access road for cranes, accompanying and transport vehicles that was used during the installation of the wind turbine, still accessible? New routings, new buildings, water courses, electrical transmission lines and other things might have occurred that might restrict the access.
The dimensions, weights and balance of all items that have to be carried by the crane and a low-loading truck are relevant for many aspects of the disassembly:

- Selection of the roads and bridges that have to be cruised
- Load-bearing capacity and arrangement of the cranes
- Selection of the fixing devices
- Load-bearing capacity of the transport vehicles
- Organisation of the loading with the interim storage etc.

Rotor
Is the rotor disassembled „as a star", i.e. all three blades still connected to the hub, or is each blade disassembled separately at hub height?
In general, the disassembly of the rotor should be agreed with the manufacturer of the wind turbine or the rotor blades under any circumstances - this will ensure that no breaking of the rotorblade rear edges or blade tips will occur. Special attention has to be turned to the suspension of the entire rotor and the fixation of the sheets and the crane loop of the auxiliary crane at the blade tip (during disassembly of the rotorblades together with the hubs, i.e. as a „star") or the loops (for single blade disassemblies).

Blade of wind energy converters are, despite of their huge dimensions and high weight (some blade types weigh more than 10 tons) aerodynamically very sensitive components, that might make unpredictable, aggressive moves even at lower gusts. In addition, their edges and surfaces can be damaged very easily. Therefore, rotorblades should be treated with maximum care.

Please note! If accidents occur during the craning of the blades, this causes most probably damages with human beings, machines and material involved!

Nacelle

The nacelle has to hang horizontally at the crane hook otherwise problems might occur when positioning it above the fixation holes to put it on the transport devices. Therefore, special spots have been determined where the nacelle has to be fixed - this ensures that every involved fixing device carries about the same load and that the nacelle balance is located directly below the crane hook. Different from work in the manufacturing hall and the installation, there is hardly an opportunity to equilibrate the nacelle while disassembling the plant.

Please note! As soon as the connection screws have been loosened, the nacelle must not be entered for shortening or moving the fixing devices

The following questions have to be answered prior to the disassembly:

- Where are the fixing points of the nacelle located?
- Are there more than one construction variants of this wind energy converter? Which fixing point fits for the plant to be disassembled?
- Are there single, heavy components to be disassembled and craned separately and prior to reduce the weight of the nacelle and to keep the balance? Have, for instance, the tower cable, bolts and tools been stored in the nacelle and, thus, been part of the balance?
- Are there special devices (such as stay bolts to be screwed in with eyebolts or crane lugs to be assembled) required for fixing?
- Do components block the way inside the nacelle and have to be disassembled prior to the craning or protected by special devices?
- Has the nacelle lid to be removed for fixing the crane load attachment rigging?

Tower

The different tower types require very different ways of disassembling. Apart from the main question what tower has to be taken apart, the following general questions have to be solved:

- What fixing devices are required?
- How are these fixing devices to be assembled (tightening torques of the bolts etc.)?
- Are there special crossbeams for the crane needed?
- Are there footing, at-grade areas on the territory next to the wind energy converter where the tower segments can be stored intermediately?

- Are there possibilities to provide the transport vehicles in the required order next to the wind energy converter for loading?
- Are there assembly components that has to be loosened prior to the disassembly or that has to be removed?
- Is the personal safety system inside the tower operating during the disassembly, too?

Dangerous aspects
The aspect that can be hardly judged during the assembly work is the weather. The best conditions (calm, 20°C and a cloudy sky) occur quite seldom on wind turbine sites. Wind speeds and wind directions forecasted for the day of disassembly are influenced by local daily curves, thunderstorms, rain fronts, geographical peculiarities of the region and various other things.

Please note! Crane work should never be carried out „in a rush" in advance of a thunderstorm or shower of rain. Delays have always to be expected - in case of doubt the work should be postponed several hours for safety's sake.

A particularly critical point during the disassembly has arrived when the rotor has to be loosened and put down. The long blades cannot always be kept safely by the ground team. In case the rotor or single blades start to swing back and forth due to the wind, a collision with the nacelle, the tower or the crane jib might occur easily.

The crew is very much in danger while preparing to put the blades down at the transport devices: An horizontally swinging rotor with a dead weight of 30 tons cannot be stopped by a human being.

Please note! At certain wind turbines the climbing safety devices become unserviceable when the tower is disassembled. For this, alternative safety measures have to be taken. They should be carried out by the team members under any circumstances.

With older wind energy converters, the manufacturer information on weights and centres of gravity edited in the documentation are not in accordance with reality. The crane operator, supported by the assembly team, should slowly grope his way towards the real values with every component to be carried by the crane. The measured weights and the determined working steps have to be documented for the later installation or re-installation.

Boltings
Inform yourself in advance about the pick-ups of all relevant boltings to ensure that the appropriate tools are available when loosening the boltings.

Corrosion

Rotten boltings are one major problem during the assembly of older plants. If, for example, the hub and the centering ring of the shaft flange are connected with each other by corrosion, it can be a very time-consuming procedure and cause high crane and personal costs to pull the hub away from the spigot. It may take hours or even days to get additional tools or to develop alternative solutions. The assembly team, the transport vehicles and the cranes remain available but have to wait inactively until the work can be continued.

Required auxiliaries for the disassembly

The following auxiliary devices are particularly required for the disassembly of the WEC:

- Tools, especially electrical or hydraulic power wrenches and hammers to loosening the boltings
- Current supply via the grid or an emergency power supply
- Walkietalkies with spare accumulators for construction site manager, the crane operator, the working teams (3 ground teams and one team at the hub to release the rotor maximum)
- Long ropes that can be grasped very well to move the crane cargo
- Main crane and auxiliary crane
- Lorries
- Transport devices for tower segments, nacelle, hub and blades
- Covers for tower segments, nacelle, control cabinets, transformers, hub and blades
- Sanitation

Main crane

As a rough empirical formula, the following can be estimated: The lifting capacity of the crane has to be twenty times as high as the heaviest component to be carried. This means that for a nacelle that weighs about 20 tons a crane with a lifting capacity of about 400 tons has to be taken into consideration. This value might vary depending on the crane type and hub height.

Please note! The maximum hook height of the crane has to exceed the hub height for several metres: The crane stands a few metres, mostly one or two metres deeper as well. In addition, the crane jib shows not directly upwards but has to reach, coming diagonally from the front, behind the crane's centre of gravity.

Auxiliary crane

The auxiliary crane is needed for putting down the tower segments and the rotor on the ground or for disassembling the rotorblades. Such a crane will be available at the site any-way if the main crane is not able to transfer the counter weights. The auxiliary crane has to be able to carry at least half of the weight of the heaviest tower segment. The hook height depends on the task it has to fulfil.

In some cases, auxiliary drives are required for the disassembly of single blades to relocate the rotor. With other turbine types, only the rotorblade showing downwards will be disassembled with a special device, the nacelle will be brought down together with the two remaining blades.

General course of disassembly

Preparation of the wind energy converter

In advance of the disassembly, some preparations have to be made. Areas which are heavily polluted with hydraulic oil and bearing grease have to be cleaned in some of the plants so far that an operation of heavy devices will become possible at all.

Crane time costs money. Therefore, the following preparation work should be finished prior to the beginning of the crane work:

- Providing and mounting the needed fixing devices inside the nacelle or inside the hub
- Disassembly of disturbing component groups
- Disassembly of the tower cables (in case the generator will not be used to turn the rotor)
- Saving the control cabinets, onboard crane, loose items or devices
- Removing all oil leakages inside the nacelle
- Cleaning the hub interior from all grease and oil films
- Setting a temporary power supply fort he control and the drive engines of the wind energy converter

Disassembly of the entire rotor as one unit

With this variant, the rotor will be disassembled „as a star”, i.e. with blades that are still assembled to the hub.

Both cranes and the transport devices of the hub have to be arranged in a way that all three blades can be reached by the cranes from any side after the rotor has been laid on the ground.

The rotor has to be brought into V-position (one blade directing downwards, the two other blades towards upper right and left) and to be locked.

The staff standing inside a man basket has to fix the ropes at the end of all three blades (minimum length: 2,5times longer than hub height). A crane slope should be attached to the blade that directs downwards in addition.
The sensitive rear edges of the blades have to be equipped with a special edge protection.

The blades of the wind energy converter have to be pitched so far that the rear edge shows sideward or, the perfect position, towards the front. Otherwise it won't be possible to put down the entire rotor as the rear blade edges reach much further then the bearing surface of the hub.

All hydraulic and electric components and all items that might cause a hooking of the hanging rotor with the nacelle cover have to be loosened.

For this, two loops are put around the blade roots of the rotorblades that show upwards and hinged into the crane hooks. There are turbine types where the hub is equipped with a special device for hinging the crane harness.

The crane operator loads the crane hook with a load as high as the dead weight of the entire rotor.

The boltings of shaft flange and hub are loosened for several millimetres. Afterwards, the hub is cautiously pulled away, using the threads inside the shaft flange intended for that or other technical devices (generally, the shaft step is 30 to 60 mm long). By then the rotor is hanging freely at the crane hook.

Please note! Move the rotor away from the nacelle immediately and slew it towards the side - at any time a suddenly occurring gust might make it swing so much that it hits the crane jib or the tower.

The work of the ground team dealing with the three ropes at the blade ends requires experience, it has to adjust the rotor and protect against swinging. The ropes of the swinging component must be pulled only as long as the fixation end moves backwards. If you still pull after reversing the motion, energy will be given into the system, the swinging will be accelerated instead of absorbed. The co-ordination among the team members who stand far away from each other has do be done perfectly, preferably by an experienced member who is standing near the crane operator. The tow bar of the service vehicles may be used for holding the ropes.

Please note! A rotor that is hanging on a crane rope might develop an enormous tensile force even in minor gusts!

Lowering the rotor
The rotor will be lowered until the blade directing downwards hangs shortly above the ground. The hook of the auxiliary crane is attached to the additional loop.

Now, the main crane lowers the rotor while the auxiliary crane keeps the blade tip on a constant level of height. Both cranes have to be co-ordinated in a way that both crane ropes hang perpendicularly all the time. The teams standing at the two remaining free blade ends have to protect the rotor further against swinging.

The hub is put down with the flange on the table of the transport device and protected temporarily with some bolts.

Disassembly of the rotorblades
Two blades will be propped with pedestals (devices, pallets or similar) near the blade tip at the spots intended for this. The third blade is hinged with loops around the blade root into the hooks of the main crane and at the relevant spot of the blade end (edge protection!) into the hook of the auxiliary crane.

Both cranes tighten slightly to release the bolting.

Loosen the nuts and adjust the crane so that the blade hangs at the blade flange. Only then, the nuts can be removed and the blade slewed away. The bearing surface of the blade root should be lined with carpets or tarpaulin, the blade root has to be propped with pallets or something similar at the well-known spots. For some transport devices it is recommendable to disassemble the blades even by now.

Proceed with the two other blades correspondingly.

Screw the hub tightly towards the transport device and seal it at the openings of the blade bearing, the front holes etc. with tarpaulins.

Disassembly of single blades
This way of disassembly can only be executed with wind turbines that have an appropriately designed drive train and correspondingly strong locking devices for the rotor.
The two cranes have to be installed in a way that the main crane is able to reach the blade root and the auxiliary crane the blade tip of the blade in assembly position.

An auxiliary drive should be assembled to the drive train, if necessary. This auxiliary drive is designed to turn the rotor after the disassembly of the first and the second blade safely into the right position to disassemble the next blade.

One tightening crane loop is put around the blade root of the blade to be disassembled, starting from the nacelle. On this loop again a rope has to be fixed (minimum: double length of the hub height) to protect the blades moves from the ground.

Turn and lock the rotor in a way that the blade to be disassembled is adjusted horizontally.

Operating from a man basket pulled by the main crane, a rope (same length as above) and a crane loop are attached to the blade end. The rear edges have to be protected with a special edge protection. The crane loop has to be attached to the waiting crane hook of the auxiliary crane. The loop at the blade root will be thrown over the hook of the main crane from nacelle direction, after the man basket has been set down.

Both cranes tighten slightly to unload the boltings. Loosen the nuts and adjust the cranes in a way that the blade is hanging on the blade flange. Only then, the nuts can be removed. The blade is slewed away from the nacelle.

Now, the cranes are lowering the blade while keeping it constantly in horizontal position to avoid that it slips out of the loops. Both cranes have to be coordinated in a way that the crane ropes hang perpendicularly all the time.

The bearing surface of the blade root should be lined with tarpaulin or carpet. The blade tip should be propped with pallets or something similar at the well-known points. For some types for transport devices it is recommendable to disassemble them even by now.

Afterwards, the rotor is turned further until the next blade has reached horizontal position. Proceed further as described above until all three blades are stored safely on the ground.

Usually, the hub remains attached to the shaft of the drive train during the disassembly of the nacelle. But in case it shall be disassembled as well and no particular devices have been provided, the hub is hooked to the main crane with a loop that has been thrown through two blade flange openings. An additional loop is located at the opposite end, it is thrown through the front hole and the third opening of the blade flange. All loops are protected against sharp edges. The maximum load of the fixing the devices must not be exceeded.

The crane operator loads the crane hook with a load that corresponds with the dead weight of the hub with all fixed equipment.

The boltings of the shaft flange and the hub are released for several millimetres.

Afterwards, the hub will be pulled away with the help of the thread inside the shaft flanges intended for this or other technical devices.

Move the hub away from the nacelle, slew it sideward and lower it with the crane until the hub is located directly above the ground. The lower, still unused loop is attached to the hook of the auxiliary crane now.

Bring the hub into an upright position so that it can be driven together with the shaft flange over the transport devices and put down there by both cranes together.

Loading the blades

The loading procedure for the blades depends mainly from the construction of the transport devices. If possible, the transport devices of the blade tips and the blade roots should be assembled to the blades when they are still stored on the ground. With a twisted hinging of the loops, the blades are cautiously brought into upright transport position and moved on the lorry by crane.

The disassembly of the nacelle

There are different devices and procedures available for the fixation of the nacelle at the crane hook. Take always care that the nacelle, with its mostly very high centre of gravity, can never slip within the fixing devices. A nacelle that hangs leaning on the crane can hardly be put on the transport devices without larger damages.

A rope (minimum length: double hub height) is fixed to the rear end of the main frame. It allows controlling the turning of the freely hanging nacelle from the ground.

Turn the hub side of the nacelle into the wind. Afterwards, the energy supply of control system and drives can be removed. The crane devices are hooked at the crane hook or crossbeam of the main crane.

The crane operator loads the crane hook with a load as high as the dead weight of the nacelle.

Now, the service team members should loosen the boltings of the tower head and the nacelle until the nacelle can be lifted for about one centimetre. Thus, the crane operator is able to grope towards the real load on the crane.

To screw out the entire bolt, the nacelle will be put tightly on the tower head once again.

Please note! After removing the last bolt, the team members inside the tower head have to rescue themselves to ensure that nobody is injured when the nacelle suddenly turns sideward caused by a gust or a drifted pull occurs.

While it is lowered to the ground by the crane, the nacelle is directed by the members of the ground team with the help of the ropes.

To bring the screw holes of the bottom flange of the nacelle into the right position towards the transport device, threading cones or other long and bending-strong rods can be screwed into some of the screw holes.

The disassembly of the tower

Concrete tower
Depending on the construction type, single component groups attached to the concrete tower can be disassembled prior to the demolition. As the height of the building makes it difficult to crushing with special devices difficult the same applies for cast concrete towers as for those consisting of cemented segments: They have to be blasted.

The residuals that lay on the ground have to be crushed and removed from the site. The ground next to this tower ruins has to have enough bearing capacity that excavators and fully-loaded lorries may drive on it.

Lattice tower
As a principle, lattice towers can be disassembled beam by beam starting at the top of the tower. In practical work, this is not too easy, for safety and working technology reasons.

With smaller lattice towers, it is sufficient to loosen the foundation boltings and to put down the entire tower to the ground with the help of the two cranes. To take it into pieces, a smaller crane can be used only which is much cheaper.

Larger lattice towers have to be brought to the ground segment by segment. To define the separation spots, a detailed knowledge about the former installation process would be very helpful.

Please note! The disassembly of a lattice tower is work and time consuming!

Conical tower
The disassembly of all tower segments is carried out in the same way.

The fixing devices have to be fixed at the upper flange and hooked into the crane hook of the main crane. At the separation spot towards the next segment, all connections such as ladders, climbing protection, cables etc, have to be removed.

Now, the crane operator loads the crane hook with a load as high as the dead weight of the tower segment. Afterwards, the bolts are loosened until the segment is hanging several millimetres above the flange. Only after this, the bolts must be removed!

Please note! Take extreme care when removing the bolts - moves of the hanging tower segment might cause injuries.

Lower the segment until it hangs directly above the ground. Now the fixing devices of the lower flange have to be assembled and hooked to the auxiliary crane. Both cranes bring the tower segment into horizontal position. As far as the tower segment will not simply be stored temporarily on the ground, the transport devices have to be attached in this position.

Repeat this procedure with the other tower segments. When lifting the lowest segment, consider that there are control cabinets or pedestals inside which are loaded for transport at the end of the disassembly.

Please note! A tubular tower without its nacelle on top should not remain standing as a whole, in case the weather conditions get worse. At certain wind speeds, hunting aerodynamic chords occur at the backside of the tower. The aerodynamic forces resulting from this periodic fore and backward trailing at the downwind side can initiate extreme vibrations which might lead to a destruction of the entire building. Thus, the nacelle should either remain on top of the tower or at least the top segment should be dismantled. No anchoring of the tower will not be sufficient. Ask the manufacturer for information about the proceeding under any circumstances when dealing with this topic.

Disassembly of the transformer

With older plants, the medium voltage transformer and switchgears are located inside smaller transformer stations next to the tower bottom. These component groups can be disassembled easily and loaded for transportation with a crane.

Disassembly foundation

The foundations of conical towers are large plates, sometimes additionally buttressed with pilings in softer grounds. The connection between tower and foundation is ensured either by a short tower segment cast into the concrete or by a steel flange on top of the foundation and tension rods that are several metres long and reach deeply into the foundation. In addition, there are one or more layers of concrete reinforcement with a total length of several hundred metres.

In general, foundations cannot be moved to another construction site. If the building regulations or the contracts require to remove the socket and the residuals of the transformer station, this is mostly connected with filling up the empty pit, dismantling the construction road and the crane site, both able to carry heavy loads, as well as re-naturing the construction site

Foundations of wind energy converters of the power class around 500 kW have got an edge length of more than 10 metres, thicknesses around 2 metres and a weight of more than 500 tons - this mass has to be crushed and transported away for the required removal.

Recovery of earth cables
Depending on the contract situation, the earth cables up to the next junction have to be recovered out of the ground as well.

Recycling of components that are not used for the re-installation, disposal
Some projects are not suitable for a recycling of all transportable components. Therefore, it should be considered, for instance, whether a new construction of the tower is even cheaper. In case the used wind energy converter shall be installed some thousand kilometres away, it can indeed make sense to bring only the technologically high-grades components there.

The non-used residuals of a wind energy converter that has been disassembled for reconstruction have to be disposed of and incur costs. Alternatively they can be sold as used components to a dealer or to another operator or sold as scrap to a scrap dealer. For wind turbines that experienced an average before, it is possible that a repair of the components is not worth it - here, items have to be disposed of as well. The removal of the residuals to a disposal company or a scrap dealer has to be carried out by the WEC owner.

Please note! High-solid preloaded bolts must not be used again as their physical properties cannot be guaranteed anymore. These bolts have to be replaced and treated like scrap.

„Second-hand component market"
As a principle, everything can be sold second-hand that can be taken away from the construction site without destroying it. The problem is to find a purchaser and, until he has been found, to store the components so that they do not lose their market-value and do not cause storage costs higher than the price to be achieved.

How to find potential purchasers for single used components:

- Some component manufacturers buy their own products back and offer them by themselves after an overhaul.

- The same applies for repair companies. Especially blades, gearboxes, generators and drive technology can be used again after an overhaul carried out by an expert.
- Service companies from the wind energy branch might be interested in special components to keep them in stock as spare parts.
- Single manufacturers keep reference lists of all installation sites of turbines of the same type. These lists can be useful to determine owners of the same type of wind turbine that might be interested in these components.
- There are several second-hand turbine markets to be found in the internet.

Material disposal incurring costs or cost-free

With a disposal of the following materials, not only transport costs have to be paid but also the disposal itself:

- Concrete scrap from foundation and transformer station, from the tower
- Glass-fibre reinforced plastics from the blades, hub cover, nacelle cover, insulation matting
- Electronic scrap such as control cabinets, light fitting, computers and monitors

Valuable materials

These residuals could be sold with a good profit. The prices that can be achieved depend on the fluctuations in the exchange of metal stocks and can differ a lot within shortest periods of time. In any case, offers from several dealers should be inquired.

Valuable and available to a greater extent in wind energy converters are steel scrap from the tower and the machine components as well as copper from the cables. In 2004, about 100 Euros were paid per ton of steel, for cable copper about 2000 Euros per ton.

Transport of used wind energy converters

Restrictions in connection with the transport

Apart from the above-mentioned general transport conditions within the direct environment of the wind turbine (bearing capacity of the access roads and bridges, minimum headroom etc.) there are various restrictions for the heavy goods vehicle traffic that might influence planning and costs:

- Weekend ban on driving
- Special regulations during holiday seasons
- Bans on driving in the daytime

- Roads closed for heavy goods vehicle traffic
- Special roads for very wide transports
- Required escort vehicles
- Queue times at customs when crossing national borders

Truckage companies are familiar with all current general conditions and regulations and, thus, should be integrated into the scheduling in an early stage.

Component transport

All larger components of the wind energy converter are stored on special devices connected to the loading space of the lorry with straps or boltings during the transport.

Blades

The blades of smaller wind energy converters with a blade root diameter less than about one metre can be stored in a threesome on one lorry in most cases. With larger rotorblades it has to be estimated whether the dimensions in loaded condition allow a storage of two blades on the same loading space or a separate transport vehicle is needed for every single blade due to a necessary tilting of the blade.

If the blades are protected with cargo straps attached to the loading area, the loaded rear edges have essentially to be equipped with edge protection against breaking. With wind turbines that have blade tip brakes, the periscope segments have to be transported separately or have to be protected against unintended moves. The openings at the blade root should be protected with tarpaulins against water or dirt..

Nacelle

The nacelle is fixed to a supporting frame with some bolts. The total height of the transport should not exceed the normal headroom. For some plant types the height can be reduced by removing the nacelle cover. In this case, admittedly, the cover needs to be transported separately.

Protect the nacelle against a twisting of the yaw bearing - an tilting of the nacelle would make the lorry turn over inevitably.
The nacelle should be protected against water and dirt as well to prevent the electronics and the mechanical components from getting damaged. The sensitive control cabinets that cannot be heated during transport and provision at the construction site have to protected against moisture with thick tarpaulins.

Hub
If the hub cannot be transported connected to the nacelle, it has to be loaded attached to an own supporting frame. In both cases, the hub has to be protected against moisture and dirt as well.

The best way to do this is to cover the hub entirely and including all cases with tarpaulins. Special protection is needed for the electronic components and the blade bearings, where rainwater might get into the runways.

Towers
In general, mass and dimensions of the tower segments of conical steel towers are designed regarding their transportability and craneability during the development and design period. The segments are designed in a way that one transport vehicle is needed for every component.
If the segments are covered during the transport, this reduces the cleaning effort prior to the re-installation of the wind turbine.

Dismantled lattice towers can be transported easier due to their much smaller volume - the amount of needed vehicles depends on the permitted total weight. Take care that the corrosion protection of the single profiles remains undamaged during loading and transport.

Please note! All movable items such as the hatch cover have to be protected against moving or transported separately as the other dismantled items as well.

Additional remarks

The control cabinets of the tower bottom and the transformer station and the transformers itself have to be transported in closed-up lorries. A complete covering of the cabinets with tarpaulins is recommended.

All dismantled platforms, measuring masts, hatch covers or tower doors and all additional items have also to be loaded into one lorry.

The re-installation of the wind energy converter

The descriptions in the following chapter are based on the assumption, that the majority of the required tools and information for a re-installation are available. If the project developer organised the disassembly by himself, he has own experiences with the topic. The installation of a wind energy converter purchased in disassembled condition, should be based on the experiences and devices of the company that carried out the disassembly. In addition it can be assumed that the medium voltage cable has already been wired up to the connection point.

Required information for the installation

In addition to the information and general conditions that were described in chapter „Disassembly of wind energy converters", the following has to be considered for the installation of the plant:

- Working drawings have to be available for all newly manufactured components and items.
- All newly manufactured items and buildings have to correspond with the type certificate of the wind energy converter regarding material, dimensions and manufacturing. Without valid permission, no other designs of the foundation, tower and blades must be used.
- The characteristic values of the ground have to keep within the limits defined by the type test, which has to be verified by a soil expertise.
- The construction site must be accessible for all vehicles.
- The construction site must be prepared to carry the loads of transport vehicles and cra-

nes by solidifying and covering with gravel.

- High solid-galvanized bolts must not be re-used. Only new ones must be used which were ordered as sets which means that the bolts were delivered with washers and nuts. Never mix different charges!
- Torques are needed for all component joints with boltings. The sources for these information are mainly the manufacturer, possibly the manuals, inspection reports or expertises of the plant as well.
- Pick-up regulations for the boltings of tower, hub, blades and nacelle have to followed necessarily. For this, the bolts have to be fastened in the right order, the torque levels during the different phases have to be considered as well as the lubrication status of the threads.
- Ask the manufacturer for the provisional torques during the assembly, too. Thus, for instance the tower bolts are only tightened up to the required torque after the installation of the WEC.
- A proper operation of the safety devices for personal safety has to be ensured at any time during the installation of the tower.

General course of the assembly

Preparation of the wind turbine

The following preparatory work have to be carried out prior to the assembly:

- Place the stay bolts with a template if this type of connection to the foundation is intended.
- Provide and assemble the required fixing devices of the nacelle, the tower segments and the blades.
- Place the bolts where they will be needed later. The tower bolts, for example, could be packed into bags and fixed on stable spots with tightening straps and, thus, be available on every single platform. This will save several crane procedures later.
- Protect the control cabinet, on-board crane, loose items, tightening straps etc.
- Prepare the temporary power supply for the control and the drive engines of the wind energy converter

Please note! Crane operation time is expensive. That is way all preparatory work should be finished before starting it.

Installation of the foundation

The foundation has to be installed at an early stage. Concrete needs time to mature until its final stability. A period of several weeks has to be planned for this, which depends on the temperatures during the maturing period and partly on the additions to the concrete.

Please note! Items that shall be moulded into the foundation have to be on the construction site several weeks prior to the installation of the wind energy converter. This means, for instance, that the flanges of the towers and the foundation have to be delivered to the tower manufacturer long before the manufacturing of the segments.

If stay bolts shall be moulded into the foundation for the connection between the foundation and the first tower segment, an extra day should be planned to level the thread bars exceeding form the foundation (using templates) and to clean the flange.

The installation of the transformer station

Under certain condition, a small transformer station has to be built next to the tower bottom for the medium voltage transformers and switching devices. For this, local norms have to be followed. Standard components, available at specialist suppliers, can be used for the transformer station.

Special attention has to be drawn to the cable entry into the transformer station and into the tower: these openings have to be waterproof and inaccessible for animals to avoid inundations or scuff mark from rats etc.

The installation of the tower

Concrete tower

Concrete towers have to be either cast with a timbering that comes along upwards or assembled of pre-manufactured segments which are pre-tensioned with steel ropes laid along the tower wall and bonded at the connection points.

Lattice tower

Lattice towers are pre-assembled on the ground and then, depending on their height, erected with a crane completely or segment by segment.

Conical tower

As during the disassembly, the processes are the same of every tower segment with this tower type. The fixing devices have to be attached to the top flange and to the lowest flange and hooked to the cranes. Both cranes lift the tower from the transport vehicle together. The transport devices are disassembled after the segment is hanging directly above the ground.

Both cranes bring the tower segment into horizontal position directly above the ground. The devices at the bottom of the component have to be disassembled while the tower segment is still hanging at the main crane.

When the segment is hanging above the foundation flange, either the stay bolts of the foundation have to be threaded into the holes or, if a single component moulded into the foundation is used, the bolts are plugged from the top through the two flanges. The latter should be done preferably at a tower segment hanging directly above the connection. The manufacturing tolerances amount to about one millimetre. Thus, even a slight displacement of the fully rested segment might cause that a number of bolts cannot be plugged into the congruently positioned holes.

Please note! It is not allowed to hammer the bolts through the holes - the threads of the bolts are not designed for this.

After the bolts are tightened temporarily with a power wrench, the upper fixation tools can be unscrewed and lowered to the ground with the crane. This procedure is repeated with the other tower segments. Take care that the ends of the ladder are meeting each other appropriately

Assembly of the nacelle

The nacelle with the fixing devices is hooked to the crane. A long rope is attached to the rear end of the main frame. It allows to control rotations of the freely hanging nacelle from the ground.

The bolts towards the transport device have to be loosened.

The crane operator pulls the crane hook until the nacelle hangs several millimetres above the ground. It has to be checked whether the nacelle hangs horizontally or its position has to be adjusted. Thread cones and other auxiliary devices for positioning the nacelle on the tower head flange can be assembled after lifting the nacelle further.

While lifted by the crane, the nacelle is guided by members of the ground team with the help of ropes.
All bolts should be screwed into the bearing ring when the nacelle is still hanging some millimetres above the tower flange. The nacelle should be set down only after. All boltings have to be tightened.

Assembly work at the rotor: Assembling the entire rotor as whole

Position the two cranes and the nacelle in its transport devices in a way that all three blades of the rotor laying on the ground can be easily reached by the cranes from all sides.

The pitching devices of the blades inside the hub have to be in a position that allows an assembly with the rear blade edges showing sidewards or to the front.

The blade is hooked to the main crane via the loops hinged around the blade root and hooked to the auxiliary crane at the relevant spot of the blade end (edge protection!). After that, it can be lifted.

After disassembling the transport devices, it is moved in horizontal position towards the hub which is attached to the transport device and threaded into the boreholes of the blade bearing.

Tighten the nuts temporarily with a torque below the final value (to be taken from the assembly or maintenance manual of the WEC).

After propping the blade tips with pallets (or something similar) at the well-know spots, the straps are removed from the crane hook and assembled to the next blade.

If not special devices are available, two loops are put around the blade roots of two blades and hooked to the crane after the pre-assembly of the rotor.

Please note! If there is only one rotor position that enables to enter the internal space of the hub, this position has to be reached after assembling the rotor.

Long guide ropes have to be attached to all three blade ends. In addition, a crane loop has to be assembled to the blade showing downwards. This crane loop has to be hooked to the auxiliary crane. The sensitive rear edges of the blades have to be protected with special edge protection as usual.

With the help of the two cranes, the rotor is lifted for several metres. Afterwards, only the main crane lifts the rotor further. The auxiliary crane keeps the height of the blade tip and readjusts the position until the rotor is hanging in horizontal position. Three ground teams guide the rotor with ropes over the entire craning process.

On top of the shaft flange, the crane has to push the hub over the shaft level until the bolts can be plugged in. The hub must not bend out of line and the centering must not be damaged! Long thread rods or thread cones can be used as aid.

After tightening the boltings between hub and shaft flange temporarily, the loops can be removed. Now, the electric and hydraulic connections of the hub can be connected. The final torque can be applied to the boltings.

The boltings of the blade pins with the blade bearings can only be brought to the final torque when the rotor of the wind energy converter can be operated via the control system.

Please note! To tighten the nuts, the corresponding blade has to hang downwards. The relevant guidelines have to be inquired at the blade manufacturer and have to be followed under any circumstances!

Assembly work at the rotor: the assembly of single blades

The two cranes have to be positioned in a way that both the main crane and the auxiliary crane can reach the blade root and the blade tip and can lift the blade until hub height in horizontal position.
If necessary, it is required to assemble an auxiliary drive to the drive train.

The hub has to be brought into a position where the blade can be assembled horizontally, still hanging on the cranes and locked there.

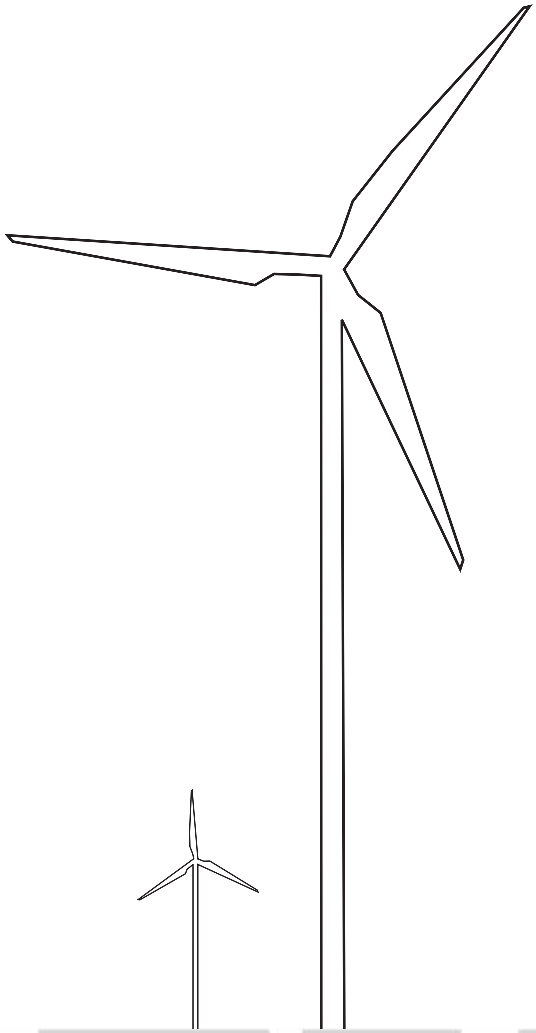
Tightening crane loops are hinged around the blade root and the blade tip of the assembled blade. Both loops are attached to long ropes for saving them from the ground.

The loop of the blade root is hooked to the main crane, the loop at the blade tip to the auxiliary crane. For an assembly to wind energy converters without pitching devices, the blade has to be positioned in the loop according to the its later position during plant operation. A later correction of incorrectly assembled blades cannot be done without cranes.

Now, the cranes lift the blade until hub height while keeping it permanently in horizontal position to avoid that it slips out of the loops. Both cranes have to be coordinated so that the crane ropes are hanging perpendicularly all the time. Two ground teams have to protect the entire craning procedure with ropes.

The blade bolts are threaded into the boreholes of the blade bearing, the nuts are tightened temporarily with a torque that remains below the final value. The loops, edge protection and guide ropes have to be retrieved using a man basket.

Afterwards, the rotor can be turned further until the next blade flange has reached the required position. Then, the blades are preassembled to the hub as described above. The boltings of the blade pins with the blade bearings are only brought to the final torque when the wind energy converter can be operated via the control system.



Glossary

ActiveStall
With ActiveStall-plants, the blade stall can be controlled actively. For this, the rotor blades is assembled mobile to the rotorhub. The angle of incidence is adjusted via a pitch mechanism according to the wind speed. Meanwhile, the front edge of the rotorblade is turned out of the wind so that the angle of incidence increases.

Wind power
The power of the wind derives from the kinetic energy of the moved air masses. The cinetic energy is proporational towards the air mass that flows along the rotor's area of circle and proportional towards the square of the wind speed.

$$\mathrm{E} = \frac{1}{2}\mathrm{m} \cdot \mathrm{v}^2$$

The airmass is determined by the volume and the density of the air.

$$\mathrm{m} = \rho \cdot \mathrm{V}$$

The volume is determined by the rotor's area of circle and the way covered by the airmass. As the power is considered as energy or work per time unit, the volume flow passing the rotordiameter is considered here.

$$\frac{\mathrm{V}}{\mathrm{t}} = \mathrm{A} \cdot \mathrm{v}$$

$$\mathrm{P} = \frac{1}{2}\rho \cdot \mathrm{v}^3 \cdot \mathrm{A}$$

From this formula it can be seen that the wind speed has the largest influence on the power of the wind energy converter. Thus, the site become the most relevant factor.

Material fatigue
Material fatigue describes the maturing process of a material caused by environmental influences such as mechanical load, temperature or a corrosive medium (see chapter „Corrosion”). During the lifetime of the relevant component, fatigue might cause a failure in serviceability or even a total failure. Because of this, the life time of critical components is evaluated, calculated and even tested in advance to estimate its durability.

Pitch
In this context, the word „pitch” refers to a changeability of the rotor blade stall. Due to this, the airflow effects on the blade profile even at higher wind speeds.

Pitting
Pitting is a very common form of tooth flank fatigue, a material fatigue caused by permanent loading and unloading of the tooth flanks. If the bearable compression of the engaging teeth is exceeded, particles will be released from the tooth flanks. After a correspondingly high number of overruns, pitting-like cavities occur.

Relative motions
Examining two bodies that move with different speed, these bodies have speed towards each other that results from the difference of their absolute speeds as they are to be examined from the outside.

Stall
Blade stall occurs if the angle of incidence of the airflow at the rotorblade becomes too large. The airflow does not run along the blade profile but parts from it. Thus, air vortexes occur and the uplift disappears.

Elastic limit
The elastic limit of a material is the stress (force per area) a material can bear without any plastic (lasting, irreversible) distortion. If the stress remains below the elastic limit, only elastic (reversible) distortions occur. The material returns to its original form after the stress has been released. If the elastic limit is exceeded, plastic distortion occurs that remain there even after the stress-release.

Vortex-Generator

Vortex-generators are small panes (often only about 0,01 m), that are attached to the blade surface. These panes are alternating inclined towards left and right and create a small, turbulent airflow on the blade surface. The distances between the panes have to be kept very carefully to ensure that the turbulent layer suspends precisely at the rear blade edge. It is peculiar that these tiny turbulences prevent a blade stall at lower speeds

The rotorblades of wind energy converters tend to a blade stall near the blade root at lower wind speeds where the profiles are very thick. Because of this, some newer rotorblades have a stripe, about 1 metre long and with vortex generators on it, at the blade inlet side, near the blade root.

Hydrogen embrittlement

Hydrogen embrittlement is caused by the penetration and inclusion of hydrogen in metal. As hydrogen is the lightest and smallest element, it can escape from metal as diffusion comparatively easy. Some of the hydrogen is included in the metal during this process and, thus, extended. The result is an embrittlement of the metal at this spot were the hydrogen has been absorbed into the lattice. Even after the hydrogen escaped from the metal again, a failure in the lattice remains which saps the structure durably. By and by, the metal embrittles that strong that a breaking occurs. This effect resembles the material fatigue process very much.

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