If things can go wrong - they will
Design of Supervisory and Control Systems of Wind Turbines by using FMEA

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Summary
With its fast increasing plant size the wind energy technology has developed into a high-tech industry. However, the statistics of failures and damages indicate that its design, operation, and maintenance cannot be compared for a long time yet to other high-tech products such as from the automotive and aircraft industrial sectors. One step towards this direction is the application of established quality assurance methods in order to optimise the technical availability and the reliability of wind turbines and wind farms. The targeted use of the failure mode and effects analysis (FMEA) can act as a method which can be applied from the design to the operation. It can detect failures and avoid them in advance and can help to reduce the risks during design, construction and operation. This is demonstrated by way of example for a supervisory and control system of a wind turbine.

Impact of erroneous measurements on the operation
In publications and corresponding failure statistics pictures and even videos are frequently shown which suggest the occurrence of faults and damages which could have been avoided by taking reasonable precautions. This may start with harmless malfunctions and often ends with the total loss of components or even the whole turbine. With increasing sizes of the wind turbines and keeping up the "try and error" principle during the design, erection, and operation a high financial risk will arise especially if the source of errors affects a complete mass production. Particularly for offshore plants it is important to detect malfunctions, sensor and software failures, and human errors at a very early stage in order to take preventive measures. If faults and errors occur during test, commissioning and operation, related information and measures have to leave their marks on the redesign of the current model and the new developments. At present some of this information delivered by the maintenance staff still disappears unseen and unvalued in the files. An example will show the necessity of an early detection and analysis of the possibilities of faults of the whole process of the supervisory and control system of a wind turbine. The fault in the example has been monitored at a prototype and some commercial wind turbines. However, it was not possible to screen the data from the measurement systems or from the printout of the control system in all the cases. The related fault has to be investigated if it can result in
damage or in a loss of a component or even the loss of the whole turbine. Furthermore it should be known how long the undetected fault occurred with regard to the loss of production. It should be analysed if the fault could have been detected early by using the available sensors of the turbine. In order to solve the problem or to prevent the recurrence of the fault a catalogue of measures has to be found.

With present-day pitch controlled wind turbines a fault situation may occur if simple sensors fail or faulty signals are misinterpreted by the control system. The occurrence of a yaw error in a pitch controlled wind turbine has been recorded for the first time at the 100 kW turbine of the DLR at the test station "Ulrich Hütter" in the highlands of Southern Germany [1]. The turbine was equipped with a tail rotor at the nacelle which was moved into the right wind direction by a worm gear. During normal and steady changes of the wind direction the tail rotor operated correctly and adjusted the nacelle properly into the wind. With abating winds from the West and subsequently freshening wind from the East, the wind blew along the tail rotor's area and consequently, the nacelle was not turned into the right wind direction. The downwind turbine was changed to an upwind running and - in the position of the so called "waiting mode" - the inflow to the rotor blade cross section came towards the trailing edge. The aerodynamic situation for both cases, the normal and the faulty one – here marked with “situation 2” – are depicted in Fig. 1. Consequently the rotor rotates in the wrong direction and so does the rotor thrust. This relatively simple sensor failure results in a critical situation for the generator if the aerodynamic manages to accelerate the rotor to the synchronisation speed in spite of lower lift to drag ratio of the airfoils.

Tail rotors cannot be found at modern wind turbines any more. The yaw control is managed by sensors at the top of the nacelle and corresponding servo motors. However, the authors could make more than one observation which presumes similar situations at today's wind turbines. One of the cases could be documented by photograph and video sequence as shown in Fig. 2. In order to avoid the faulty situation an internal power curve check or a function check of the sensor can be used. Also doubling the sensor as used in aircraft technology can solve the problem easily. In the situation described above the modern wind turbine converts from an upwind to a downwind machine. The possible consequences are as severe as with the old turbine. The example already shows that many
situations may occur which are not detected automatically by the control system and may generate consecutive faults and damages. An early detection of possible faults is extremely important for offshore plants. The access of these turbines is limited due to the large distance and the mostly rough wind and wave conditions. Especially for those wind farms the technical availability and reliability must be improved considerably.

**Early detection of faults**

A method to detect faults at an early stage is the FMEA for the analysis of systems, failures, and risks. Experience and the knowledge about the coherence of faults and their effects on the quality of products, processes, and systems are documented systematically, completely, and durably by this method. By using the FMEA critical components and weak constructions can be detected at an early stage and thus, the failure connected risks can be reduced sig-
nificantly. Development time and tasks and with it the cost for development and for fault recovery can be reduced too [2]. Starting point for the FMEA is the assumption of a system fault such as a faulty component of a wind turbine. In the subsequent analysis of the fault the possible consequences caused by the fault are identified and their impact and probability of occurrence or detection, respectively, are assessed. In addition, appropriate measures can be taken in order to avoid or to diminish the effect of the failure [3,4]. An overarching team of experts should be significantly involved in the process of the FMEA. This ensures that the experience and the knowledge of all departments concerned contribute to the analysis [3].

In the field of wind energy techniques these could be the departments for design, construction, and operation and maintenance. The technical plant management is very much suited for the application of the FMEA method. This results in a higher occurrence of faults which is proved by statistical evaluations in [6]. In the field of technical management of a wind turbine or a whole wind farm high costs for operation and repair can be reduced. In the following example the design and optimisation of a control system by use of FMEA method is explained by a faulty measurement of the wind inflow on the nacelle.

Design of the supervisory and control system of a wind turbine using FMEA

The basis for the FMEA for a wind turbine is the understanding of all functions and systems of the machine, i.e. a complete system analysis. The supervisory and control system comprises the whole data acquisition system as well as the combined control system. All sensors, the data conversion, the data processing for the control system, from the wind measurement to the monitoring of frequencies, are being analysed. The control system has to take into account all the processes and sub-processes such as normal operation and partial power or full power operation. Various technical modules of the control system are part of the sub-process. In the example shown these are the wind vane at the nacelle to measure the oblique inflow and the drive train to yaw the nacelle. On the other hand the technical modules are affected by the parameters “personnel, environment, techniques, and check method”. For the measurement of the correct yaw position during full power operation the system analysis is depicted in Fig. 3.

On the basis of the system analysis the fault analysis of each of the specific technical modules is performed. Types of faults and errors are defined and the related causes are evaluated on the level of the influencing parameters and their effect on the technical and financial results. During the design of the control system it is important to detect the human and the technical weak points in order to optimise the system. Check functions or the use of a second sensor could help to avoid these faults. The levels of failures considered in Fig. 3 are the technical modules as they deliver erroneous data to the control system which causes a fault operation which leads to a reduction of power production or even to a damage of the turbine. Fig. 4 shows the fault analysis with an error during the measurement of the yaw position.

The concluding risk analysis is then performed by means of the FMEA form. Constitutive to the fault analysis to each possible fault the consequences and the related causes are summarised. The risk assessment is done by defining the parameters probability of occurrence (O), the severity of effect (S), and the probability of detecting (D). So called risk priority numbers (RPN) are allocated by the faults. Corrective measures are then developed for faults with high risk priority numbers. The Fig. 5 shows the risk analysis for the above mentioned example.

**Recommendation and perspective**

Faults with high risk priority numbers should be counteracted by appropriate measures. A damaged wind vane leads to a wrong signal for the yaw position and the rotor is facing in the wrong direction. The rotor could even start with wrong rotational direction and connect the generator to the grid. The results are remarkable losses of production, a damage of a component or even the loss of the whole structure. Small yaw errors can be not detected easily; a strong deviation can be detected by poor production in comparison to neighbour turbines in the farm. However, this is only possible after a certain time period if the operation protocols are checked regularly by the technical staff. For fast and simple error detection a second vane with an interdependent check could be recommended. Furthermore the power versus wind speed function can be checked. A calibration of the nacelle anemometer according to the IEC recommendations for the type of turbine and nacelle is an appropriate tool. Dependent on the control system the power, rotor speed and blade pitch angle versus wind speed at the nacelle can be used for error detection at an early stage. Even existing control systems can be modified and continuously optimised. Most of the sensors and signals needed are already implemented and a modification of the control software for a large number of wind turbines of the same type can be realised at low effort and costs.

**Fig. 6** shows an example of characteristic diagrams with typical tolerance ranges embedded in a control software. Using such information together with external temperature sensors and heated anemometers at the top of the nacelle, icing conditions can be detected rather fast [6]. The method of the FMEA provides not only the possibility to improve the control system and thus the reliability and availability of single wind turbines but also to improve the whole system of an offshore wind energy power plant from single participants to logistic systems [7]. Up to date the FMEA method is only a little used by the industry during design, planning, construction, operation, and maintenance of wind turbines and farms. However, the FMEA method is known as a suitable tool to improve the development of wind turbines, but the few experiences and the suspected high effort are still an obstacle for its implementation. Faults which are methodologically detected in the forefront of commissioning and operation of a wind turbine improve the production of energy and lead to a higher ecological and economical quality.

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**References**

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