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PC Control for wind turbines

Fuzzy controller for improved pitch control

The pitch control of wind turbines is based today on PD or PID controllers. Due to the non-linear behaviour of the turbines, the design of these controllers is usually a very time-consuming affair. The use of fuzzy controllers in future promises a faster and more efficient procedure. Nils Johannsen, who works in the Wind Turbine Application Software Department at the Beckhoff Wind Expertise Centre in Lübeck/Germany, presents an overview of fuzzy pitch control.

Modern wind turbines control the power extracted from the wind by changing the rotor blade angle. The wind generates a lift force at the rotor blades which results in a rotary movement of the rotor. However, from a wind speed of approx. 12 m/s (wind force 6 Bft), the power taken up as a result by the rotor would be larger than the rated output of the wind turbine and must therefore be limited. To this end, the inflow angle of the wind is modified by adjusting the rotor blades, thereby reducing the rotor output. This method of regulating the speed via the blade angle is usually called pitch control. The associated control loop is highly non-linear, primarily as a result of the aerodynamic behavior of the rotor blades. In modern wind turbines, therefore, the PID controller employed is supplemented by filters and further additional functions such as gain scheduling.

In designing the mechanical construction of a wind turbine, the loads acting on the turbine are decisive. They form a spectrum of extreme loads and fatigue loads. The former can be reduced through intelligent operational management, the latter through careful parameterization of the speed controller.

The pre-configuration of the controller parameters takes place as part of the load calculation for a wind turbine. A turbine computer model is subjected to standardized wind profiles in simulation runs. Competing optimization criteria have to be taken into account in the controller design. The optimization process can, therefore, be complex and protracted, since several iteration loops are required before the optimum can be determined. The "optimum" determined in this way is still only a best possible compromise. In addition to this pre-configuration, it is usually necessary to optimize the parameters determined in the simulation during commissioning of the turbine. This process can also be rather complex, since the required wind speeds are not available 'on tap' and, moreover, only occur for a limited period of time, depending on the site.

Characteristics of fuzzy logic

Unlike the PID controllers that are predominantly used today, fuzzy controllers are already non-linear state controllers with a reputation for great robustness. It is known from other applications with similar boundary conditions that the use of fuzzy controllers in highly non-linear systems leads to better control characteristics.

The difficult stability check and the lack of a systematic design procedure are often mentioned as disadvantages of fuzzy controllers. In order to check the stability, a model would be required, which could in turn be used for the adjustment of a PID controller. However, the fuzzy controller needs only an indistinct mathematical model and not a detailed one. In the case of wind turbines the model is always only a reproduction, since the real conditions of the wind, turbulence and aerodynamics can only ever be approximated. Changes in the air density, the rotor blades and the inertia in the drivetrain are already enough to cause great changes in the aerodynamic behavior of the rotor.

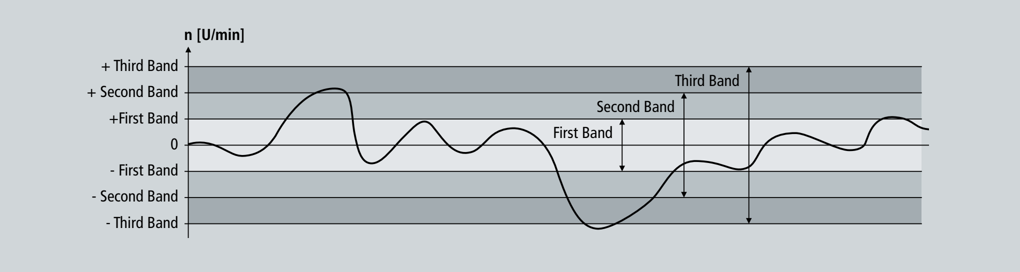
PID controllers are based on the model of the turbine, to which the parameters are oriented. If the model changes, the control quality is automatically reduced. Fuzzy controllers, conversely, are based on rules. Even if the model were to change strongly, the fundamental process would still be the same and the rules would still be fully valid. The control value is calculated on the basis of these rules, for which reason no exact information about the system needs to be available. The controller reflects the human behavior of the expert who designed these rules and enables an individual reaction to each state. As a result, fuzzy controllers are considerably more robust in relation to changes of the turbine, the set-point or faults. In addition, parameterization is considerably simplified, because cognitive, not mathematical knowledge is required.

Motivation: fuzzy controller for the TwinCAT automation suite

Based on these experiences, Beckhoff designed a fuzzy controller for the TwinCAT automation software in order to regulate the pitch and, thus the speed of turbine rotors more effectively. Apart from that, the use of fuzzy controllers for wind turbines is expected to reduce the time and effort involved in designing the controller. Since the understanding of the controller is considerably simplified, the necessary time for optimization can be significantly shortened. Moreover, it should be possible to use a controller for different turbines without modification, irrespective of the rotor diameter or the tower height. Since the fuzzy controller is a multi-variable controller, reaction to various states of the turbine is thus considerably more flexible. However, these advantages only become relevant if the control quality and the energy yield are comparable and the turbine loads are not increased as a result. If on the other hand the loads could be reduced, then the fuzzy controller would prove to be significantly more efficient.

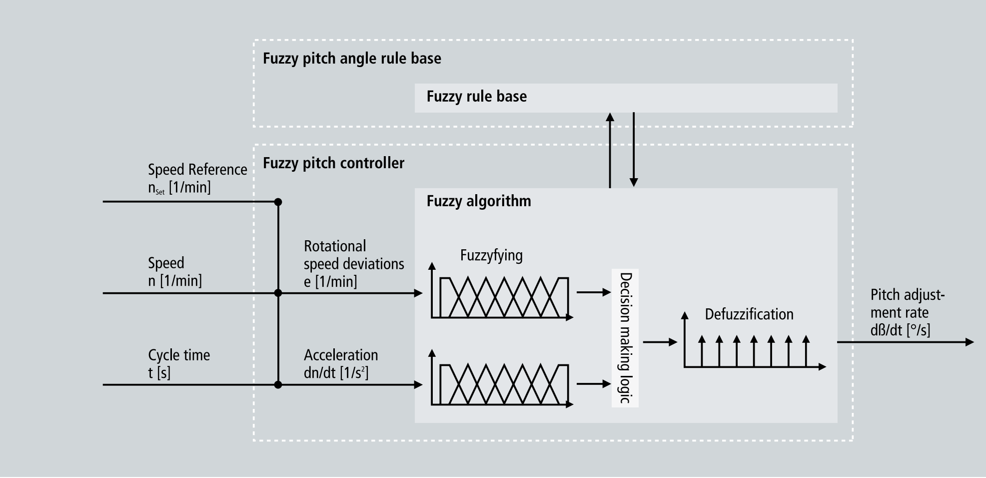
Structure of the pitch controller

In principle, the fuzzy pitch controller for TwinCAT monitors the rotor speed and outputs a pitch adjustment rate. The deviation of the speed from the set value and the acceleration of the rotor are calculated internally. The two inputs are assigned fuzzy quantities, also known as "fuzzification." This assignment takes place via bands placed around the value. A speed deviation of zero would be the center point, a slight deviation would be assigned to the first band and larger deviations to the higher speed band in each case. A total of three bands are used for the respective input, wherein a distinction is made between negative and positive deviations and it is determined whether the value possibly lies outside the defined bands. In turn, three bands are created for the output – the pitch adjustment rate – from a slow rate to the maximum rate of adjustment, in each case positive and negative. The width of these bands is specified via parameters. This produces three parameters for the speed deviation, three for the acceleration and three for the adjustment rate.



The definition of the speed bands

The rules are then evaluated on the basis of these fuzzy quantities or speed bands. A total of 49 rules were created, one for each possible state. These rules are defined on the basis of the assignment to the respective bands of the inputs and to the output used. Processing takes place by means of the so-called decision logic. One rule would be, for example: if the speed deviation is in the first positive band and the acceleration is in the second negative band, then the pitch adjustment rate is set to the first negative rate. A negative pitch adjustment rate would mean turning the rotor blade into the wind and increasing the power coefficient. This rule demonstrates the flexibility of the fuzzy controller. A proportional controller would have stubbornly output a positive adjustment rate in the case of positive speed deviation. However, since the rotor already exhibits a negative acceleration, i.e. the speed is dropping, the rotor would be decelerated further, leading to underspeed and a reduction of the energy yield. The rule of the fuzzy controller, however, deals with the negative acceleration. Instead of reducing the rotor speed further, the controller attempts to work against the acceleration in order to avoid underspeed. The aim is to regulate more specifically toward the nominal speed and to increase the energy yield.



General structure of the fuzzy pitch controller

Weighted outputs are determined and the pitch adjustment rates are calculated by the evaluation of all rules whose conditions are fulfilled. This process is known as "defuzzification." In order to avoid excessively fast changes of the control value, the pitch adjustment rate is additionally smoothed via a first-order filter.

The input quantities, rules and output quantities together represent the knowledge base of the controller. The rules are permanently implemented and cannot be changed, since they ensure the stability of the controller and contain the expert knowledge of the process. The input and output quantities can be changed via the bands and thus adapted to the rotor employed, if necessary. The smaller the speed bands, the stronger the controller reacts. The controller behaves in the same way for the other bands. The knowledge base is thus very simply structured and comprehensible, even for those who are not control technicians.

Practical verification of the controller

The fuzzy controller design from Beckhoff was verified in co-operation with WINDnovation GmbH, based in Berlin, Germany. The fuzzy pitch controller was compared with a conventional PD controller in the BLADED design software from GL Garrad Hassan on the basis of an existing turbine model. WINDnovation had already carried out the complete load calculation and designed the PD controller for this turbine. The results are therefore comparable with one another without reservation. It must be pointed out that several days were required in order to parameterize the PD controller so that the rotor speed could be stably regulated. After that, several more weeks were required in order to determine the optimum control parameters. The fuzzy controller was implemented into this load calculation and used with a standard rule set. The rotor speed was stably regulated immediately and the parameter set was not changed any further for the subsequent load calculations.

The 69 load cases used for the simulation were generated according to the Germanic Lloyd guidelines for the certification of wind turbines and contained wind profiles with wind speeds from 3 to 25 m/s according to wind class IIA. These time series were simulated in each case for the conventional controller and the fuzzy controller, and the control quality, extreme loads and fatigue loads were evaluated and compared with one another.

The control quality was determined by the evaluation of the rotor speed, the electrical power and the pitch adjustment. The average values and deviations from the set values were calculated for all load cases. The results show that the average deviation of the rotor speed from the set value is smaller when the fuzzy controller is used. In addition, the average rotor speed and the electrical power were increased. To this end, the fuzzy controller requires increased activity of the pitch adjustment. The extreme loads achieved comparable values with both controllers. The loads on the rotor blades also correspond. The evaluation of the fatigue loads shows that the loads are reduced when the fuzzy controller is used. Exceptions to this are the loads acting on the tower. The loads on the drive train and the rotor were reduced by an average of 4 % and in some cases even up to 13 %. Despite the increased pitch adjustment, the loads on the hub, rotor blade and blade root were also reduced.

Comparison of the blade angles of the PD and fuzzy controller

Summary and Outlook

The comparison of the load calculations shows that the fuzzy controller delivers comparable and in some cases even better results, although no optimization of the parameters took place. Trial changes to the parameters also prove the robustness of the fuzzy controller. The adjustment of the parameters is simplified due to the understandable knowledge base, and time and effort are substantially reduced. Further optimizations based on the respective turbine would surely lead to further improvements. In summary, it can be said that the fuzzy controller fulfills the expectations, even when the parameters are only broadly configured, and has proven itself to be ideal for pitch control.

In the future, the results must be verified in further load calculations and the controller must work satisfactorily on a real turbine. In addition, there are still further possibilities to extend and optimize the controller. Extension by filters could reduce the loads further. Circumstances could be dealt with and reacted to with foresight by means of the evaluation of additional inputs. Additional outputs could be used to enhance the functionality of the controller and enable greater intervention in the process. Combination with a neural network, also known as a neuro-fuzzy system, would enable automatic optimization of the parameters.

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Product information The fuzzy controller for TwinCAT is only available as application software.