Wind Turbine Control

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Abstract: Control systems are an essential part of mechanical engineering design. In the design and operation of wind turbines good control allows for a maximal cost effective output, whilst always operating the turbine in a safe manner. This report analyses the system control design process and examines a selection control systems available and in common use in modern wind turbines.

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1. Introduction

The need for wind turbine control from the most extreme point of view can be illustrated by the catastrophic outcomes of wind turbines that lose control. Figure 0-1 is a picture of run away wind turbine which was operated in such high wind speeds that the blades bent and contacted the column support, causing them to shattering.

Figure 1-1 Wind turbine self destructs

The report shall divide the topic of control into two main sections supervisory and safety (Manwell et al). The supervisory control is the system responsible for normal changing of operational state i.e. on and off. This contrasts the safety control, which is a distinct system that is designed to be failsafe, and is there to protect the wind turbine from a potentially severe hazard (Burton et al).

Essentially the control system must be able to limit the power that the wind turbine extracts from the wind. The controller must therefore be able to set the torque on the drive shaft in the case of a variable speed wind turbine or for fixed speed operation it must regulate the drive shaft speed. The second objective is to reduce fatigue of components and maximise the power output. For this two aspects of the wind turbine have to be con trolled the yaw and blade rotation speed. The report looks at the closed loop control system used for this.

2. Design of Wind Turbine Supervisory Control System

This section covers the design considerations for each stage of the wind turbine power control system, as described by Nise N.S. (2004).

2.1 Transformation of Requirements into a Physical System: Objectives and Issues

The primary objective of limiting power or rotor speed has already been mentioned. These objectives can be broken down into more precise requirements (Burton et al.).

1. control aerodynamic torque above a threshold wind speed
2. reduce peaks in gearbox torque
3. minimise unnecessary pitching
4. minimize tower vibration and
5. hub and blade root loads

Further design specifications include transient response time and steady state error. For good control of power the error margin must be small. However this error margin can only be reduced so far before pitch activity becomes excessive and thus a compromise must be made. The response time depends on the controller gain. For wind speeds close to rated the blades will be close to the optimum angle and a large change in pitch would not result in large forces. At high wind speeds the converse is true and therefore a small gain is best, preventing overshoot and sudden movements that induce large forces.

Other issues worth considering are resonant frequencies and positive feed back (Burton et al). Resonant vibrations at the blade tower passing frequency or drive train torsional resonance may feed back fluctuations measured in the generator torque and cause useless high frequency pitching. A typical system addition to prevent this is notch filters. Another issue is in tower dynamics. With increasing wind speed the drag force which deflects the tower down wind is reduced. This decreased deflection then makes the apparent wind stronger and produces positive feedback. To prevent instability the gain has to be sufficiently small.

2.2 Functional Block Diagram

The functional block diagram indicates the generally required steps and their interrelationship. The functional components of this system are described in section 2.2.1.

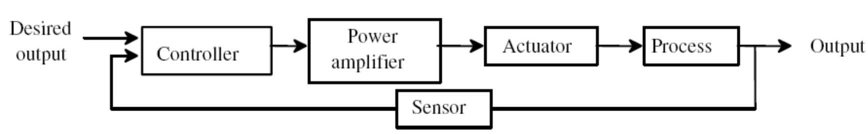

Figure 2-2 (Manwell et al) Wind turbine control block diagram

2.2.1 Control System Components

The practical requirements for a closed loop control system that might be used in a wind turbine are summarised below. The five aspects of a generic wind turbine control system are (Manwell et al)

1. It must be possible to change or influence the process in some way at a particular point.
2. Sensors are required to indicate the state of the system usually including

- Wind vane
- Anemometer
- Rotor speed
- Electrical power
- Pitch position
- Limit switches
- Vibration
- Temperature and oil level
- Hydraulic pressure
- Operator switches

3. A controller of some sort must be present. This could be a simple mechanical system or more complex hardware or software.
4. Amplifiers are necessary to convert a low power signal into a high power control action
5. To implement the above system components an actuator or other sort of physical interface is required.

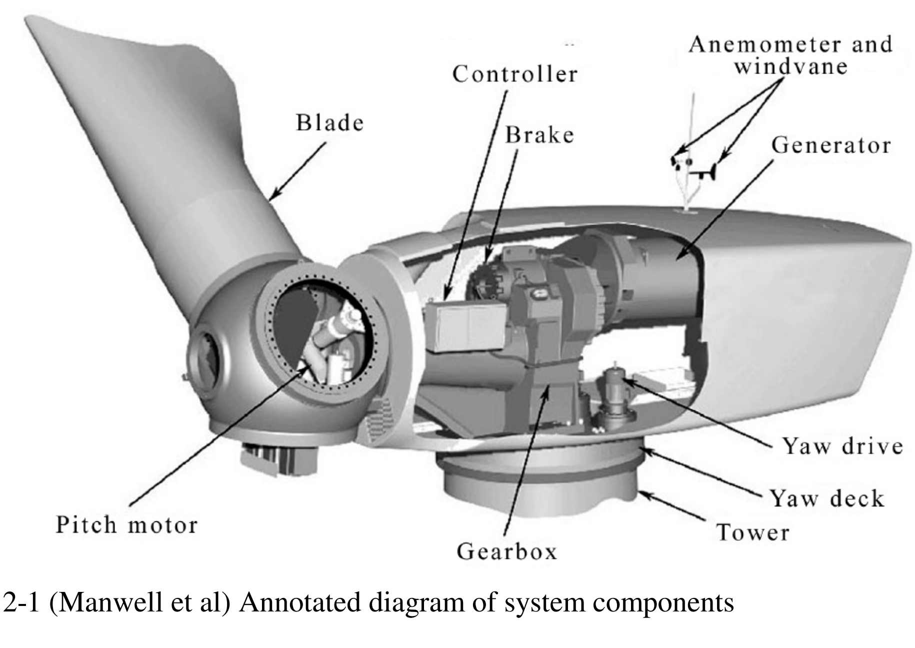

Figure 2-1 (Manwell et al) Annotated diagram of system components

The typical location of the control system components are given in figure 2-1. The controller indicated is the pitch and generator speed controller. It communicates with the anemometer and windvane sensor annotated (Figure 2-1), as well as the other sensors already mentioned. The controller sends signals to the master controller through high speed fibre optic cables which prevent electrical noise and interference.

2.3 Schematic Diagram

After producing a functional block diagram it is possible to relate this to a schematic which represents the physical system.

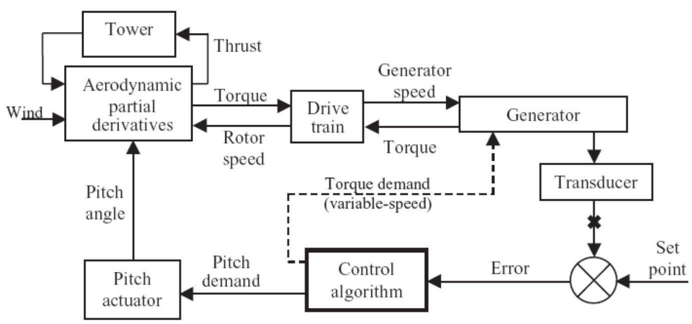

Figure 8.9 Typical Linearized Turbine Model

Figure 2-3 (Burton et al) Schematic of a variable speed wind turbine

2.4 Mathematical Model

The system can be linearized and represented by the Laplace equation:

$$y = \left(K_p + \frac{K_i}{s} + \frac{K_d s}{1 + sT_d} \right) x \qquad (3.4)$$

The above equation (3.4) is a PID equation, with K_p, K_i and K_d the proportional, integral and derivative gains respectively. The gains K_p, K_i and K_d are respectively responsible for the responsiveness; the steady state error and low-pass filter to ensure the algorithm does not increase indefinitely. The gains for the wind turbine control system, as explained in section 2.1, are decided in a trade of between various associated characteristics.

2.5 Simplify

The system can be simplified to model with a transfer function G(s) and a controller with a gain of k and a transfer function C(s).

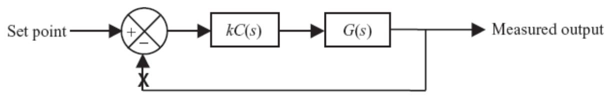

Figure 2-5 (Burton et al) Simplified model

2.6 Analyze and Design

Having followed the steps outlined previously it is then possible to design the system by varying system parameters. There are two strategies for electricity production from wind turbines. One is to use a variable speed and torque generator or alternatively to use a fixed speed variable torque generator.

2.6.1 Aerodynamic Torque and Rotor Speed Control

The control of wind turbines usually takes advantage of the varying aerodynamic properties of airfoils at different angles of attack. Methods that use this principle are discussed in the proceeding subsections.

2.6.1.1 Variable Speed Wind Turbine

For a variable speed wind turbine once a maximum torque is reached, the aerodynamic lift is reduced. This can be achieved by pitching the blades to a certain angle. Also for a given wind turbine there is a maximum allowable rotational speed. The rotational speed can be restricted by manipulating the generator torque. The generator torque can be varied in a variable slip induction generator or by using a frequency converter. The effect of this is two fold as changing the rotational speed also changes the efficiency and thus the aerodynamic lift. The use of generator torque variation to control aerodynamic torque is explained next for the fixed speed wind turbine.

2.6.1.2 Fixed Speed Wind Turbine

In the case of a fixed speed turbine, with increasing wind speed the drive shaft is loaded such that the rotational speed is constant, resulting in an increase in angle of attack. Ultimately if this angle is increased sufficiently the blade will stall. This angle can be altered dynamically or in the case stall regulated wind turbines this property is predetermined by a fixed pitch angle. Such a primitive design as the latter is reliable but has some drawbacks. The design works by always stalling at a predetermined wind speed which cannot be changed without redesign. Also this means that the wind turbine for the majority of the time is operating at angles of attack well below the stall angle. At these angles of attack the wind turbine is less efficient. Further more, wind speeds above the rated speed cannot be used. This is not the case in designs, which pitch the blades so that the rated power can still be extracted and is common in large modern wind turbines. The next section will therefore go into depth on the topic.

2.7 Pitch control

There are two main methods of pitch control: pitching to stall and feathering the blade. The different approaches have varied characteristics. Pitching to stall requires less pitch activity to maintain a constant torque but, the main disadvantage is that it cause larger thrust forces due to drag. The pitch can be controlled in a number of ways. In Figure 2-1 a pitch motor is depicted. The motor can be positioned quiet precisely and controlled by a computer for a particular optimisation algorithm. However more basic solutions also exist in the form of passive pitch regulation.

2.7.1 Passive Pitch Control

The pitch of the blade can be changed mechanically in a variety of ways. This is the simplest means of speed control with the earliest example dating back to Edmund Lees design in 1745 (Nise N.S.). The simplest in principle is to use a material which flexes in an appropriate manner in strong winds. However this requires an intimate understanding of materials and is still an area of research (Burton et al). A more common method (and the one used in Edmund Lees design) is to exploit forces present during the operation of the wind turbine. To illustrate how such a device might work Figure 2-7-1 has been included. The device uses centrifugal and shaft forces to compress the springs which in turn feather the blades.

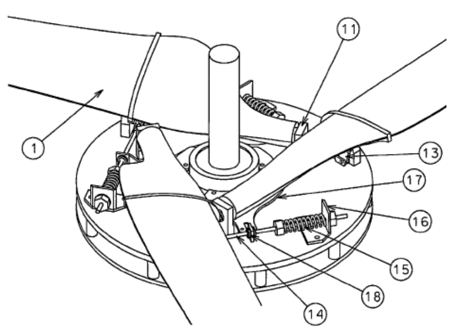

Figure 2-7-1 (http://www.freepatentsonline.com/7172392.pdf)
A possible solution to passive pitch control

2.7.2 Individual pitch control

Individual pitch control has the benefits of potentially reducing the asymmetric loading on a wind turbine. Since a number of force variations, such was wind shear and tower shadow, are a function of rotor azimuth the rotor angle can be used as the error signal in individual pitch control. For steady winds this is a fair assumption, unfortunately it is not true in gusty and turbulent conditions. The subsequent stochastic nature of system makes it unfeasible.

3. Safety Control System

The safety control of a wind turbine is a smaller topic than supervisory control since the system is intentionally much simpler. However the topic is still of interest as it illustrates the design process for a system in which reliability is key. Furthermore due regard must be paid to such a fail-safe as it is essential to prevent dangerous and costly incidents. To prevent catastrophic events a safety system must ensure that the following faults are not dangerous (Bolton W., 2004)

1. Component failure
2. Failure which causes cable open or short circuiting
3. Foreseeable modes of failure

To achieve these aims the safety system is built so that any fault must result in the activation of the safety system. The safety control is hard wired with relays that are held closed during normal operation. Any fault will trip the relays and activate the system which usually stops the turbine by releasing spring loaded brakes. To prevent likely modes of failure the system has fault indicators such as a rotor overspeed sensor and vibration sensor. To ensure that the sensors are working a watchdog timer is used. If the watchdog does not reset with each controller timestep then the safety system operates. Finally if the system fails to detect any fault there is the emergency stop button.

4. Conclusion

An insight into the design considerations for wind turbine control systems has been gleaned. A distinction has been made between supervisory and safety control and separate control issues identified. Common control systems and methods for implementation of these systems in modern wind turbines have been examined. The approach to controlling a wind turbine may vary but the primary objectives remain the same. In achieving these objectives compromises have to be made, and therefore it is essential to choose the most appropriate control system for a particular design specification.

5. References

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