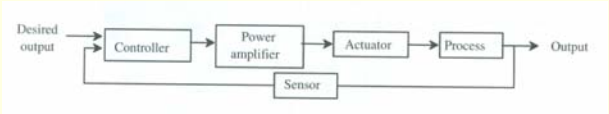
Control System

Andrew Kusiak
Intelligent Systems Laboratory
2139 Seamans Center
The University of Iowa
Iowa City, Iowa 52242 - 1527
andrew-kusiak@uiowa.edu
Tel: 319-335-5934 Fax: 319-335-5669
http://www.icaen.uiowa.edu/~ankusiak

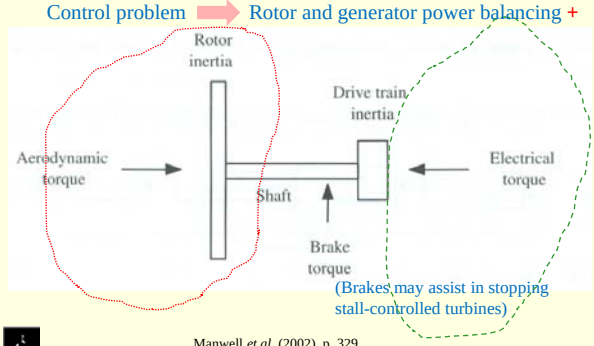
Generic Control Loop



Manwell *et al.* (2002), p. 330

Simple Turbine Model

Control problem ⇒ Rotor and generator power balancing +



(Brakes may assist in stopping stall-controlled turbines)

Manwell *et al.* (2002), p. 329

Goals of Turbine Control

- ✓ Maximization of energy production
- ✓ Safe turbine operations
- ✓ Minimization of operations and maintenance costs (by reducing loads and increasing life-time of components and subsystems)

Power (torque) balancing

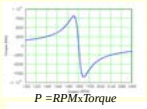
Below rated power

Above rated power

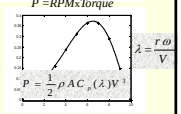
Typical Control Strategies (1)

U = wind speed

$U_{cut\text{-}in}$, $U_{cut\text{-}out}$ = cut-in, cut-out wind speed



$P = RPM \times Torque$



(one of many possible objectives)

Max power

Power limitation

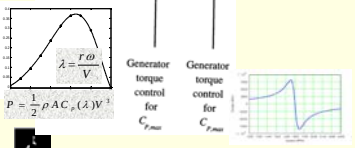
Typical Control Strategies (2)

Examples

Fixed speed, stall – synchronous generator; AC
Fixed speed, stall – asynchronous generator; AC

Fixed speed, pitch – synchronous generator; AC
Fixed speed, pitch – asynchronous generator; AC

Variable speed, stall – asynchronous generator; AC
Variable speed, pitch – asynchronous generator; AC



$P = RPM$ x $Torque$

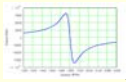
Typical Control Strategies (3)

Examples

Fixed speed, stall – synchronous generator; AC
Fixed speed, stall – asynchronous generator; AC

Fixed speed, pitch – synchronous generator; AC
Fixed speed, pitch – asynchronous generator; AC

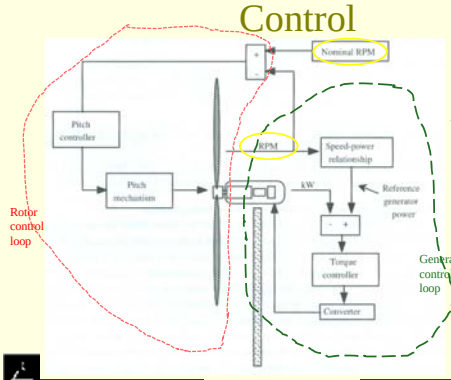
Variable speed, stall – asynchronous generator; AC
Variable speed, pitch – asynchronous generator; AC

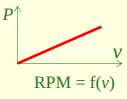


(one of many possible objectives)

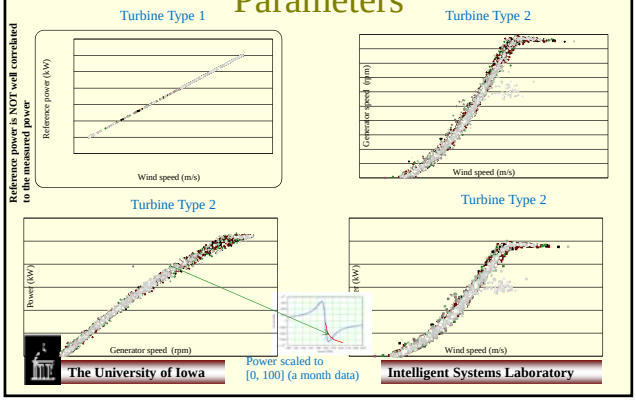
$P = RPM$ x $Torque$

Variable-Speed Closed Loop Control

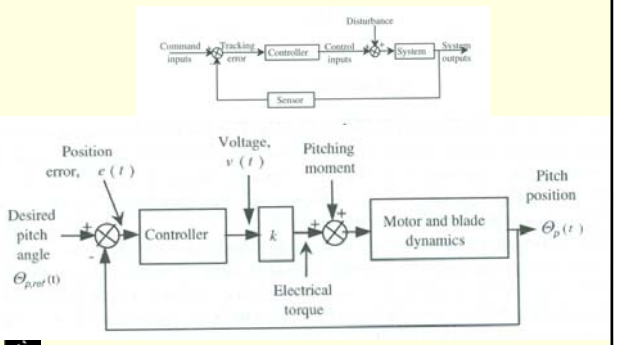




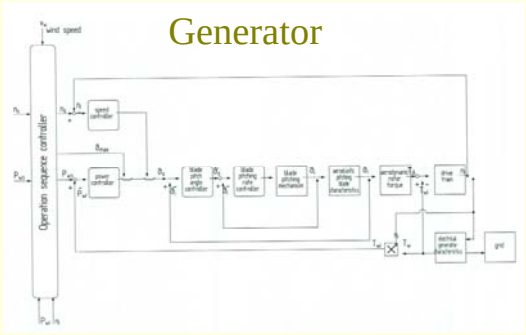
Relationships Among Selected Parameters



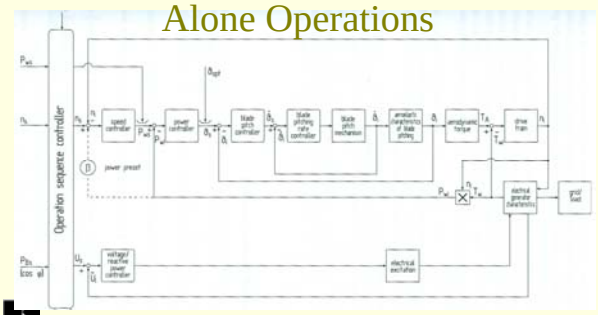
Model of a Pitch Control System



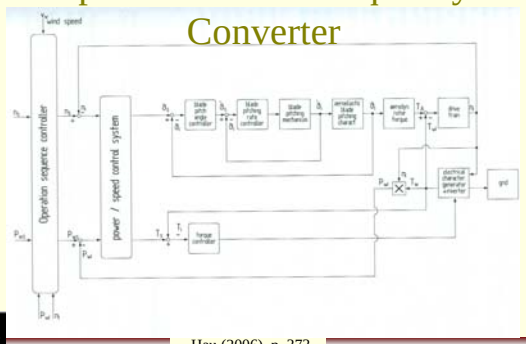
Control Structure of a Grid Connected WT with Induction Generator



CS of WT with Synchronous Generator for Grid and Stand Alone Operations



Control Structure a Variable Speed WT with Frequency Converter



Hau (2006), p. 373

Wind Turbine Controller

- ✓ The wind turbine controller consists of a number of computers continuously monitoring the condition of the wind turbine and collect data on its operations
- ✓ The controller also controls a large number of switches, hydraulic pumps, valves, and motors within the wind turbine
- ✓ As wind turbine sizes increase to megawatt machines, it becomes even more important that they have a high availability rate, i.e., that they function reliably all the time

Communicating with the Outside World

- ✓ The controller communicates with the operator of the wind turbine via a communications link, e.g., sending alarms or requests for service over the Internet or a radio link
- ✓ It is also possible to remotely collect data, and check turbine's status
- ✓ In wind parks, a control room is usually available for collecting data from all wind turbines in the park
- ✓ The substation is connected to a central control room

A fiber optics communications unit

Internal Communications

- ✓ There is usually a controller both at the bottom of the tower and in the nacelle
- ✓ In recent wind turbine models, the communication between the controllers is usually done using fiber optics
- ✓ In some recent models, a third controller is placed in the hub of the rotor
- ✓ This unit usually communicates with the nacelle unit using serial communications through a cable connected with slip rings and brushes on the main shaft

Fail Safe Mechanisms and Redundancy

- ✓ Computers and sensors are usually duplicated (redundant) in all safety or operation sensitive areas of large machines
- ✓ The controller continuously compares the readings from measurements throughout the wind turbine to ensure that both the sensors and the computers themselves are OK

What is Monitored?

- ✓ It is possible to monitor or set somewhere between 100 and 500 parameters in a modern wind turbine
- ✓ The controller may check:
  - ✓ The rotational speed of the rotor
  - ✓ The generator status
  - ✓ Its voltage and current
- ✓ In addition, lightning strikes and their charge may be registered
- ✓ Furthermore measurements are recorded:
  - ✓ Outside air temperature
  - ✓ Temperature in the electronic cabinets
  - ✓ Oil temperature in the gearbox
  - ✓ The temperature of the generator windings
  - ✓ The temperature in gearbox bearings

Different time scales

What is Monitored?

Example

- ✓ Hydraulic pressure
- ✓ The pitch angle of each rotor blade (for pitch controlled or active stall controlled machines),
- ✓ The yaw angle (by counting the number of teeth on yaw wheel)
- ✓ The number of power cable twists, wind direction,
- ✓ Wind speed from the anemometer,
- ✓ Vibrations in the nacelle and the rotor blades
- ✓ The thickness of the brake linings
- ✓ The tower door is open or closed (alarm system)

Control Strategies

- ✓ The way a controller interacts with the wind turbine components is usually proprietary to turbine manufacturers
- ✓ Control strategies are responsible for increase in wind turbine productivity
- ✓ An interesting strategy pursued by some manufacturers is to adapt the operational strategy to the local wind climate
- ✓ In this way it may, e.g., be possible to minimize tear and wear of the machine during (rare) periods of rough weather

Controlling Power Quality from Wind Turbines

A high voltage section of a controller of a megawatt machine

- ✓ Many think of the controller as the unit running the wind turbine, e.g., yaws it against the wind, checks that the safety systems are OK, and starts the turbine
- ✓ The controller performs indeed all these things, but it also looks after the power quality of the current generated by the wind turbine

Grid Connection and Power Quality

- ✓ Electric utilities require that wind turbines connect "softly" to the grid

Reactive Power Control

- ✓ Voltage and current are typically measured 128 times per alternating current cycle, (i.e., 50 x 128 times per second or 60 x 128 times per second, depending on the electrical grid frequency)
- ✓ On this basis, a Digital Signal Processor (DSP) processor calculates the stability of the grid frequency and the active and reactive power of the turbine
  (The reactive power component basically amounts to whether the voltage and the current are in phase or not)

Capacitor bank

Reactive Power Control

- ✓ To ensure the proper power quality, the controller may switch on or off a number of capacitors adjusting the reactive power (i.e., the phase angle between the voltage and the current)
- ✓ As shown above the switchable capacitor bank is quite large in a megawatt sized machine

A radiation free room with metal walls in the laboratory of one of the largest wind turbine controller manufacturers. The electromagnetic emissions from the components of the controllers are measured in this room.

Electromagnetic Compatibility (EMC)

- ✓ There are powerful electromagnetic fields around power cables and generators in a wind turbine
- ✓ This means that the electronics in the controller system has to be insensitive to electromagnetic fields
- ✓ Conversely, the electronics should not emit electromagnetic radiation which can inhibit the functioning of other electronic equipment

Acknowledgement

The material included in the presentation comes largely from the Danish Wind Industry Association