Overview of the ServoDyn Control & Electrical-Drive Module

NREL Wind Turbine Modeling Workshop

September 11-12, 2014
Bergen, Norway

Jason Jonkman, Ph.D.
Senior Engineer, NREL
Outline

• Introduction & Background:
  – Control & Electrical Drive Functions
  – Example Operational Controller for NREL 5-MW
  – ServoDyn – What is It?
  – Inputs, Outputs, States & Parameters

• Control & Electrical-Drive Models
  – Active Control Methods
  – Interfacing Active Controllers – 5 Options
  – Passive Control Methods
  – Features of FAST v8 Compared to v8

• Modeling Guidance

• Recent Work

• Current & Planned Work

• Future Opportunities
Introduction & Background

Control & Electrical Drive Functions

• Controls:
  – Operation
  – Start-up & shut-down
  – Safety & protection

• Sensors & actuators:
  – Sensors
  – Servo motors
  – Hydraulics

• Electrical drive:
  – Generator
  – Power electronics
  – Grid

• Faults
Introduction & Background
Example Operational Controller for NREL 5-MW Wind Turbine Modeling Workshop

- **Low-Pass Filter**
  - Filtered Speed
  - Generator Speed

- **Generator Torque**
  - Torque-Speed Lookup Table
  - Torque Limit Saturation
  - Torque Rate Saturation

- **Control Region**
  - (1, 1½, 2, 2½, or 3)

- **Gain Schedule**
  - Gain Factor
  - Proportional Gain
  - Integral Gain

- **Integrator**
  - Integrated Speed Error

- **Rated Speed**
  - Speed Error

- **Pitch Limit Saturation**
  - Rotor-Collective Blade-Pitch Angle

- **Pitch Rate Saturation**
  - Rotor-Collective Blade-Pitch Angle

- **Torque Limit Saturation**
  - Generator Torque

- **Torque Rate Saturation**
  - Generator Torque
Torque-Speed Curve (Left) & Blade-Pitch Gain-Scheduling (Right) of Onshore NREL 5-MW Turbine Under Operational Control
Steady-State Behavior of Onshore NREL 5-MW Turbine Under Operational Control
Introduction & Background
ServoDyn – What Is It?

- Control & electrical-drive module for wind turbines:
  - Used to be a fundamental part of FAST
  - Now split out as a callable module in the FAST framework with separate input files & source code
  - Includes control & electrical-drive models for blade pitch, generator torque, nacelle yaw, high-speed shaft (HSS) brake, & blade-tip brakes

- Latest version:
  - v1.01.02a-bjj (July 2014)

- User’s Guide:
Inputs, Outputs, States, & Parameters

**Inputs:**
- Structural motions
- Reaction loads
- Wind measurements

**ServoDyn**

**Continuous States:**
- Analog control signals

**Discrete States:**
- Digital control signals

**Parameters:**
- Controller gains
- Control limits

**Outputs:**
- Controller commands
Control & Electrical-Drive Models

Active Control Methods

- **Blade pitch:**
  - Collective or independent
  - To feather or to stall
  - Command the angle
  - No actuator dynamics
  - Override maneuvers available

- **Generator torque:**
  - Fixed (w/ or w/o slip) or variable speed
  - Command the torque
  - Indirect electrical power
  - Default models built in
  - Detailed electrical drive modeling through MATLAB/Simulink’s SimPowerSystems toolbox*

*Available in FAST v7, but not yet in v8
Control & Electrical-Drive Models
Active Control Methods (cont)

• HSS brake*:  
  – Command the deployment

• Nacelle yaw:  
  – Command the angle &/or rate  
  – 2\textsuperscript{nd}-order actuator determines the torque  
  – Override maneuvers available

• Blade-tip brake*:  
  – Command the deployment

*Available in FAST v7, but not yet in v8
Control & Electrical-Drive Models
Interfacing Active Controllers – 5 Options

1) Select from one of the built-in routines

2) Fortran subroutine:
   – Separate routines for each controller (i.e.: Separate routines for blade pitch, generator torque, nacelle yaw, & brake)
   – Requires recompile with each change to controller source code
   – Sample variable-speed torque controller based on table look-up provided with FAST archive
   – Sample PID blade-pitch controller provided with FAST archive

3) Bladed-style dynamic link library (DLL):
   – Default in FAST v8, requires customization in FAST v7
   – DLL compiled separately from FAST:
     • Mixed languages possible – Can be Fortran, C++, etc.
   – DLL is a master controller (i.e.: Pitch, torque, yaw, & brake controlled with same DLL)
   – Sample NREL 5-MW baseline controllers provided with FAST archive
Control & Electrical-Drive Models
Interfacing Active Controllers – 5 Options (cont)

4) **MATLAB/Simulink**:  
- **FAST** implemented as S-Function block (.mexw32)  
- Controls implemented in block-diagram form  
- **SimPowerSystems** toolbox for detailed electrical drive

5) **LabVIEW**:  
- **FAST** implemented as DLL callable by LabVIEW  
- Hardware-in-the-loop (HIL) possible

*Available in** **FAST v7, but not yet in v8**
### Control & Electrical-Drive Models

#### Passive Control Methods

- Apart from **ServoDyn**, **FAST** offers passive control methods:
  - Aerodynamic stall
  - Rotor teeter:
    - Optional damping & soft & hard stops
  - Nacelle yaw:
    - Free or restrained
  - Rotor furl*:
    - Optional independent up- & down-springs & dampers
  - Tail furl*:
    - Optional independent up- & down-springs & dampers

*Available in **FAST** v7, but not yet in v8
This workshop will apply **FAST v8**

- All new features are being added to the new framework
- Until all features of v7 are included in v8, both will be supported

<table>
<thead>
<tr>
<th>FAST Features</th>
<th>v7.02</th>
<th>v8.08</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blade-pitch control</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Override pitch maneuvers</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Generator models</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Torque control</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>High-speed shaft brake</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Nacelle-yaw control</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Override yaw maneuvers</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Blade-tip brakes</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Bladed DLL interface</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Simulink interface</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>LabVIEW interface</td>
<td>✔</td>
<td></td>
</tr>
</tbody>
</table>
Modeling Guidance

- No blade-pitch DOF in ElastoDyn means that controller command angle = actual angle
- Only 1 generator start & stop per simulation is possible
- To model an idling/parked rotor set:
  - BldPitch = 90° (in ElastoDyn) – Feathered
  - RotSpeed = 0 (in ElastoDyn)
  - PCMode = 0 – Disable pitch control
  - GenTiStr = True
  - TimGenOn > Tmax – Never enable generator
  - StallMod = STEADY (in AeroDyn) – Disable dynamic stall
  - IndModel = NONE (in AeroDyn) – Disable wake
- Use override maneuvers to force faults of the pitch & yaw controllers
Recent Work, Current & Planned Work, & Future Opportunities

- **Recent work:**
  - Split out **ServoDyn** as a callable module in the **FAST** framework with separate input files & source code

- **Current & planned work:**
  - Address current limitations of **FAST** v8 relative to v7
  - Wind farm super controller (**SOWFA**)

- **Future opportunities:**
  - Include more built-in methods in:
    - Generator Types 1-4
    - Input-signal low-pass filtering
    - Variable-speed torque control with transition regions & rate limits
    - Gain-scheduled PI blade-pitch control with rate limits
  - Add blade-pitch actuator models
  - Support for active-flow control
  - Support for detailed actuator modeling
  - Add measurement noise to control input signals
Questions?

Jason Jonkman, Ph.D.  
+1 (303) 384 – 7026  
jason.jonkman@nrel.gov