Turbine Controller Integration

Turbine Model: *GE 1.5 SLE*

OCS Model: *G2.1*

Date: *June 27, 2012*

Overview

The Catch the Wind, Inc. (CTW) Optical Control System (OCS) is designed to improve turbine performance by enhancing alignment of the turbine with approaching wind while maintaining or enhancing the overall safety and reliability of the turbine. The OCS utilizes state of the art laser sensors to detect the approaching wind before it reaches the rotor, and commands yaw actuations of the nacelle in order to reduce yaw error. More timely and accurate alignment with the wind leads to improved power capture. This document describes the integration concept of the OCS, with emphasis on mechanisms that maintain safe control of the turbine.

Integration

The CTW OCS is designed to take over the yaw actuation of the turbine utilizing the LIDAR for accurate and look-ahead wind data. The general integration strategy is demonstrated conceptually in Figure 1. The OCS utilizes a Bachmann Programmable Logic Controller (PLC) as the basis of the design. This system has a processor module, Ethernet ports, and digital I/O modules that allow it to easily interface with the legacy GE central controller, the laser sensor unit, and the digital hardware of the turbine.

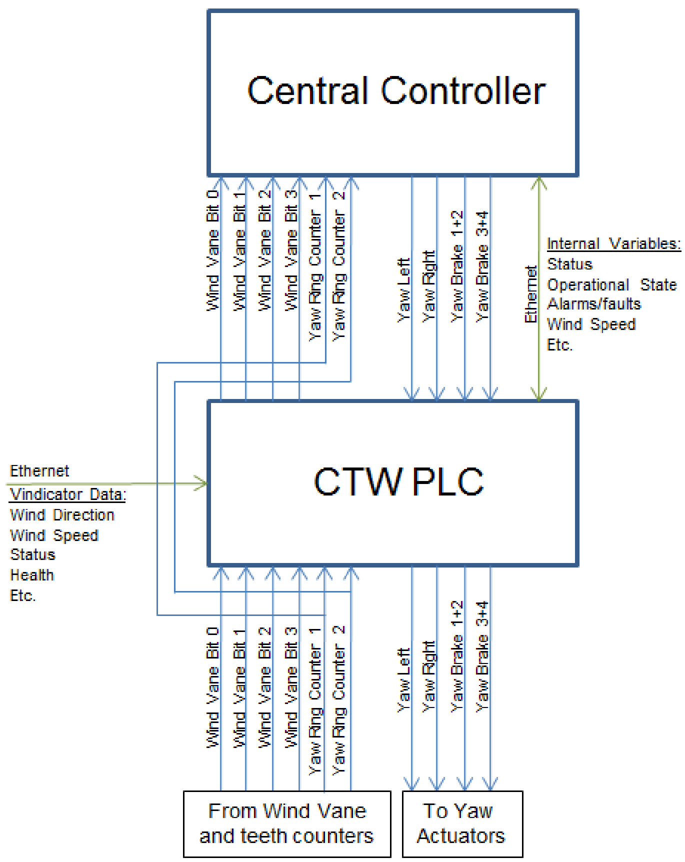

Figure 1. Schematic of the OCS control interface, showing digital I/O routing and Ethernet communication. The digital signals are intercepted so that internal OCS logic can be sent to the legacy controller and yaw actuators.

The OCS intercepts the yaw motor, yaw brake, and wind vane digital signals. The sensor and yaw hardware commands are monitored by the OCS, while the OCS performs logic to determine which signals to send to the legacy controller and the yaw hardware. The OCS monitors the yaw teeth counter digital signals, but does not modify the signals going to the legacy controller. The OCS also utilizes Bachmann communication protocols to read internal legacy control variables via the local network. This communication includes variables such as turbine status to ensure that the OCS can safely take control of the yaw actuation of the turbine. The OCS utilizes the local network to read the measured wind data from the laser sensor.

There are two primary modes of operation of the system: automatic control and bypass mode. In automatic control, the OCS utilizes the laser wind sensor to align the nacelle with the approaching wind. In this mode, the system outputs signals to the legacy controller that mimic a mean zero wind direction error – this results in the turbine operating as normal, but without the legacy system providing any yaw actuation commands to the yaw brakes or motors. The OCS then sends its own yaw commands to the yaw brakes and yaw motors to track the wind. In bypass mode, all of the digital signals are passed directly through the system, such that the OCS acts like it is not present. In bypass, the legacy controls all yaw activity.

Communication

Ethernet: TCP & SMI

The PLC communicates to the laser sensor via Modbus-TCP over a local Ethernet network. The messages the OCS monitors include wind speed, direction, status of the laser system, and validity of the measurements at the various range gates.

The OCS for GE 1.5 SLE integrations makes use of Bachmann PLC components. Bachmann PLC systems are designed for industrial control systems, and the CTW solution mirrors the GE 1.5 controller strategy. Utilization of a Bachmann PLC allows for the CTW controller to directly communicate with the GE PLC utilizing the Standard Module Interface (SMI) libraries supplied by Bachmann. The CTW PLC can directly read internal variables from the turbine so that it has knowledge of the operating conditions of the turbine.

The OCS has a Modbus server running for data capture. Internal values of the OCS are recorded along with performance data such as wind speed, direction, and power.

Digital I/O

The OCS makes use of digital Input and Output lines in order to intercept or monitor the following signals from the turbine controller and turbine hardware:

- Yaw brakes
- Yaw motors
- Wind Vane
- Yaw teeth counters

The yaw teeth counters are only read in by the OCS, but are still physically connected to the turbine controller. The OCS sends these teeth counts to the legacy controller – this ensures the legacy controller always has accurate knowledge of the absolute nacelle position.

The digital signals are connected to the OCS via a set of controlled relays. The normal states of the relays pass the original signals to and from the legacy controller and the turbine hardware. Only when in automatic mode are the relays engaged in order to intercept signals and feed OCS derived values to the legacy controller and turbine hardware. This also ensures that any issues with the OCS PLC (or the powering off of the PLC) result in the turbine returning to legacy control so that OCS does not adversely affect turbine performance or safety.

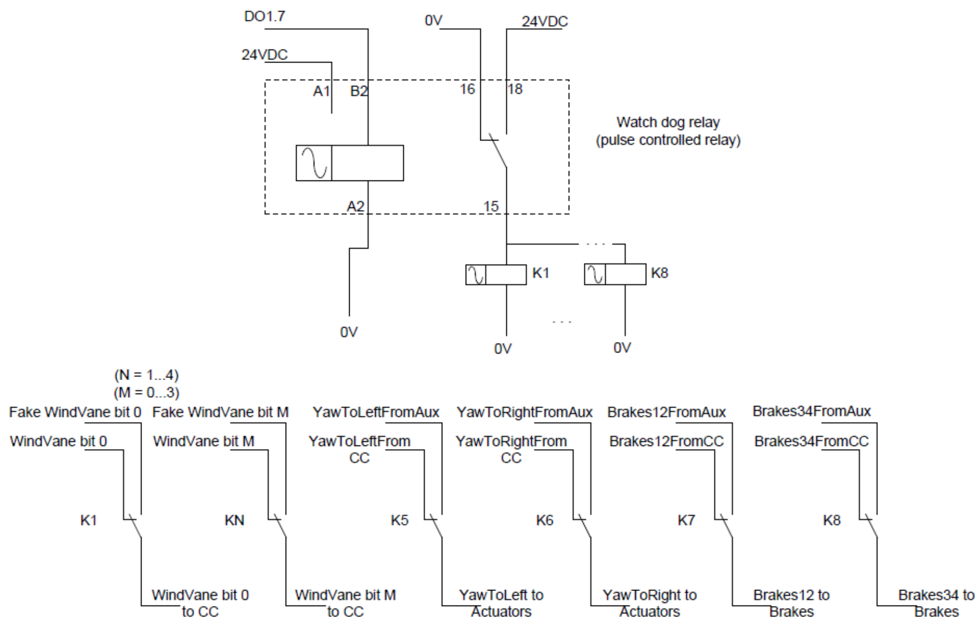

Figure 2. Diagram of relays connecting the OCS to the digital inputs and outputs of the legacy controller. Relays are shown in their normal configuration, where the original signals are passed directly through the OCS. The watchdog relay is used to engage the relays in order to intercept the signals and allow the OCS to control yaw drive hardware.

State Machine

There are four states for the OCS controller: Initialize, Auto, Bypass, and Fault (see Figure 3 and Table 1 for state transitions). The Initialize state acts as a default initialization state and dictates transitions at startup of the OCS, or when the system returns from the Fault state. The Auto state is when the OCS is directly controlling the yaw of the turbine. The Bypass state acts as if the OCS is not present. The Fault state is when there is any fault detected within the CTW OCS (not with the turbine controller). In the three states of Initialize, Bypass, and Fault, the relays for the interception of digital I/O signals are in the default state, and the turbine is wired as if the OCS is not present.

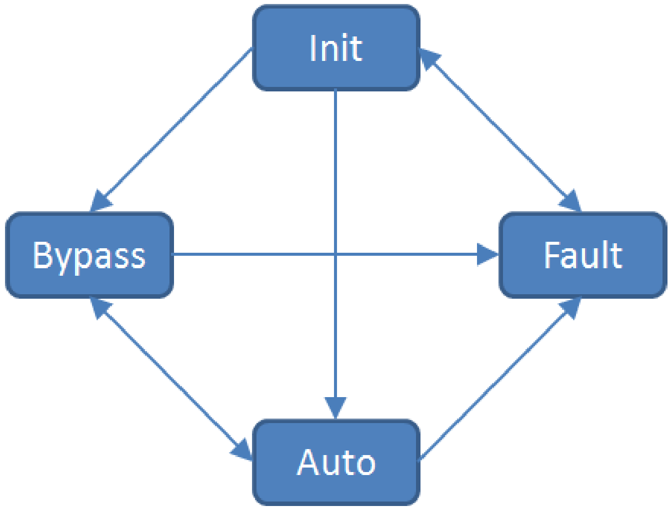

Figure 3. State diagram for the OCS, showing the direction of state transitions.

Table 1. State table for the OCS, demonstrating logic for state transitions.

State Transitions From -> To	Init	Bypass	Auto	Fault
Init		No Entry	No Entry	No Fault
Bypass	NOT bFault AND (Par_bBypass OR (Par_bSwitchBtwControllers AND bSwitchBtwCtrlsBypass)) OR NOT bLoadOperation		NOT bLoadOperation OR IN_bYawToTheLeft_CC OR IN_bYawToTheRight_CC OR IN_bYawBrakes12_CC OR IN_bYawBrakes34_CC OR bFlagAvoidRunaway OR Par_bBypass OR (Par_bSwitchBtwControllers AND bSwitchBtwCtrlsBypass)	No Entry
Auto	Ton_CentralCtrlYaws.Q bLoadOperation AND NOT Par_bBypass AND NOT bFault AND NOT (Par_bSwitchBtwControllers AND bSwitchBtwCtrlsBypass)	NOT bFlagAvoidRunaway AND NOT OUT_bYawToTheLeft AND NOT OUT_bYawToTheRight AND bLoadOperation AND NOT (Par_bSwitchBtwControllers AND bSwitchBtwCtrlsBypass) AND NOT Par_bBypass AND Ton_CentralCtrlYaws.Q		No Entry
Fault	Fault	Fault	Fault	

Logic variables

The variables used in the logic described in Table 1 are:

- bFault - Boolean variable that is true if there is a fault present (fault internal to the OCS)

- Par_bBypass - Boolean parameter that is set to override OCS control and permanently maintain legacy control
- Par_bSwitchBtwControllers - Boolean parameter which denotes that periodic switching between the controllers is activated for testing purposes
- bSwitchBtwCtrlsBypass - Boolean timing variable that denotes if the period for switching is for the Bypass state (false denotes Auto control period)
- bLoadOperation - Boolean variable that denotes the turbine is under load operation; this ensures that the turbine has status value 2 and the turbine is online – if this is true, there can be no faults with the turbine, so OCS control is possible
- Ton_CentralCtrlYaws.Q - a time delay that indicates the legacy controller has yawed, and thus reset its initial position for yaw runaway calculations (this allows the OCS to have full range of motion equal to the yaw runaway parameter 11.13 before tripping bFlagAvoidRunaway)
- bFlagAvoidRunaway - Boolean variable that tracks how much the OCS yaws the turbine relative to the last time the legacy controller yawed (and reset its runaway position value) and prevents it from exceeding parameter 11.13.
- OUT_bYawToTheLeft - Boolean that indicates commands to motors to yaw to the left (from OCS or legacy controller)
- OUT_bYawToTheRight - Boolean that indicates commands to motors to yaw to the right (from OCS or legacy controller)
- IN_bYawToTheLeft_CC - Boolean that indicates the legacy controller is sending yaw commands to the left
- IN_bYawToTheRight_CC - Boolean that indicates the legacy controller is sending yaw commands to the right
- IN_bYawBrakes12_CC - Boolean that indicates the legacy controller has disengaged yaw brakes 1 and 2
- IN_bYawBrakes34_CC - Boolean that indicates the legacy controller has disengaged yaw brakes 3 and 4

Faults

The faults that are monitored by the OCS are:

- Untwisting Right
- Untwisting Left
- Yaw drive end position
- Timeout yaw count
- Wrong yaw drive direction
- Yaw end switch activated
- Yaw motors over temperature

- OCS Communications Fault
- SMI Fault
- Wind Direction Limit
- OCS Wind Measurement Status
- UPS alarm
- UPS battery mode

States Summary

Initialize: The system enters this state upon start up. If the turbine is in load operation (status = 2 and turbine is generating power) and the turbine has yawed to reset its current position since the PLC last went in to Auto mode, then the system will transition to Auto mode. If the bypass parameter is enabled, then the Auto state will be overridden, and the system will stay in Bypass mode. If the switching parameter is enabled and the timer is currently in Bypass mode, the system will not transition to Auto, but will transition to Bypass. If any faults are detected internally to the OCS, the system transitions to the Fault state. The digital I/O relays are disengaged and the turbine is functioning as normal.

Auto: The system will utilize the laser wind sensor to track the wind and will command the yaw brakes and motors. Zero error vane signals are sent to the legacy controller to prevent the turbine from yawing. If the legacy controller does command a yaw, for any reason, the system will transition to bypass mode and pass through the yaw commands. If the turbine status changes away from a value of 2 or it is not producing power (indicating a potential issue with the turbine), the system will transition to Bypass mode. If the switching parameter is enabled, and the period for the Bypass mode is enabled, the system will transition to Bypass. If the OCS detects that it tries to yaw beyond the parameter 11.13 value, the Avoid Runaway flag will be triggered, and the system will transition to Bypass mode until the turbine resets its current yaw position.

Bypass: The system will disengage the relays and the turbine will perform in its original configuration. If the OCS does not have the Bypass parameter set, the turbine is not currently yawing, the turbine is in load operation (no alarms), the turbine has yawed such that it has reset its current yaw position for the yaw runaway alarm (since the last time in the Auto state), and the system is not switching between controllers with the timer currently set for the Bypass sate, then the system will transition to the Auto state. If a fault is detected in the OCS, the system will transition to the Fault state.

Fault: This state lets the OCS know that an internal fault has been detected and records the fault in the system's Modbus data. In practice, this state acts like Bypass, in that the relays are disengaged and the turbine is essentially in its original configuration. The Fault state allows for safe handling of the OCS interface and ensures the system is only able to control the yaw systems when safely in the Auto state. The system transitions to Initialize when the faults clear.

Auto-Bypass Switching

The OCS allows for a periodic switching between the Auto and Bypass states for testing purposes. In order to perform power performance comparisons between the legacy and OCS controllers over similar wind, atmospheric, and seasonal conditions, the switching can be done over some defined period (i.e. an hour) where conditions have not significantly changed, but long enough that the performance of the controllers has had an impact on turbine power performance. This switching mode is governed by a parameter in the controller (Par_bSwitchBtwControllers) and results in a logical variable that oscillates between each control mode (bSwitchBtwCtrlsBypass). The logic of this switching between the states based on this variable is defined by Table 1, and the conservative control strategy results in the potential for non-uniform switching. An example of this would be the need for the turbine to yaw in order for Auto mode to take over. This resets the current nacelle position for the yaw runaway calculations taking place in both the legacy and OCS controllers. If the legacy controller were to never yaw the turbine, then the system would continue to wait before entering the Auto state, and the time for this period would expire before switching to the next Bypass period.

Parameter Settings (Yaw Runaway)

When in OCS control, the OCS system is commanding yaw runaway activity. All other turbine functionality operates as normal, monitoring the teeth counters, and the legacy controller is aware that it is yawing when it is not commanding yaw activity. If the turbine were to yaw beyond the limit specified by parameter 11.13, the turbine would trigger a runaway alarm. For this reason, the parameter value is required to be increased in order to allow the OCS to have a reasonable range of motion. The OCS monitors how much it is yawing relative to the current set point of the legacy controller and does not allow itself to yaw beyond this limit. If it reaches this limit (bFlagAvoidRunaway), it transitions to Bypass mode until the turbine again yaws and resets this set point. This then allows the OCS to have its new range of motion originating at this new position.

Summary

The CTW OCS is designed to increase turbine performance while maintaining conservative safety requirements. When in OCS control, the system utilizes an advanced laser measurement device to drive the nacelle yaw motors to more accurately align the nacelle with the approaching wind direction.

This control strategy allows the turbine to maintain all of its current functionality regarding safety monitoring. The only two aspects that are affected at all by this system are yaw runaway and wind direction deviation limits. The turbine still monitors yaw runaway, but the increase in parameter 11.13 causes a minor delay in when this alarm will ultimately be triggered. Yaw runaway has not been demonstrated to be a problem on GE 1.5SLE wind turbines in the field, so this is not considered an operational issue. The OCS monitors wind direction deviation and when the limit is hit, the system reverts to Bypass mode and the wind vane data is passed to the turbine. There will be a delay when the turbine detects that the wind direction deviation occurs, and the alarm is triggered. However, this delay is small compared to the magnitude of time over which wind direction deviations occur, and the look-ahead nature of the laser measurements means the system will transition to Bypass some time before that wind reaches the turbine. Once the states transition, the turbine will be able to monitor the direction deviation and take appropriate action.

The OCS control architecture is designed to only take control when both the turbine and the OCS are operating well and without any indication of issue. In all situations where either the turbine or the OCS exhibits any cautionary signals, turbine control is returned to the legacy system until these system issues are resolved and the OCS has worked through the Initialize state.

We are committed to the safe operation of wind turbines. As such, we welcome inputs to these protocols from either the manufacturer or user groups.