Wind Turbine Pitch Fault Detection and Isolation using Discrete Time Low Pass Filtering

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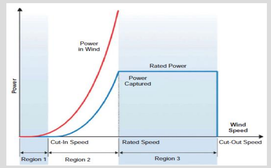
Introduction

Wind energy is projected to make up 20% of US electricity generation by 2030 [1].

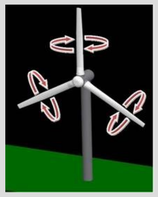
NREL operates 2 Controls Advanced Research Turbines (CART2 and CART3) to test controls. More data is generated than can be checked by workers.

CART2 [2] – data from this turbine used in this research

Wind turbine control determined by wind speed:
Region II – Optimize efficiency
Region III – Pitch blades to reduce energy capture to rated power



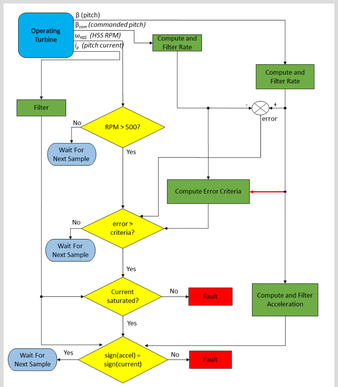
Ideal Power Curve [3] – this is the amount of energy captured by an ideal turbine as the wind speed increases



Blade Pitch [4] – blades pitch (rotate) about the axis of the blade in region III operation

Objective: To improve the pitch fault detection system for NREL's CART2 wind turbine.

Methods



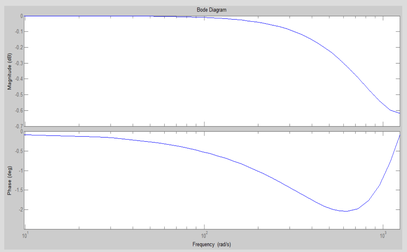
Pitch Fault Detection Flowchart – this flowchart details the fault detection algorithm used. The red line highlights the main change in the update – the inclusion of the actual rate in the error criteria computation.

Discrete Time Low Pass Filtering:

$\alpha = 1 - e^{-.01/tc}$

$X(k) = \alpha * U(k) + (1-\alpha) * X(k-1)$

Symbol	Quantity
X	Filtered data
U	Unfiltered data



Bode Plot of Filter Used on Command – this plot shows the low pass filter used on the pitch rate command, where high frequencies have decreased magnitude and greater phase shift.

Error Criteria Value Derivation:
Baseline: Error criteria based only on the commanded pitch rate

$$E = |\dot{\beta}_{cmd} * .5| + 3$$

Updated: Error criteria based on: 1. Filtered commanded pitch rate
2. Actual pitch rate
3. Commanded pitch acceleration

$$E = |\dot{\beta}_{cmd} * .60 + \dot{\beta} * .5| + |\ddot{\beta}_{cmd} * .02| + 1$$

Symbol	Quantity
E	Error criteria
$\dot{\beta}_{cmd}$	Commanded pitch rate
$\dot{\beta}$	Actual pitch rate
$\ddot{\beta}_{cmd}$	Commanded pitch acceleration

Methods Cont.

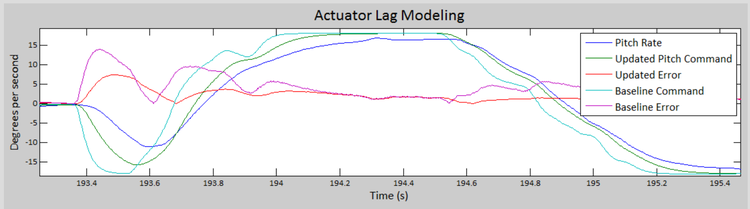
30.5 hours of operational data was used to tune the definitions

After tuning, the definitions were tested on that data and compared to baseline

New definitions were then validated and compared to the baseline using 8.1 hours of new data

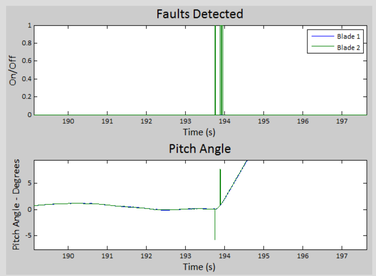
Results & Analysis

Actuator lag model improved and apparent actuator lag significantly reduced.

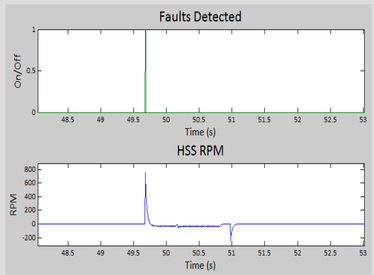


Apparent actuator lag reduction by filtering. This shows the closer fit to the actual pitch behavior on the updated command. Error is less on the update than the baseline.

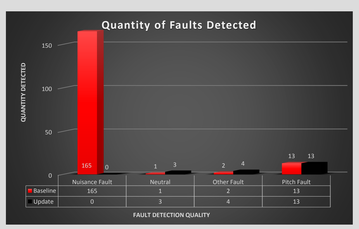
Types of faults detected:
Pitch not following command
Pitch angle sensor error
HSS position sensor error



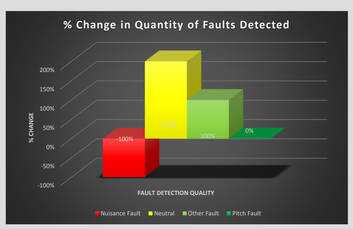
Blade Pitch Sensor Fault – a faulty reading on the pitch angle sensor triggered a fault



HSS Position Sensor Fault – a faulty reading in the HSS position triggered a fault because HSS RPM > 500 is required for fault detection algorithm



Nuisance faults are eliminated, while real fault detections either increase or stay constant.

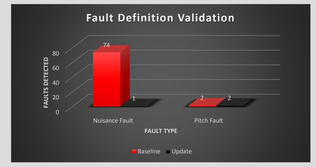


Fault detection quality improvement – one hundred percent decrease in nuisance faults while real faults detected either increase or stay constant.

Results & Analysis Cont.

Results of test of definitions on new data:

All but one nuisance faults tolerated
All pitch faults caught

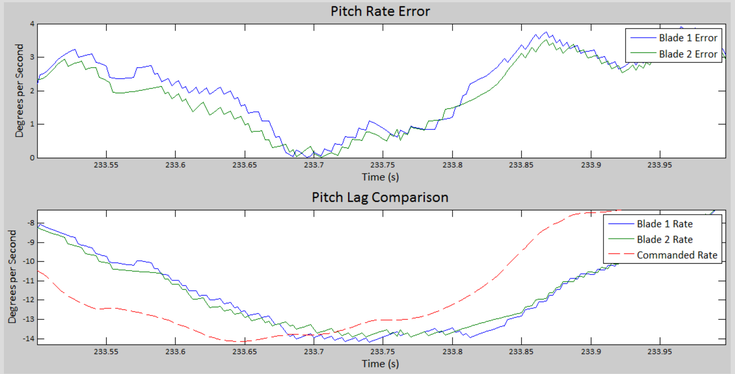


Fault definition validation on new data – nuisance faults reduced, other faults still caught.

Pitch actuator lag problem discovered:
On CART2, blade 1 consistently lags more than blade 2.
On baseline definition, more nuisance faults due to lag caught on blade 1 than blade 2:

Blade	Number of Nuisance Faults
1	88
2	77

95% confidence that blade 1 error is greater than blade 2 error over 63.32% of the population
10% trimmed mean of error difference relative to blade 2 error is 90.3%
Blade 1 mean error is 26.78% higher than blade 2 mean error



Comparison of blade 1 and blade 2 lag and error during a high pitch rate event. Blade 1 error consistently is greater than blade 2 error. Especially in high pitch rate events, blade 2 more closely follows the command.

Conclusions

Model based fault detection was successfully used to improve fault detection.

Discrete time low pass filtering was used to model actuator lag.

There is a significant difference between the two blades' pitching mechanisms' behaviors, and potentially some problem within the blade 1 pitch system.

Acknowledgements & References

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[1] "20% Wind Energy by 2030," 10 2008. [Online].
[2] P. Fleming, *CART2 wind turbine,* Boulder: NREL, 2012.
[3] D. Cahen, D. Ginley, "Wind Energy," in *Fundamentals of Materials for Energy and Environmental Sustainability*, Cambridge, Cambridge University Press, Wind Energy, pp. 396-423.
[4] "Wind Turbine Control Methods," National Instruments, 22 December 2008. [Online].