Individual Turbine Blade Pitch Control

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Purpose

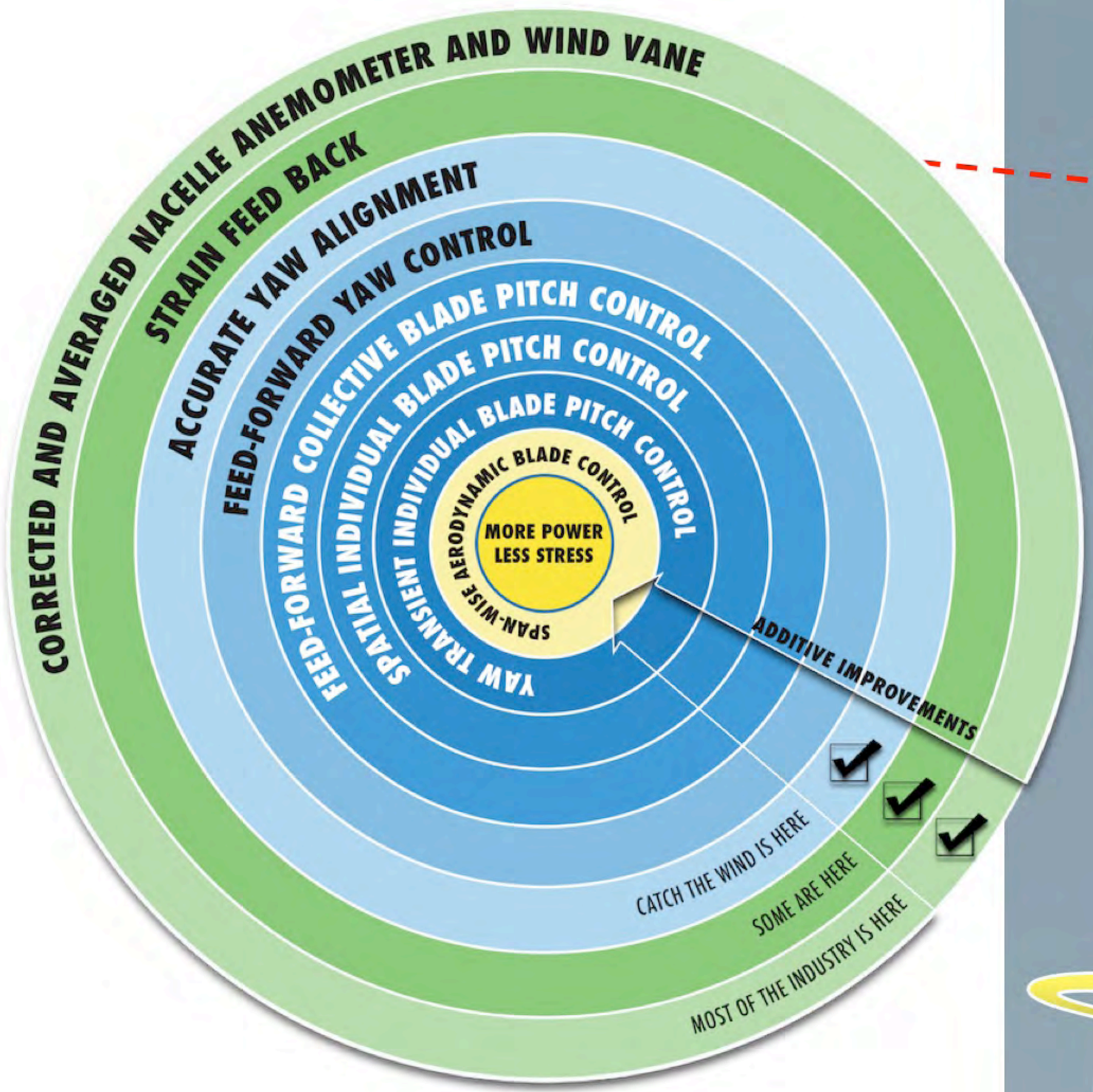
- Inform Industry of On-Going Work to Field Advanced WTG Controls
- Confirm Feasibility and Benefits of Coupling LIDAR Sensor to Collective and Individual Blade Pitch Control

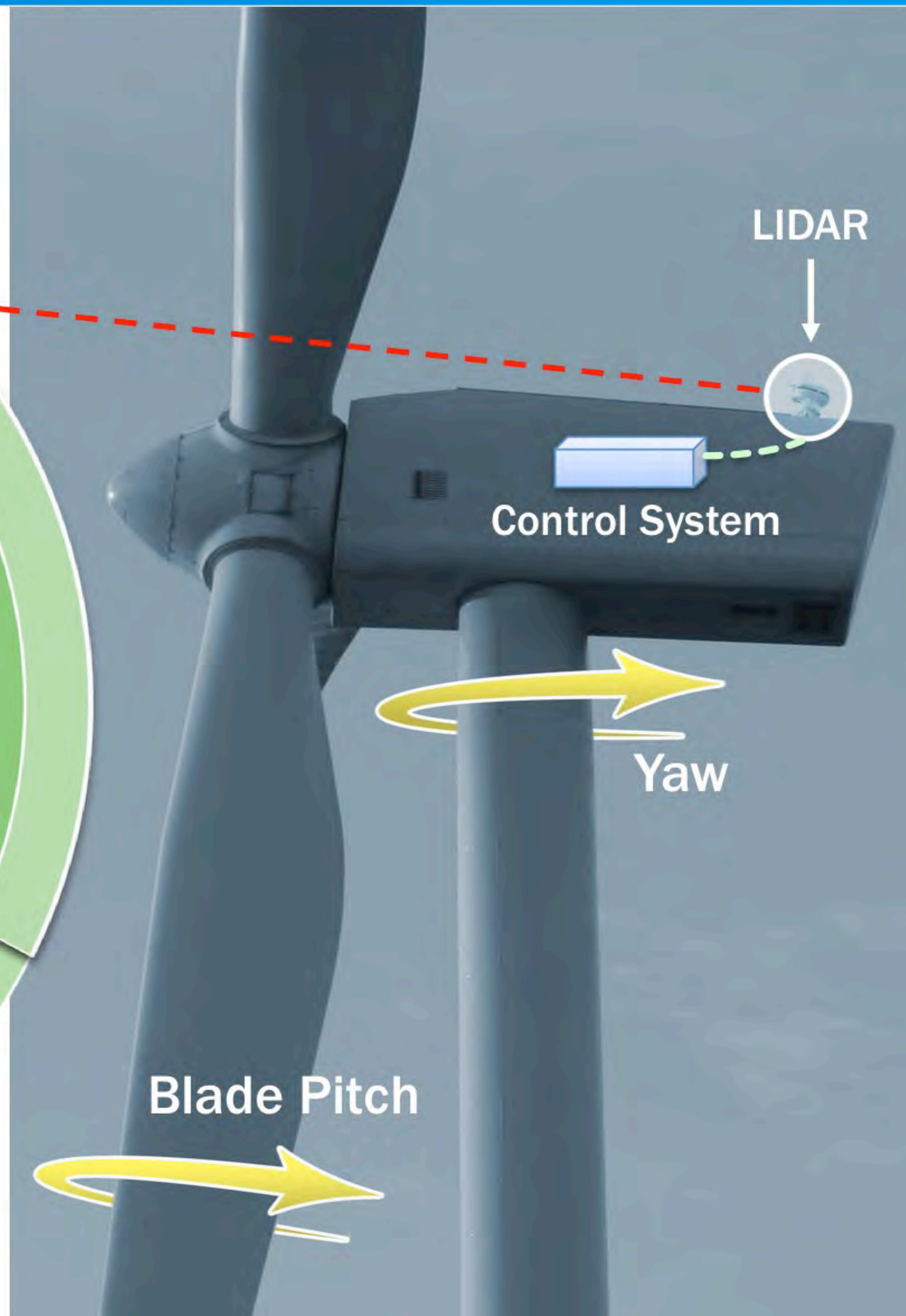
Outline

- Background
  - Remote Sensing for Feed-Forward Control
  - Steps in Advancing Turbine Control
    - Improvements Starting with Advanced Yaw Control
  - Blade Pitch Control
- Improvements from Feed-Forward Collective Pitch Control
- Independent Pitch Control System Model
- Summary

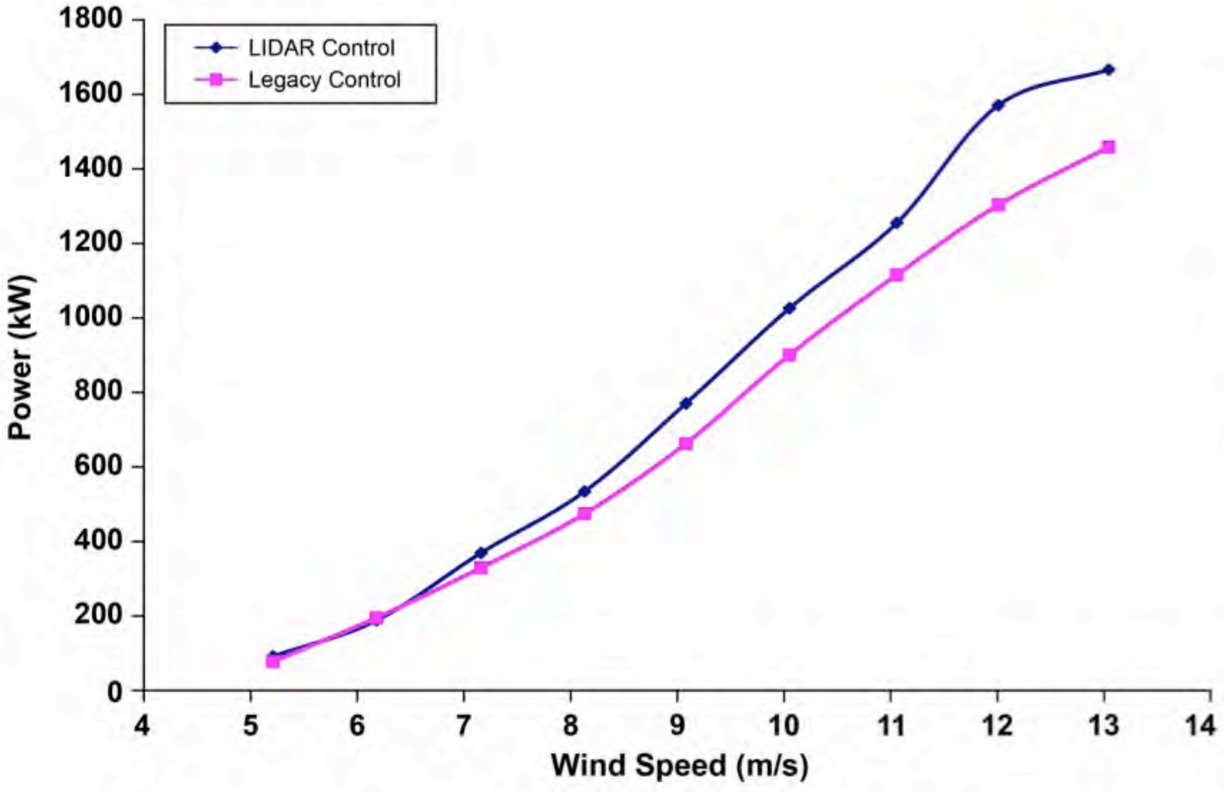
Ever-Increasing Value of Advanced WTG Controls

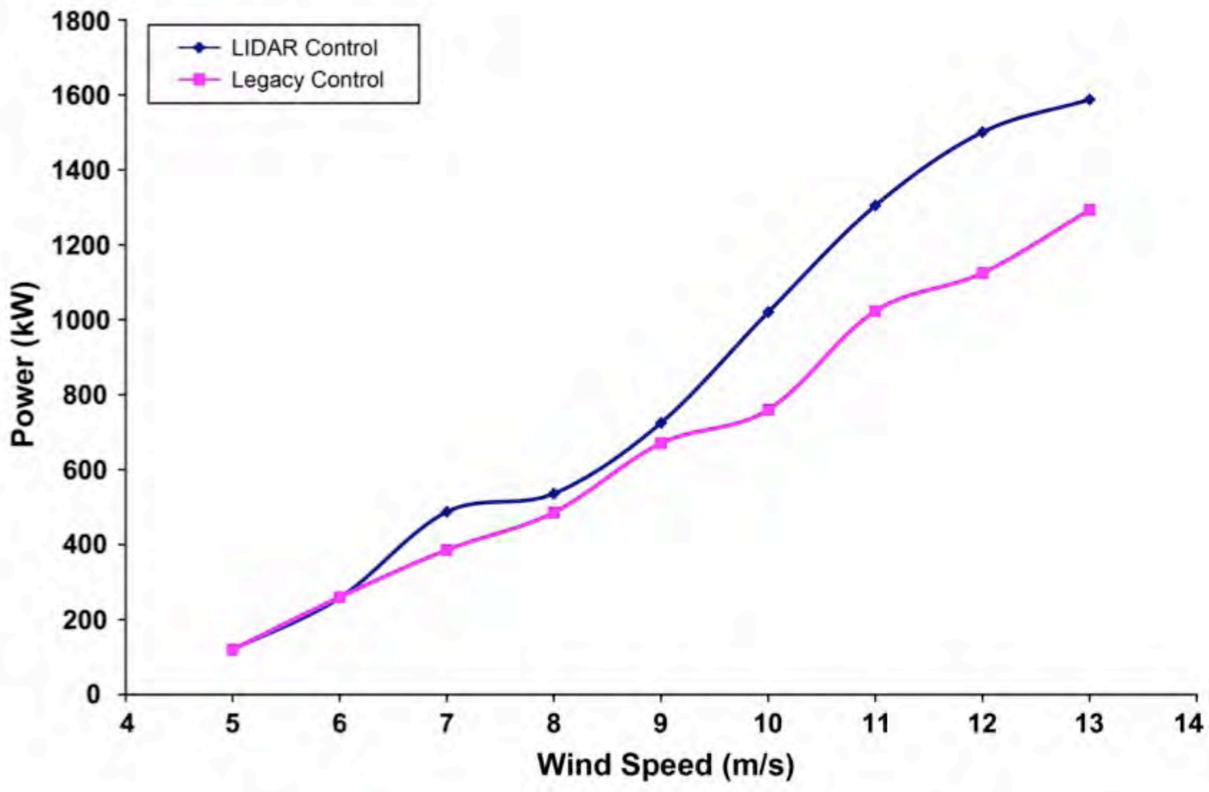
Incremental and Additive Control Improvements





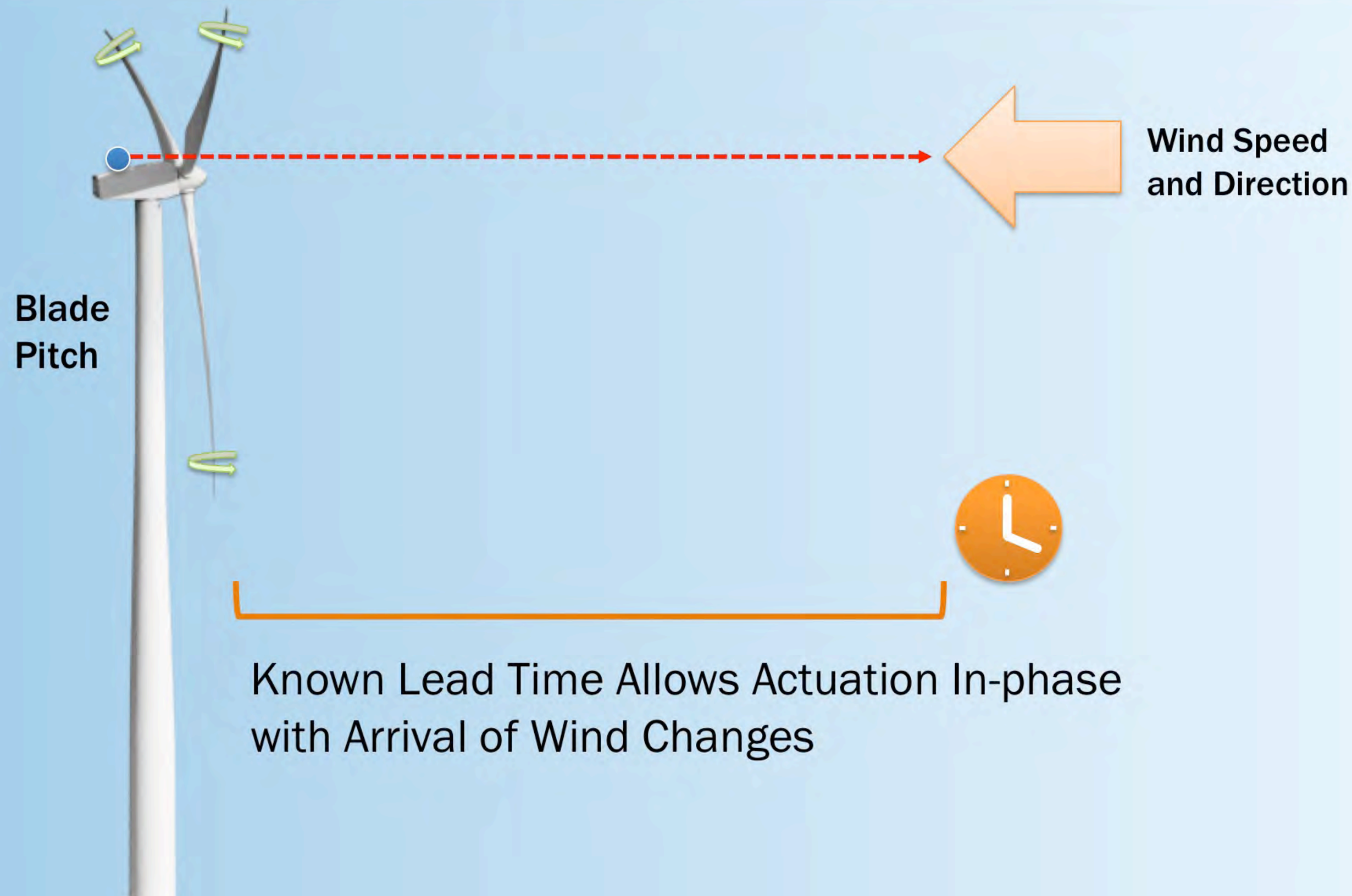
LIDAR Power Improvement from Yaw





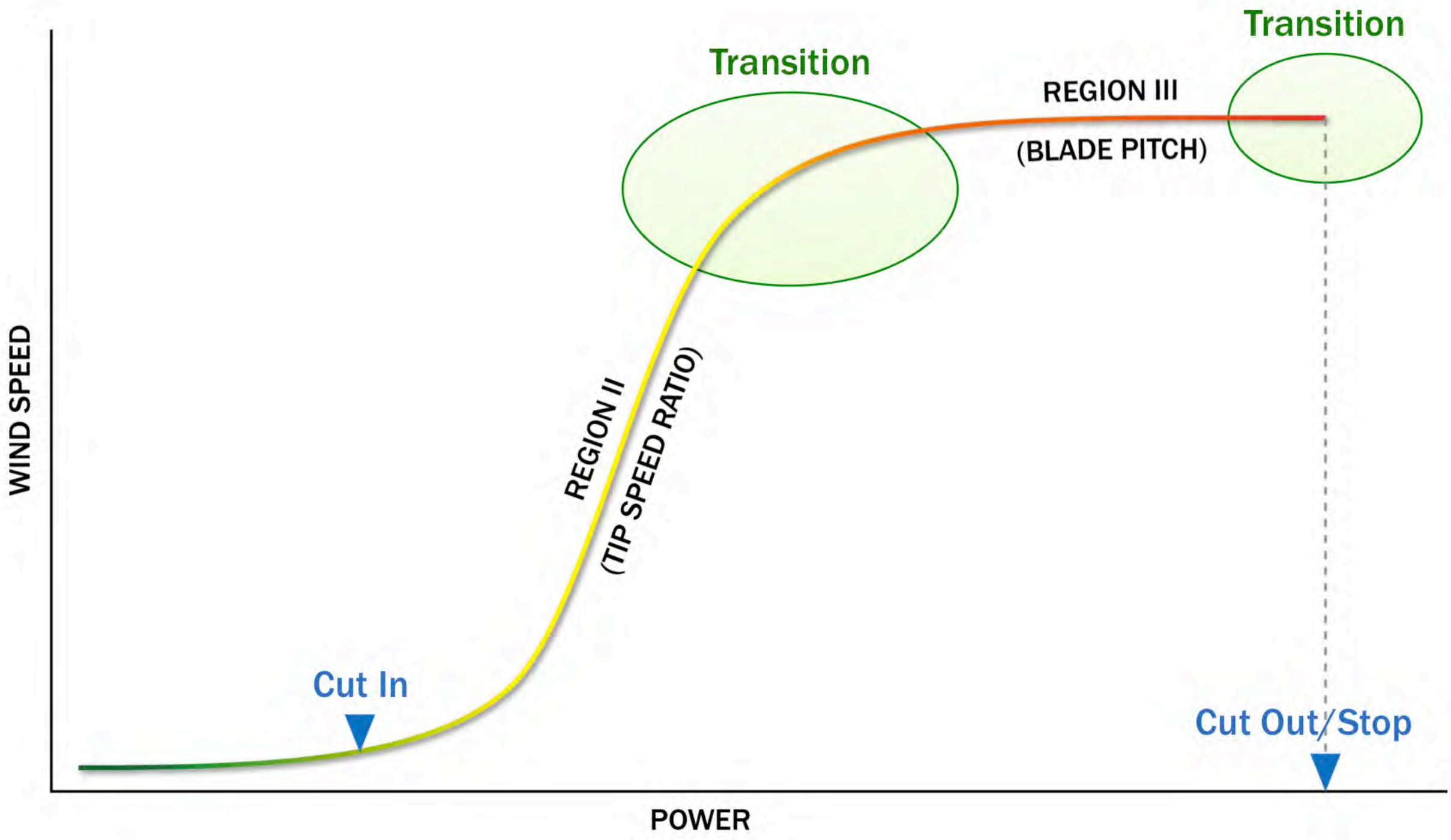
Numerous Field Trials Have Confirmed Increased Power In Region II with LIDAR Data Yaw Control

Anticipatory Blade Pitch Control



Known Lead Time Allows Actuation In-phase with Arrival of Wind Changes

WTG Control Regimes



Transitions

- Legacy Controls Lag Wind Changes
- Forward-Looking LIDAR Informed Yaw and Blade Pitch Control Achieves Rated Power at Lower Wind Speed and Can Operate Safely at Higher Speed before Cut Out
- Field Data and Calculations Show Both Result in More Average Energy and Increased Capacity Factor

Maximum and Minimum Power

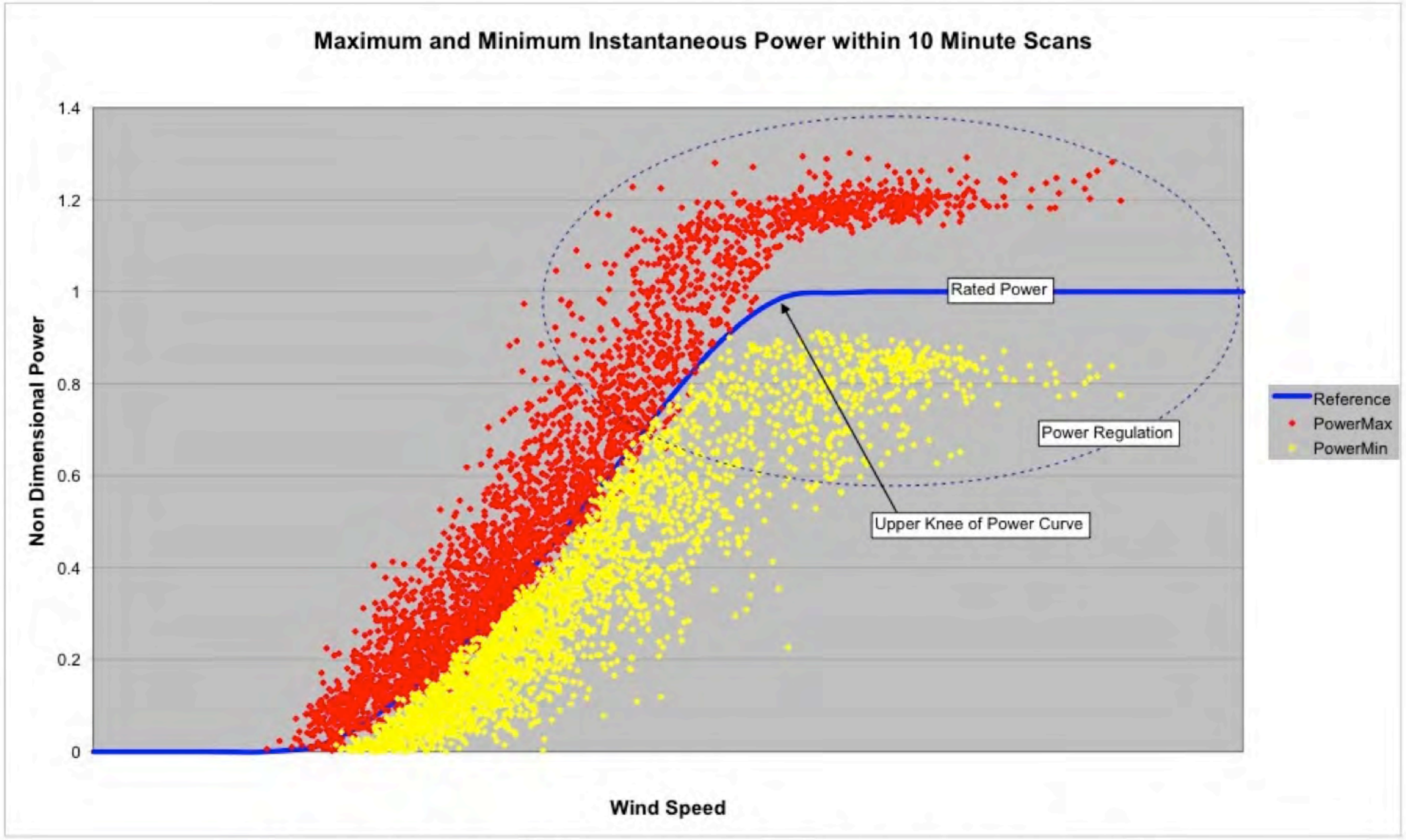


Figure 1. Maximum and Minimum Instantaneous Power

Courtesy of H. Drees

Power Curve with Anticipatory Collective Pitch

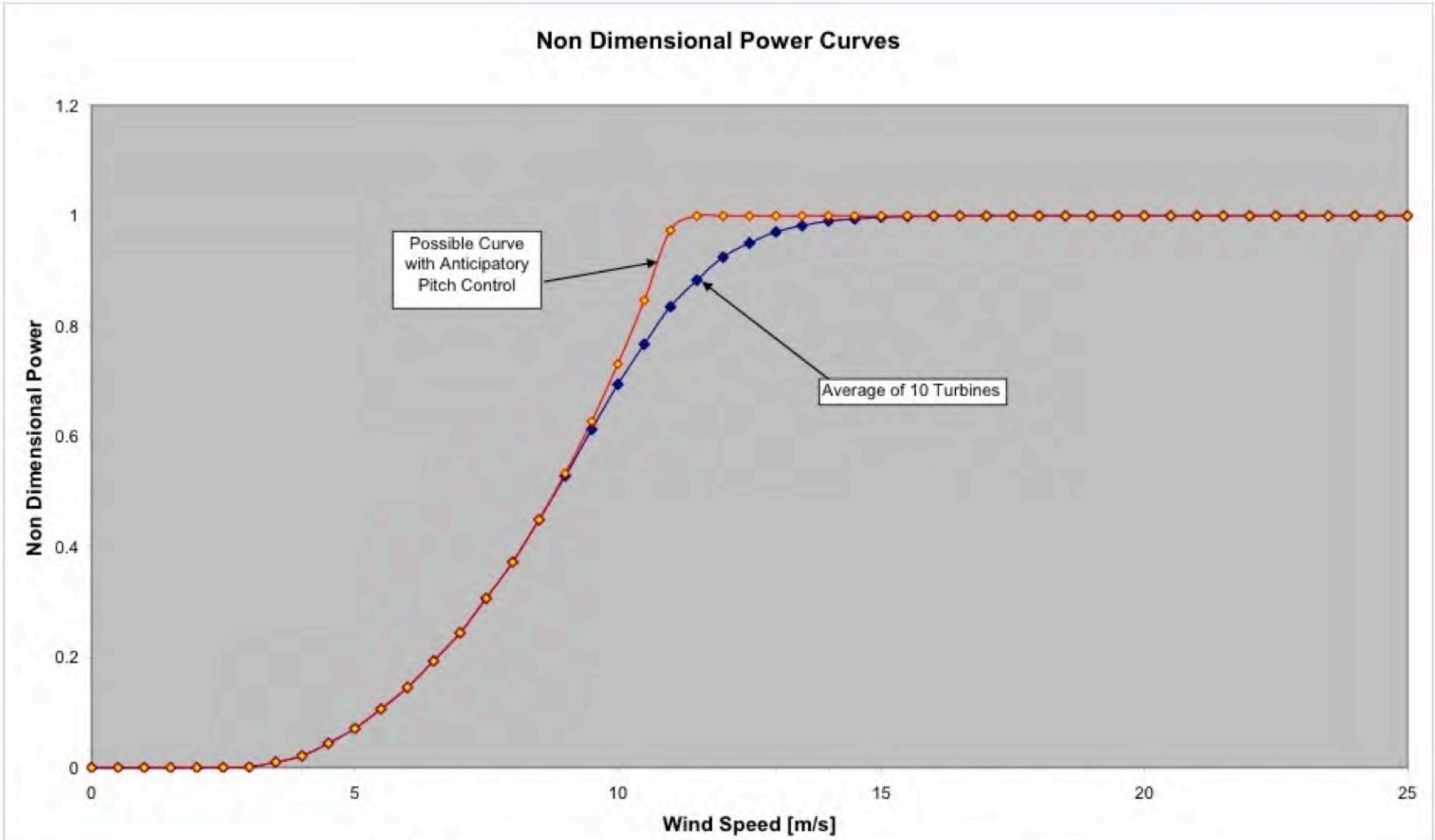


Figure 2. Representative Average and Modified Power Curves

Courtesy of H. Drees

Anticipatory Collective Pitch Improvement vs. Wind Speed

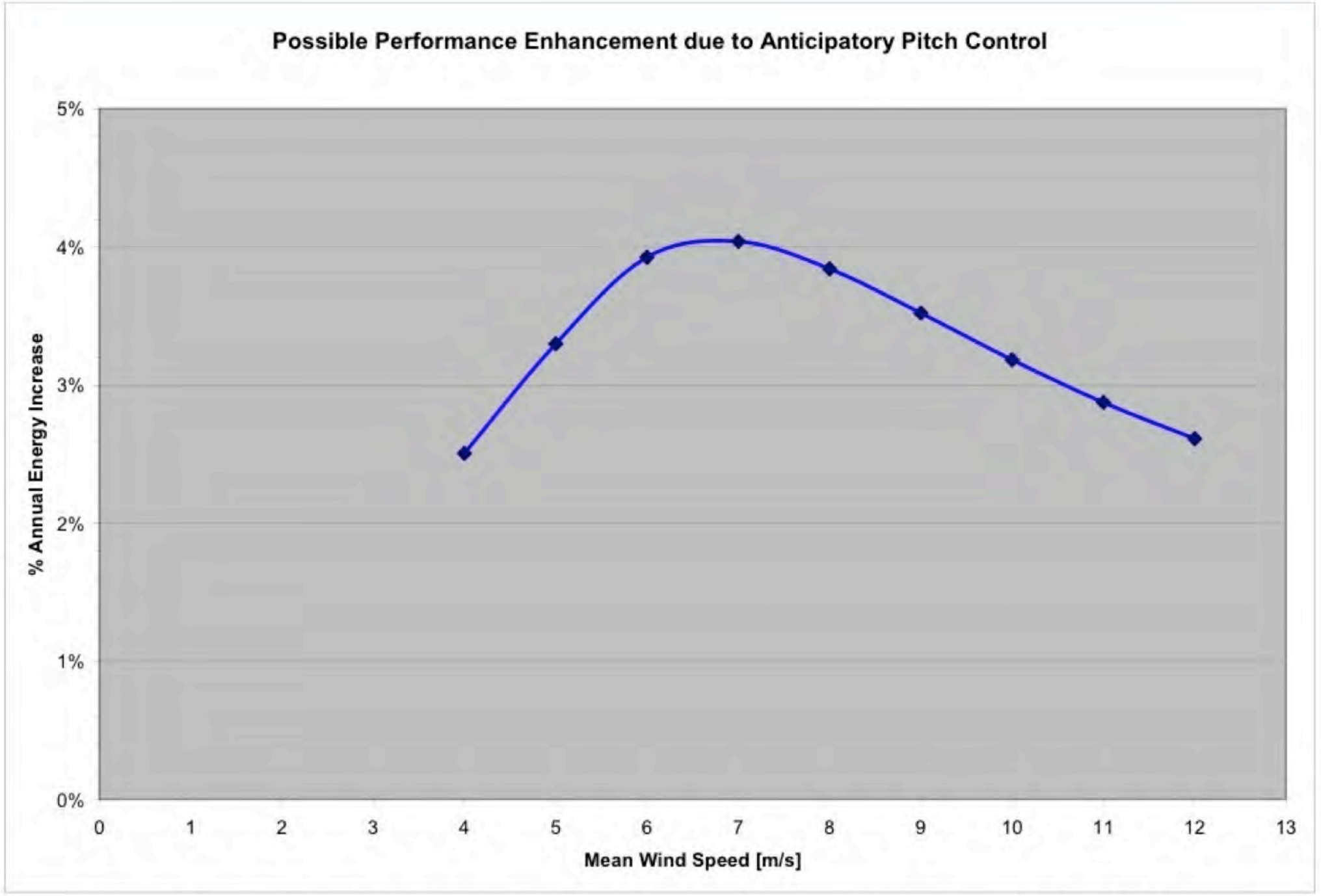
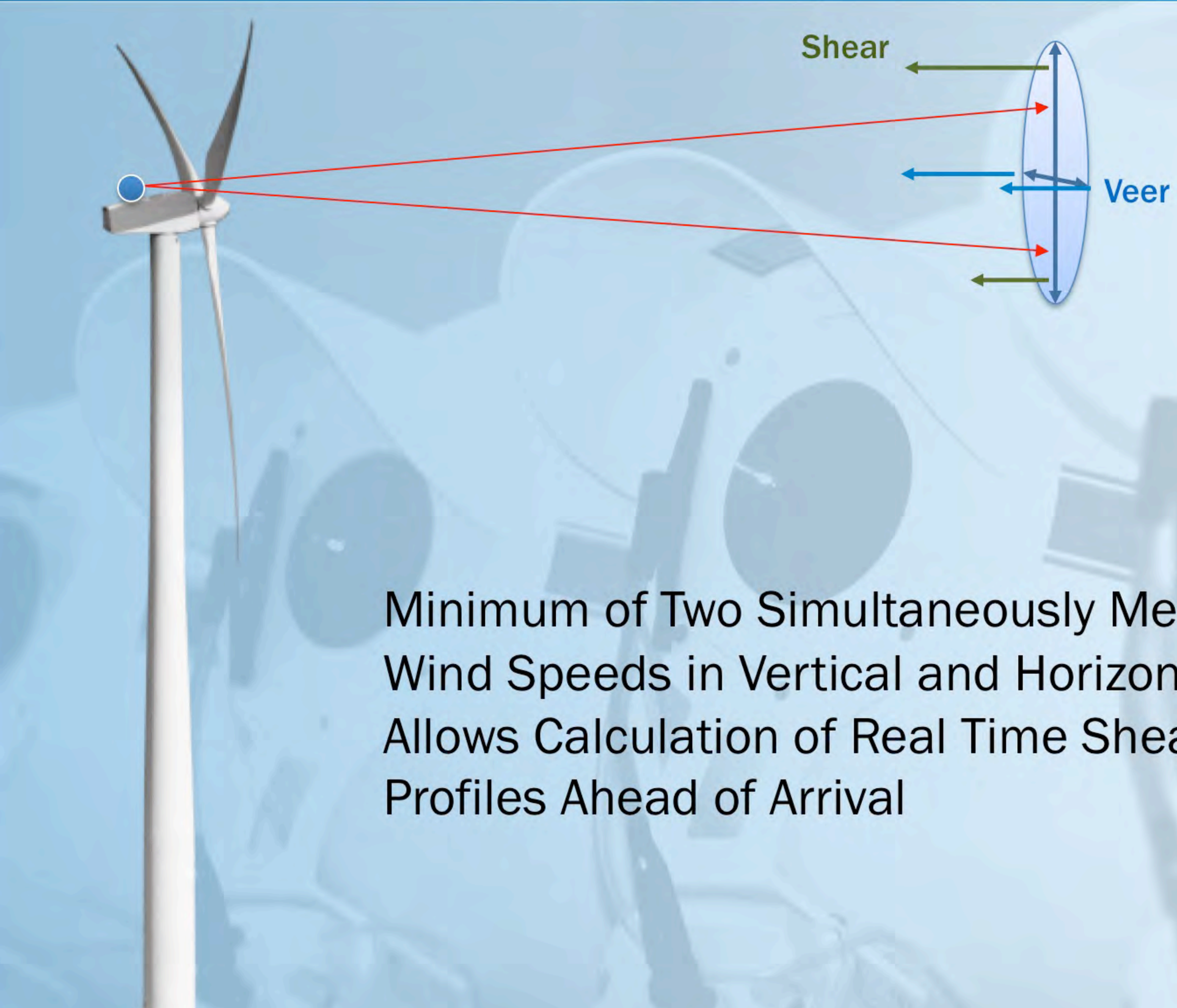


Figure 4. Possible Performance Enhancement due to Anticipatory Pitch Control

Courtesy of H. Drees

LIDAR Shear and Veer Measurement



Minimum of Two Simultaneously Measured Wind Speeds in Vertical and Horizontal Planes Allows Calculation of Real Time Shear and Veer Profiles Ahead of Arrival

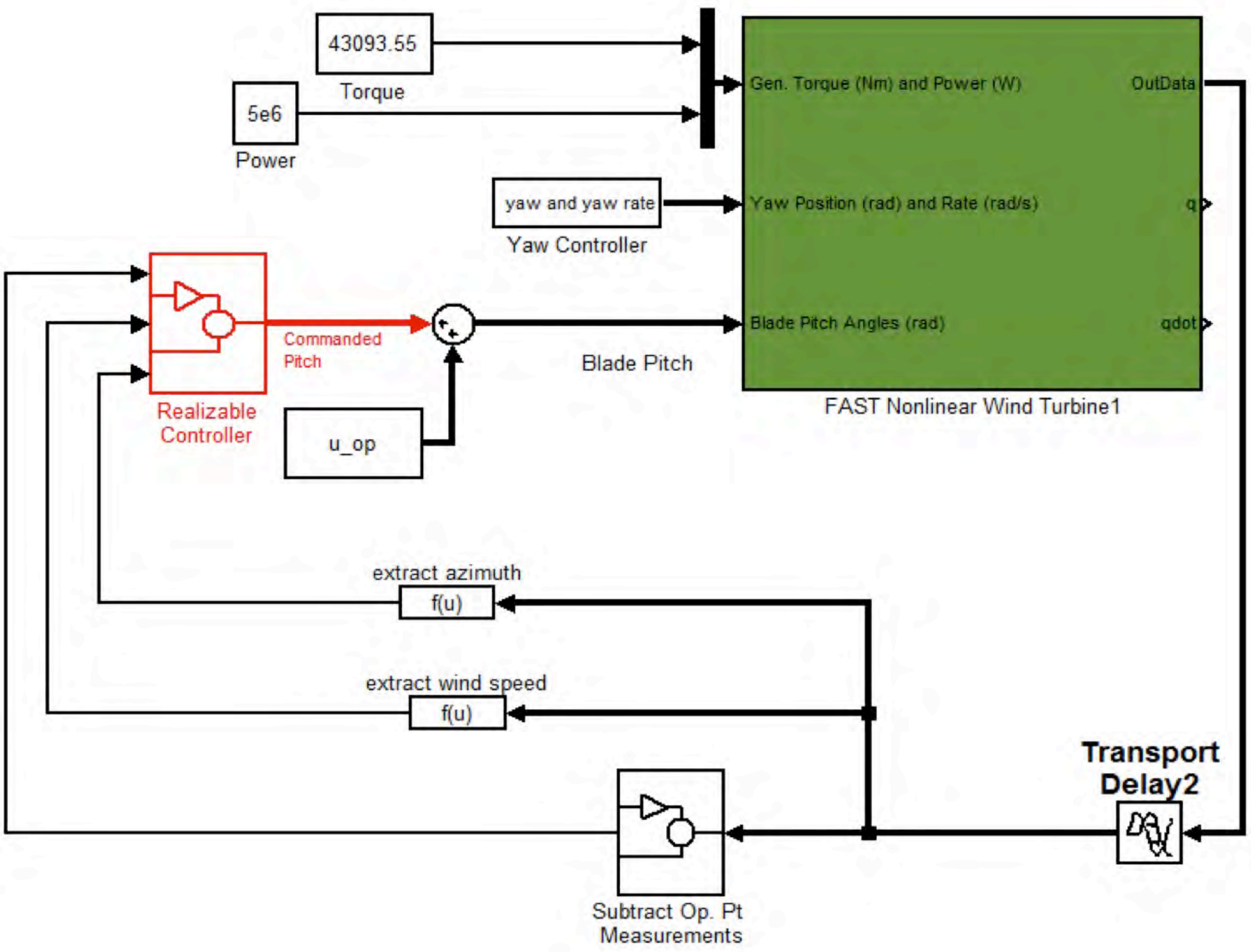
Advantages

- Look Ahead LIDAR Allows Anticipatory Control Logic
- Collective Blade Pitch Unable to Adjust to Shear and Veer
- Individual Blade Pitch Control Based on Spatial LIDAR Data Adjusts to Wind at Blade Location in In-Flow
- Eliminates Asymmetrical Aerodynamic Loading therefore Reducing Wear/Damage

Individual Blade Pitch Control Model

- DAC Individual Blade Pitch Simulation by Dr. Mark Balas (Univ of Wy)
- Use of LIDAR Gives Measured Shear Input to Control Loop
- LIDAR Data Simulation Resulted in Significantly More Stable Control Compared to Use of Disturbance Estimator

FAST Model


43093.55
Torque
5e6
Power
Gen. Torque (Nm) and Power (W)
OutData
yaw and yaw rate
Yaw Controller
Yaw Position (rad) and Rate (rad/s)
q
Commanded
Pitch
Blade Pitch
Blade Pitch Angles (rad)
qdot
Realizable
Controller
u_op
FAST Nonlinear Wind Turbine1
extract azimuth
f(u)
extract wind speed
f(u)
Transport
Delay2
Subtract Op. Pt
Measurements

Control Loop Diagram

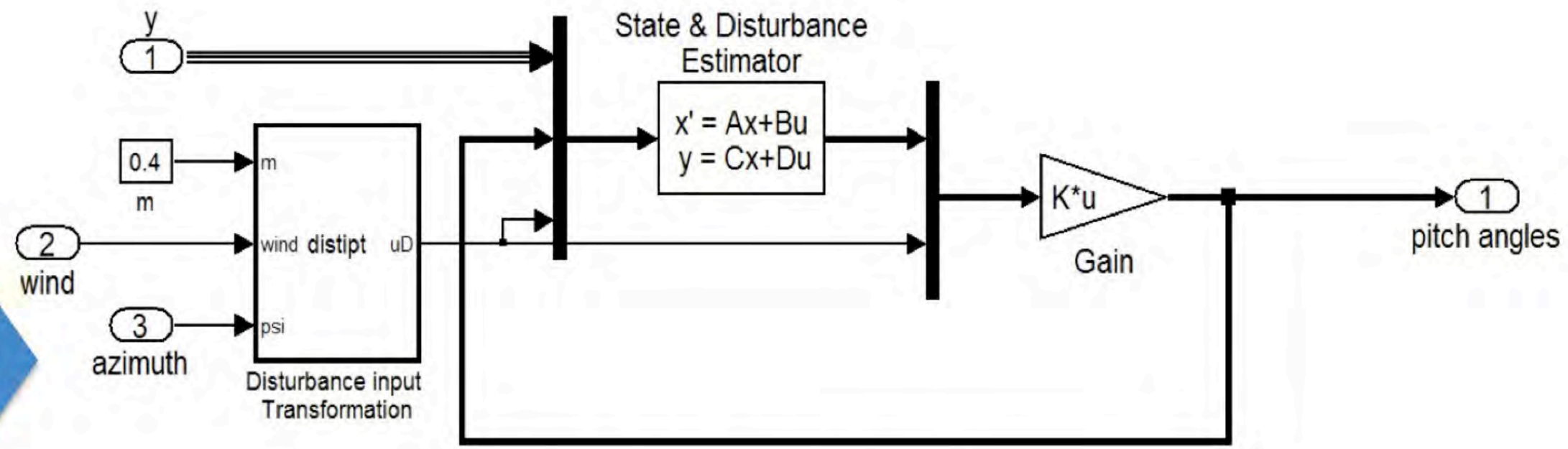


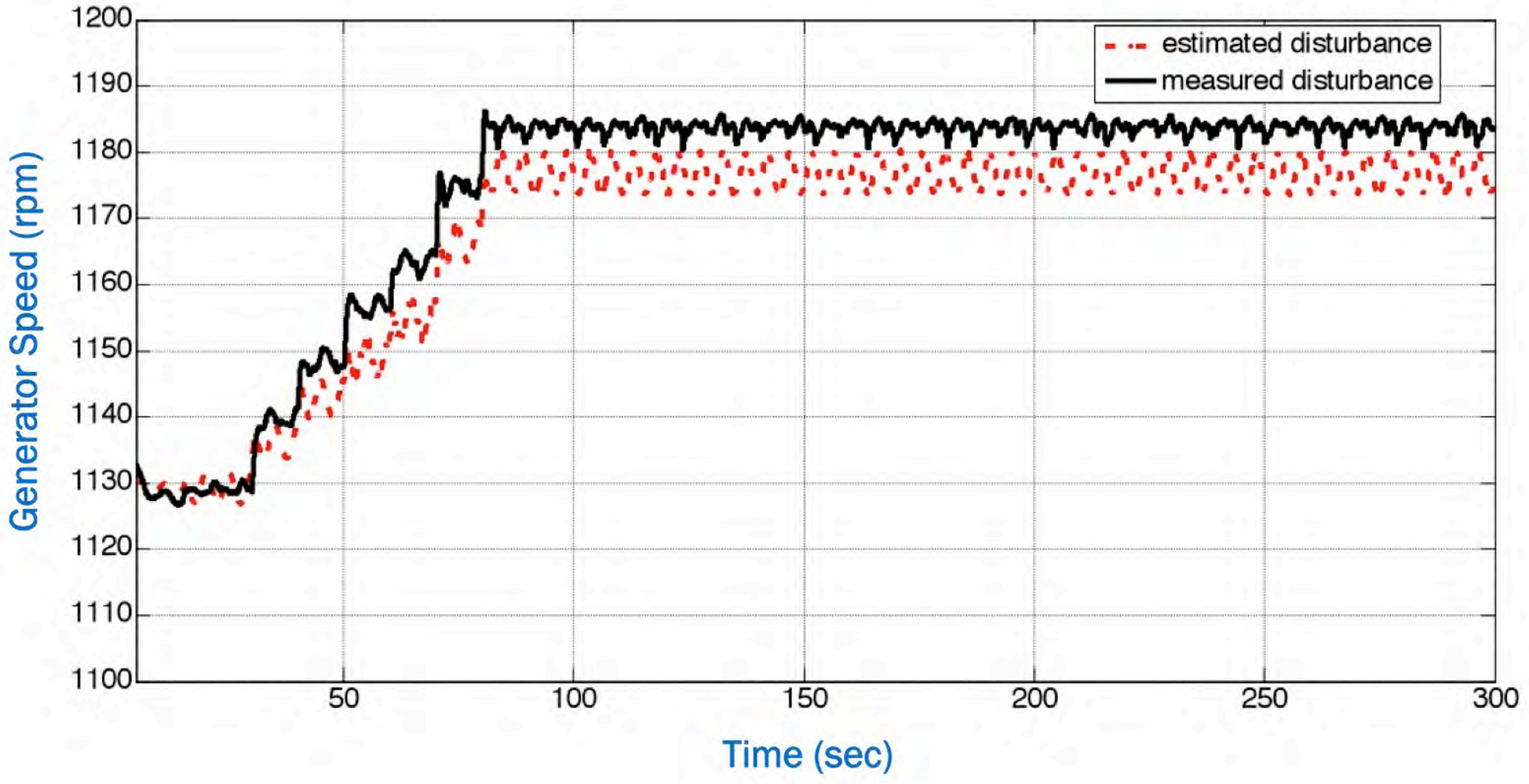
Figure2. Controller with state estate estimator
and disturbance input transformation

LIDAR INPUT

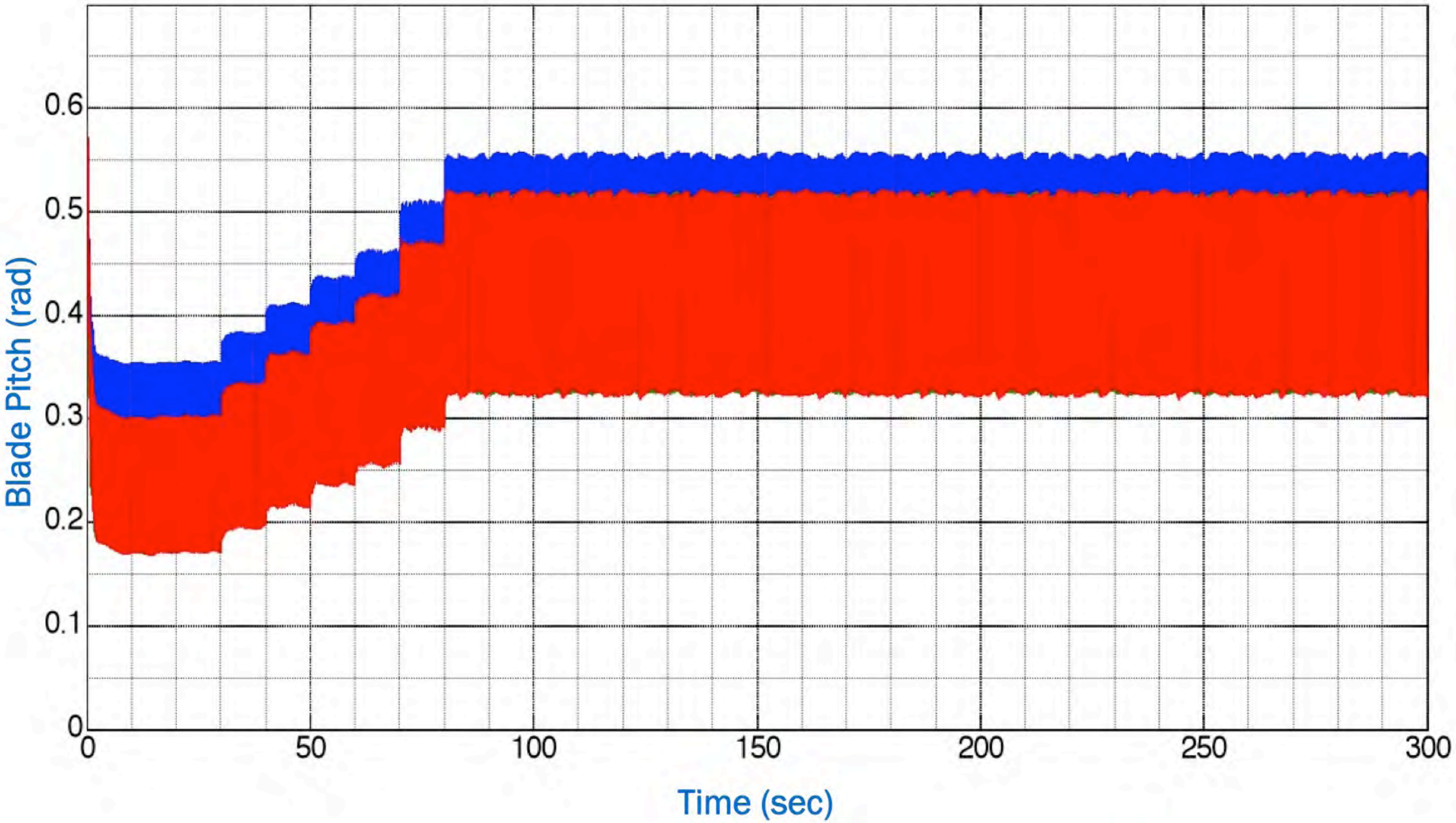
Results

- Generator Speed in Region III (IAW FAST) Control Under Shear and Wind Disturbances
- Individual Blade Pitch Position/Change Under Shear and Wind Disturbances (both as measured and as simulated)
- With LIDAR Blade Pitch Position and Generator Speed had Smoother Control Compared to Simulated Disturbance

Generator Speed Control

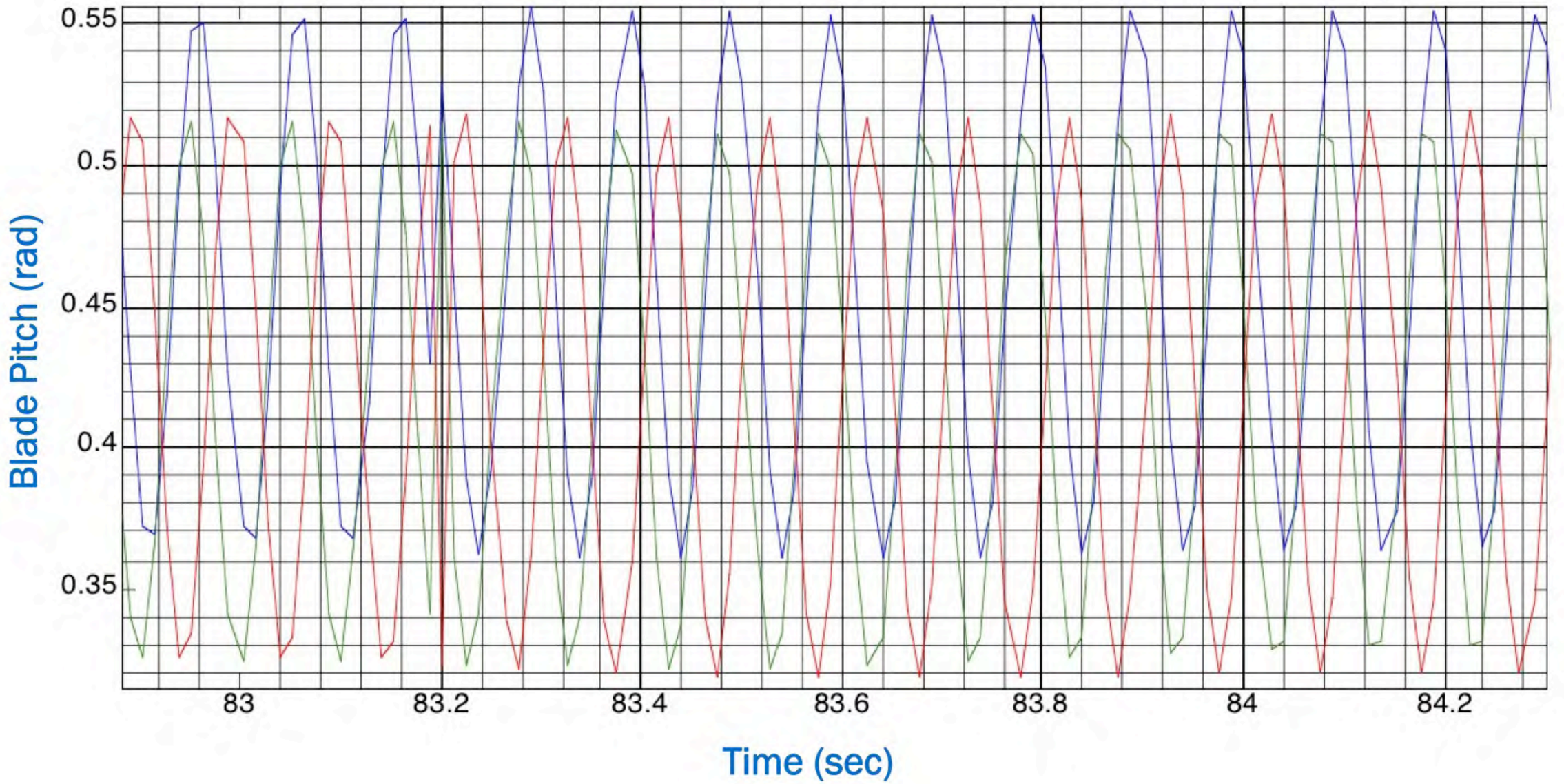


Blade Pitch



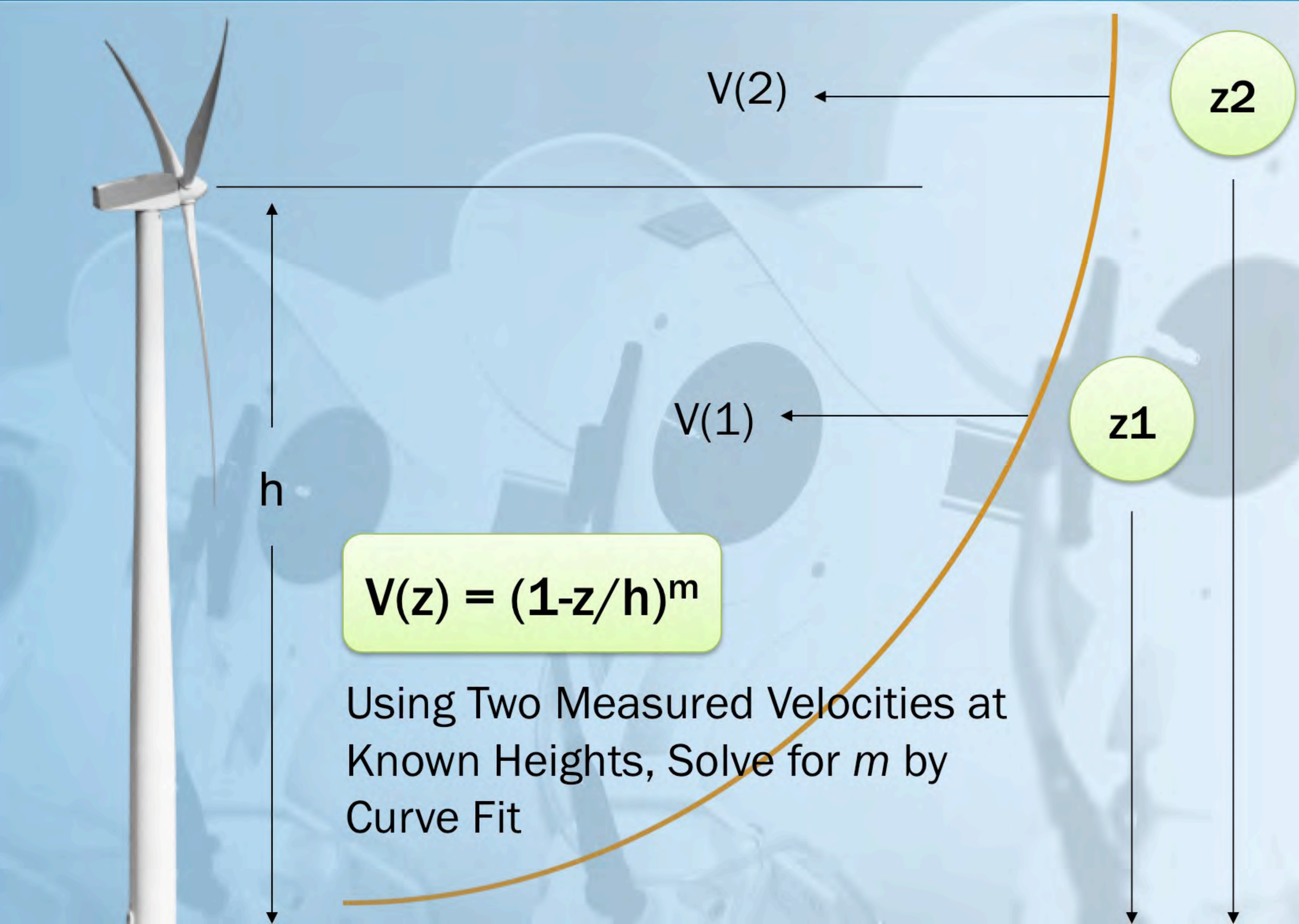
Blade Pitch with Measured Disturbance

Blade Pitch



Zoomed In View of Previous Figure

Shear Coefficient Determination



$$V(z) = (1-z/h)^m$$

Using Two Measured Velocities at Known Heights, Solve for *m* by Curve Fit

Conclusions

- Wind Turbine Control Improvements from Yaw thru Collective Pitch are Promising
- IBP Control Offers Multiple Additional Benefits
- Forward Looking LIDAR Provides Means to Inform Controls of Shear and Veer Before It Arrives
- Individual Blade Pitch Control from This Input Has Been Successfully Simulated
- Next Step: Install Control Algorithm On Full Scale WTG with LIDAR

Thank You

For More Information Please Contact:

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