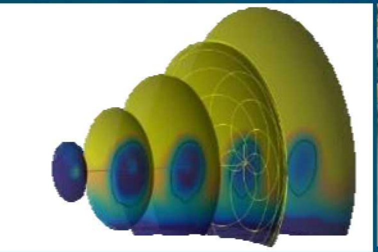
SAND2019-8317PE

NextEra Meeting



PRESENTED BY

Josh Paquette and Carsten Westergaard
Wind Energy Technology Department

SAND2019-5680 C

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Wakes & Wake Steering

Further questions, please contact:

Josh Paquette, japaque@sandia.gov

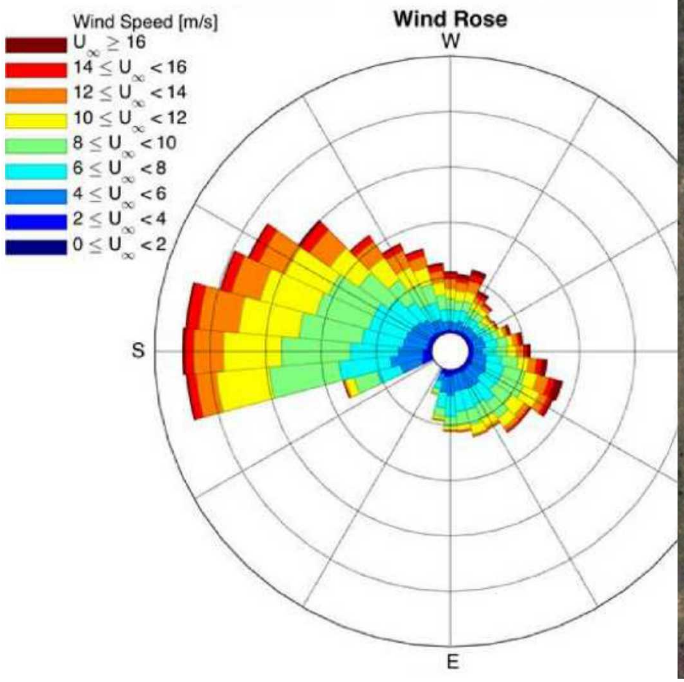
SWiFT Facility Overview

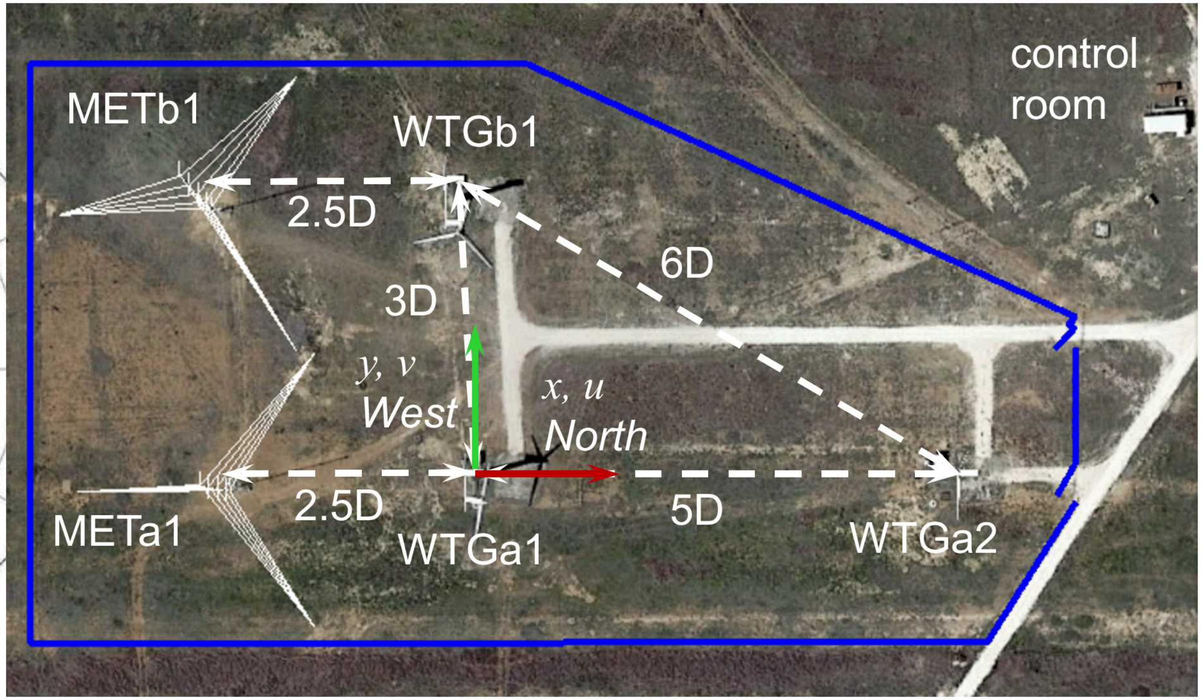
SWiFT facility created to:

- Measure wind plant flows and turbine-turbine interactions
- Perform prototype testing of innovative rotor technology

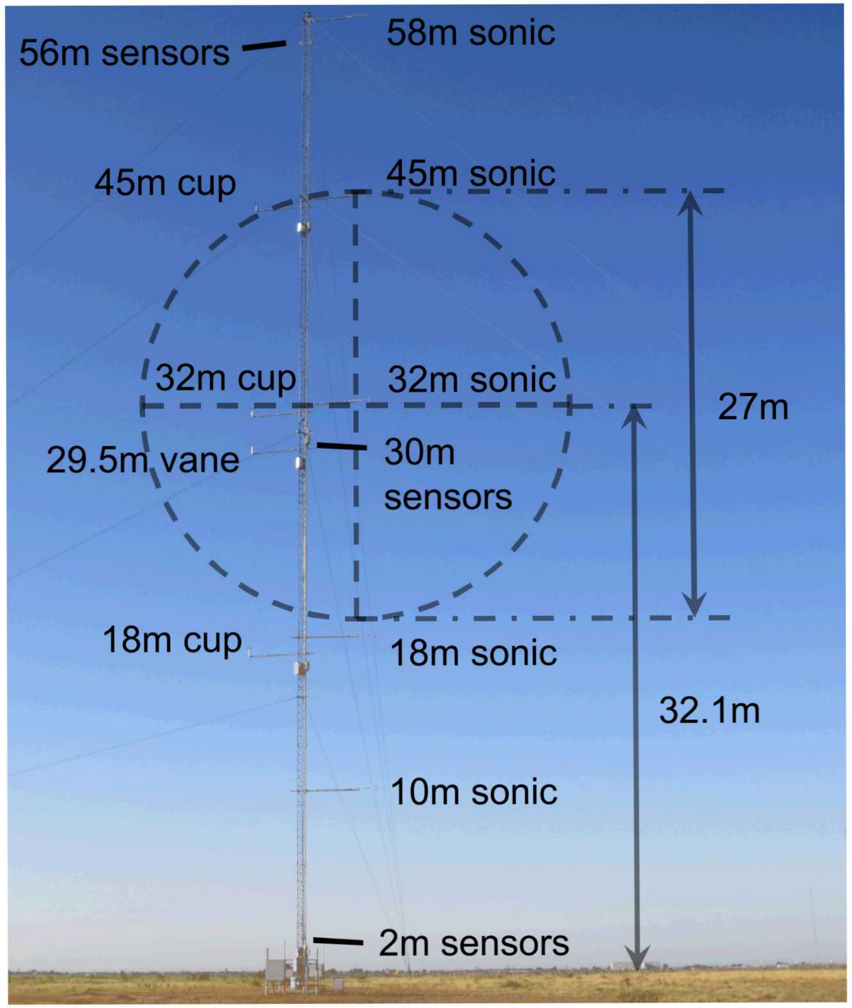
Wake steering experiment sought to quantify wake deflection vs. yaw offset and the corresponding effects on a two-turbine system

- Characterize wake shape, velocity deficit, turbulence, and dynamics under various conditions





SWiFT Site Instrumentation



All sensor channels GPS timestamped

Inflow: 59m MET Tower (5 sonics)

Turbines

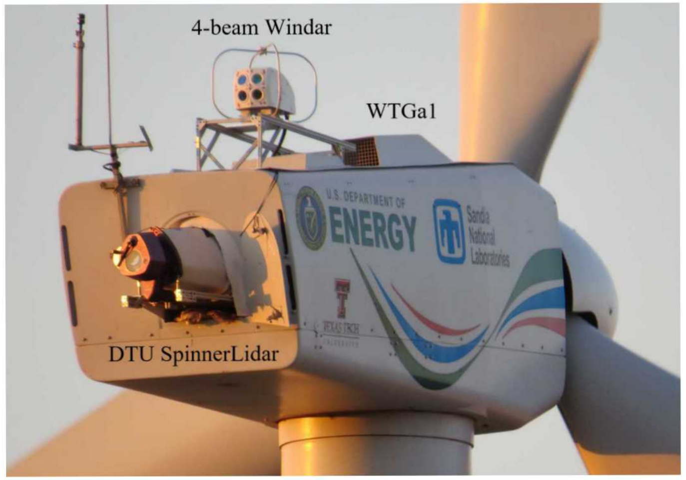
- WTGa1, upstream turbine highly instrumented, 1 blade root strain measured 4/19/17 – 7/14/17
- WTGa2, waked turbine highly instrumented, 1 blade root strain measured 7/11/17 – 7/13/17

Wake Flow Diagnostic:

- DTU SpinnerLidar

Data collected:

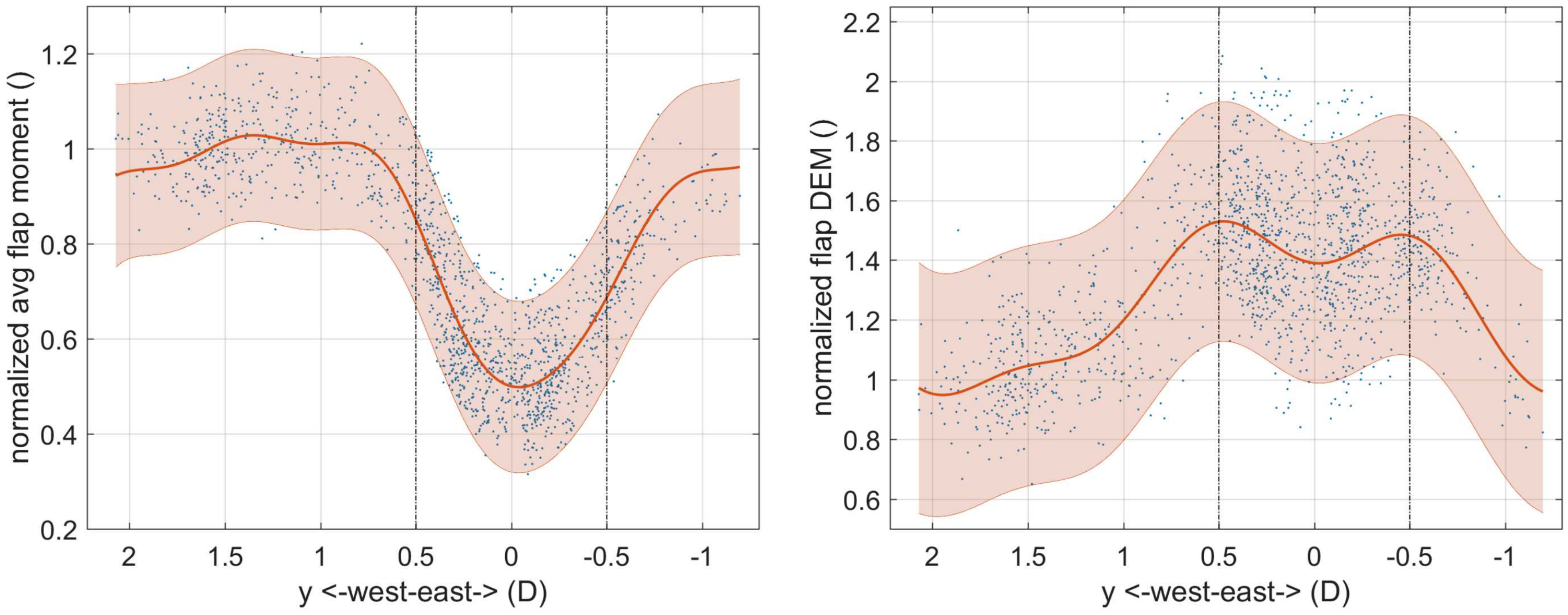
- 12/15/16 – 7/14/17



Review SWiFT wake video (online)

https://vimeo.com/212649604

Flap Moment, Average and DEM



Fatigue loads higher under waked conditions

DEM normalized by fit of non-waked DEM with met tower hub height wind speed

Partially waked turbine has 10% higher DEM than fully waked case

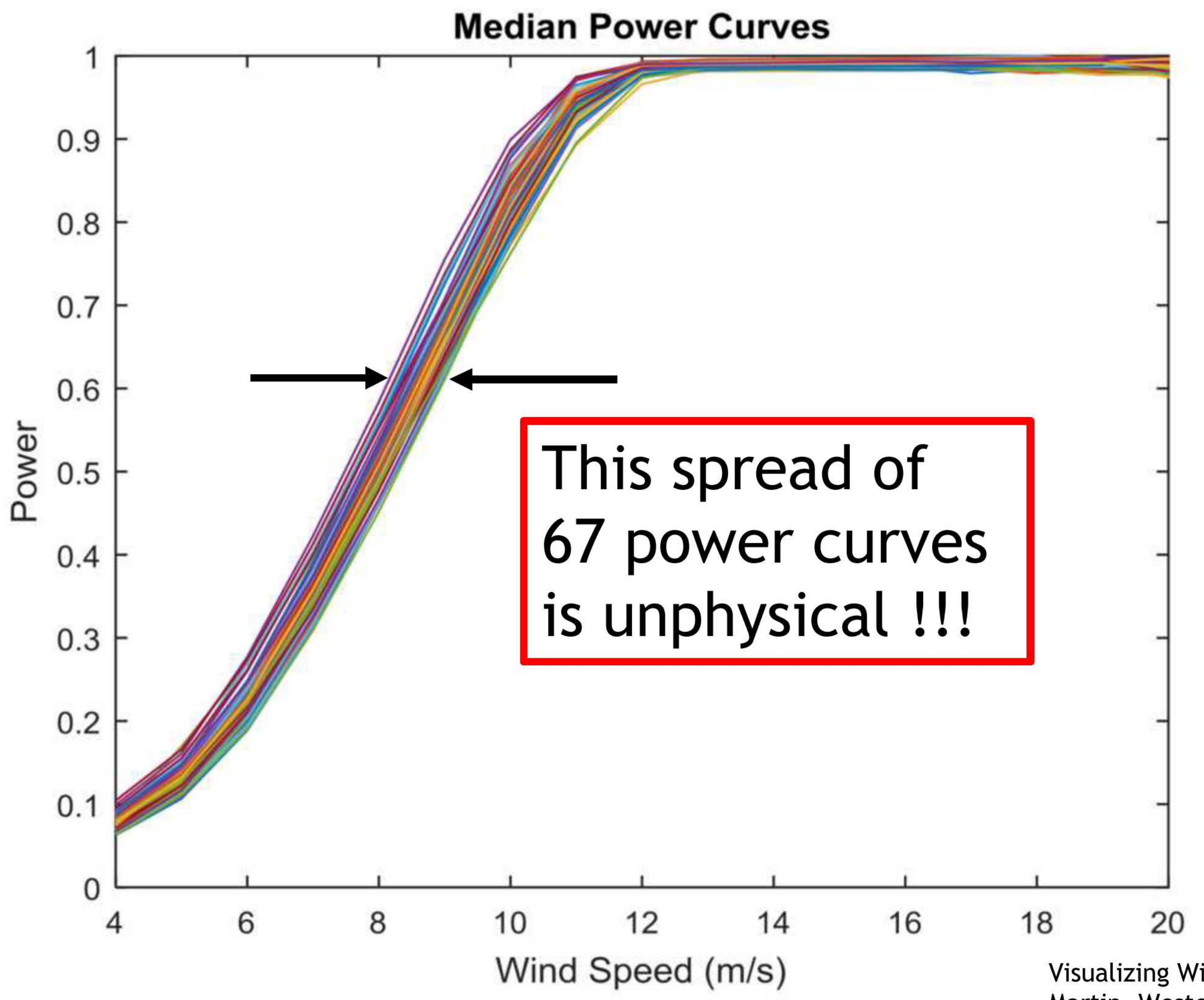
DEM returns to non-waked conditions at lateral wake positions farther than 1.5D

Data analytics

Further questions, please contact:

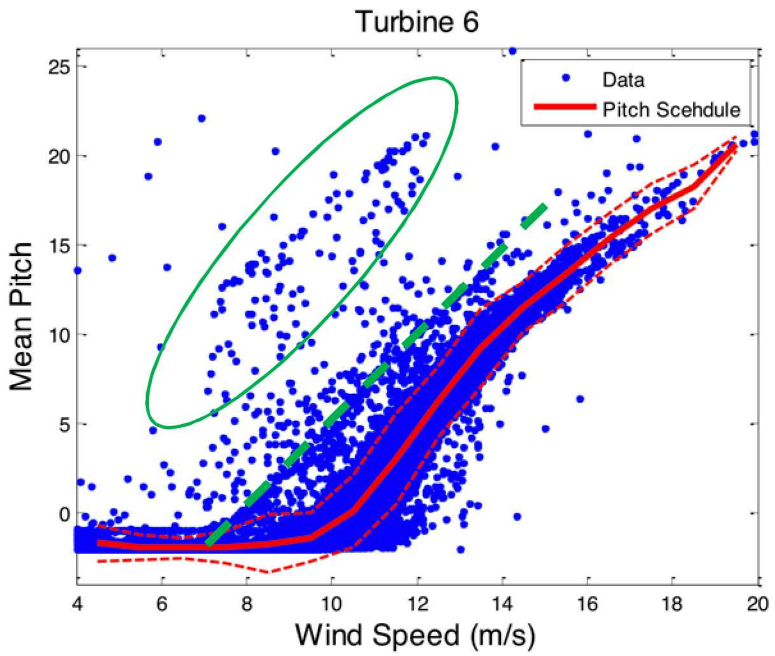
Carsten Westergaard, cahwe@sandia.gov

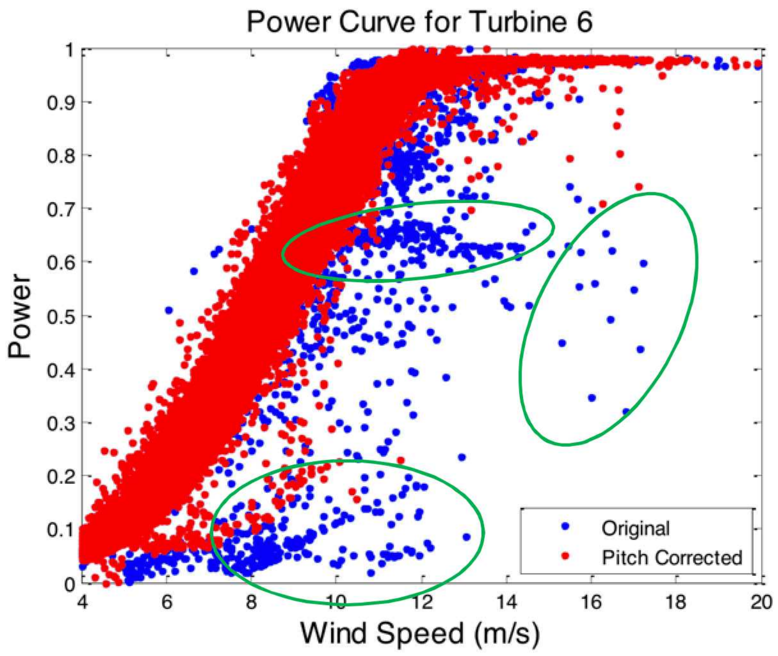
Wind speed reference is a challenge



Visualizing Wind Farm Wakes Using SCADA Data
Martin, Westergaard, White, and Karlson,
SANDIA REPORT SAND2016-4484

Filtering

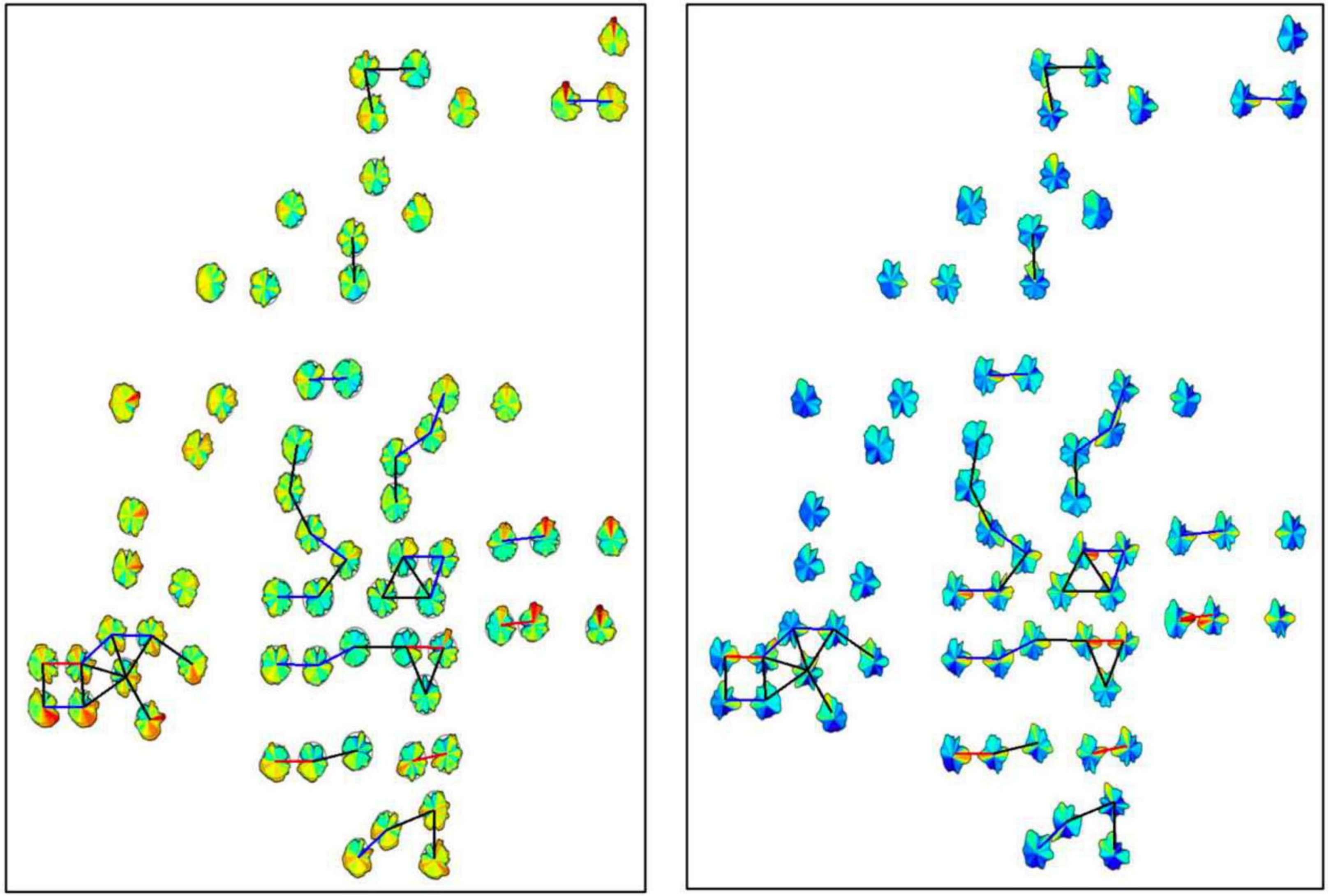




- Obvious unphysical, transitional and abnormal data **needs to be removed**
- Check both correlated data and temporal dependencies
- Check for data interpolation (more common than you think) and remove those data points

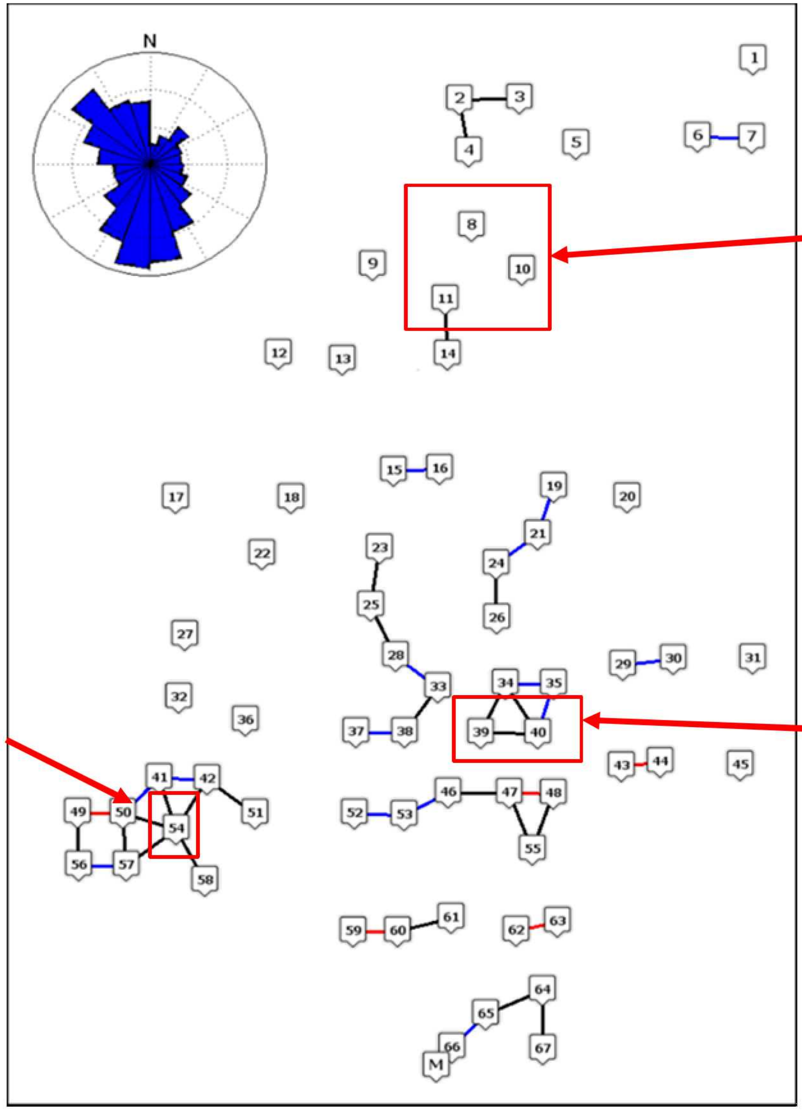
Visualizing Wind Farm Wakes Using SCADA Data
Martin, Westergaard, White, and Karlson,
SANDIA REPORT SAND2016-4484

Performance of 67 turbines over 1.5 years



Visualizing Wind Farm Wakes Using SCADA Data
Martin, Westergaard, White, and Karlson,
SANDIA REPORT SAND2016-4484

Two examples



Sparsely waked

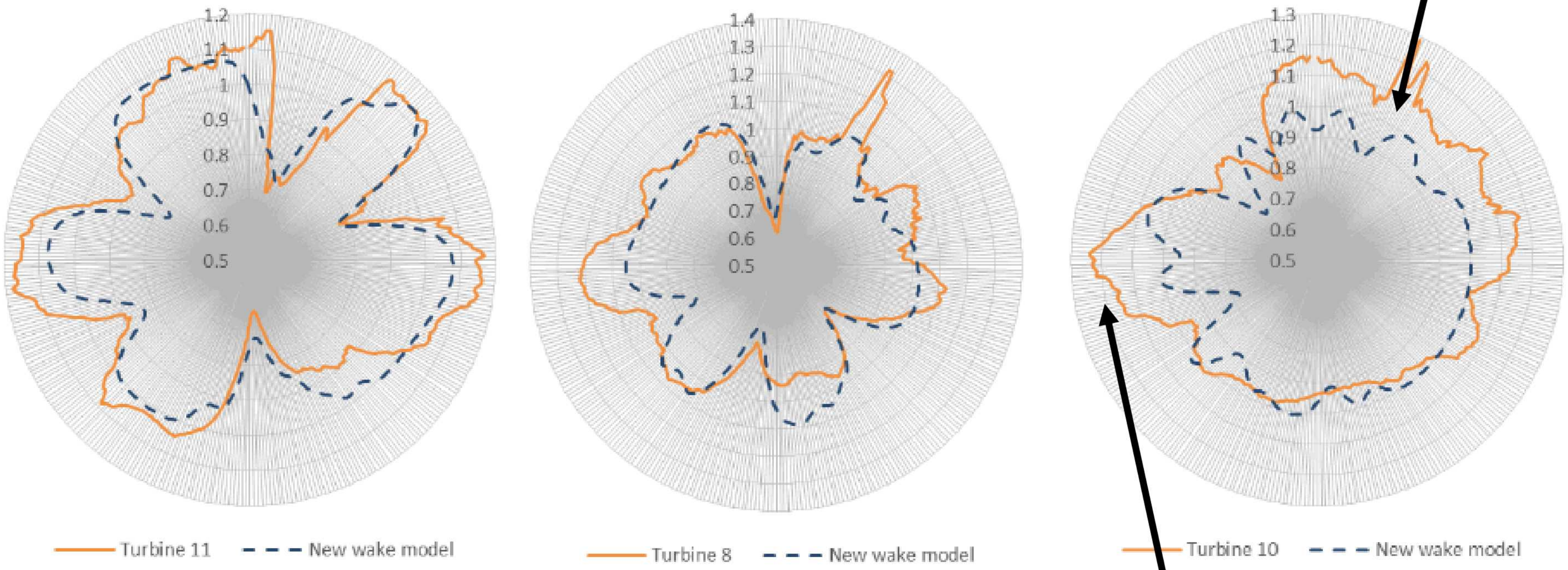
Heavily waked

Closely waked

Visualizing Wind Farm Wakes Using SCADA Data
Martin, Westergaard, White, and Karlson, SANDIA REPORT SAND2016-4484

Example: Sparsely waked

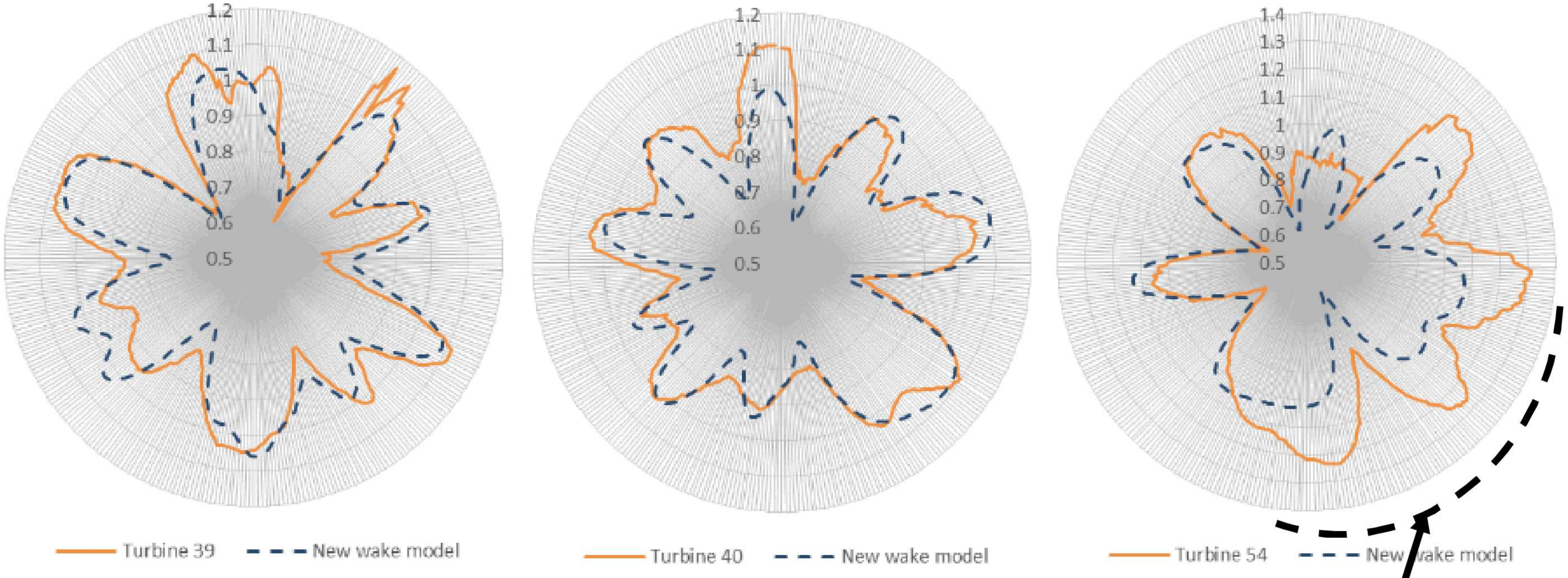
Tree cluster,
Farm building
Small hills



Multi-row of turbines
Other wind farm

Visualizing Wind Farm Wakes Using SCADA Data
Martin, Westergaard, White, and Karlson, SANDIA REPORT SAND2016-4484

Example: Heavily and closely waked



High speed-up seen at neighbor turbines, probably from the upstream wind farm

Visualizing Wind Farm Wakes Using SCADA Data
Martin, Westergaard, White, and Karlson, SANDIA REPORT SAND2016-4484

Areas of interest for discussion

- Power performance analytics, datamining for specific issues
  - Wake impact analytics
  - Long term degradation, for example leading edge issues
  - Controller related issues: yaw, pitch, setpoint
  - Upgrades
  - Operating environment impact (wind shear, turbulence, etc.)

- Power curve correction methods

- Performance and life time events

Rotors

Further questions, please contact:

Josh Paquette, japaque@sandia.gov

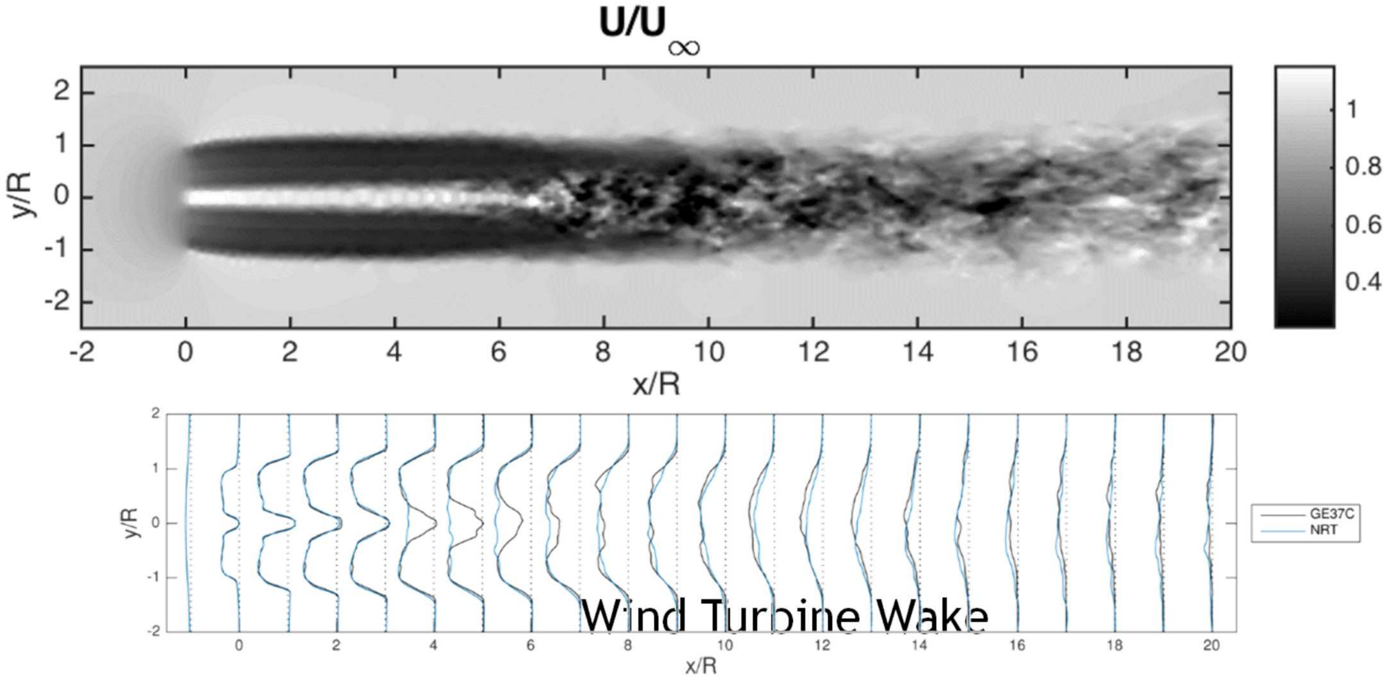
National Rotor Testbed

Modern blade for SWiFT turbines designed by Sandia to replicate wakes of the most common utility scale rotor in the U.S.

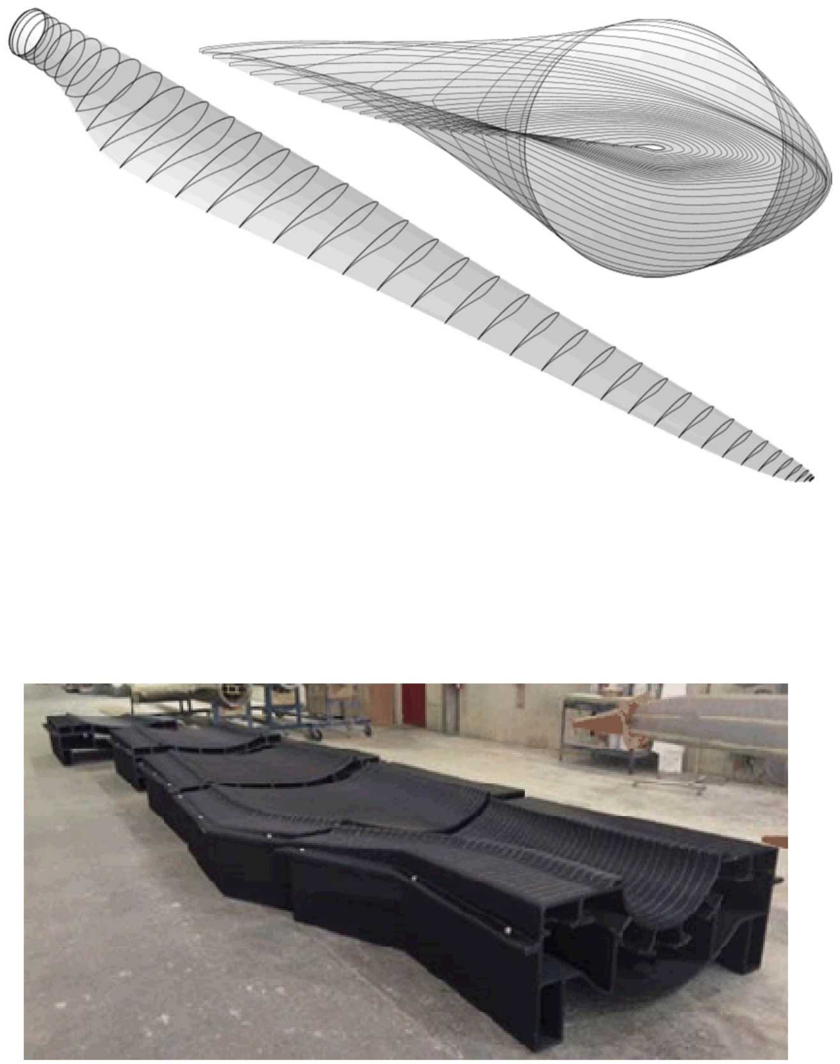
Blade set will eventually feature removable tips and aerodynamic sensors

Create a scaled wake of a GE37c wind turbine with new blades installed at SWiFT

Science panel review of scaling process

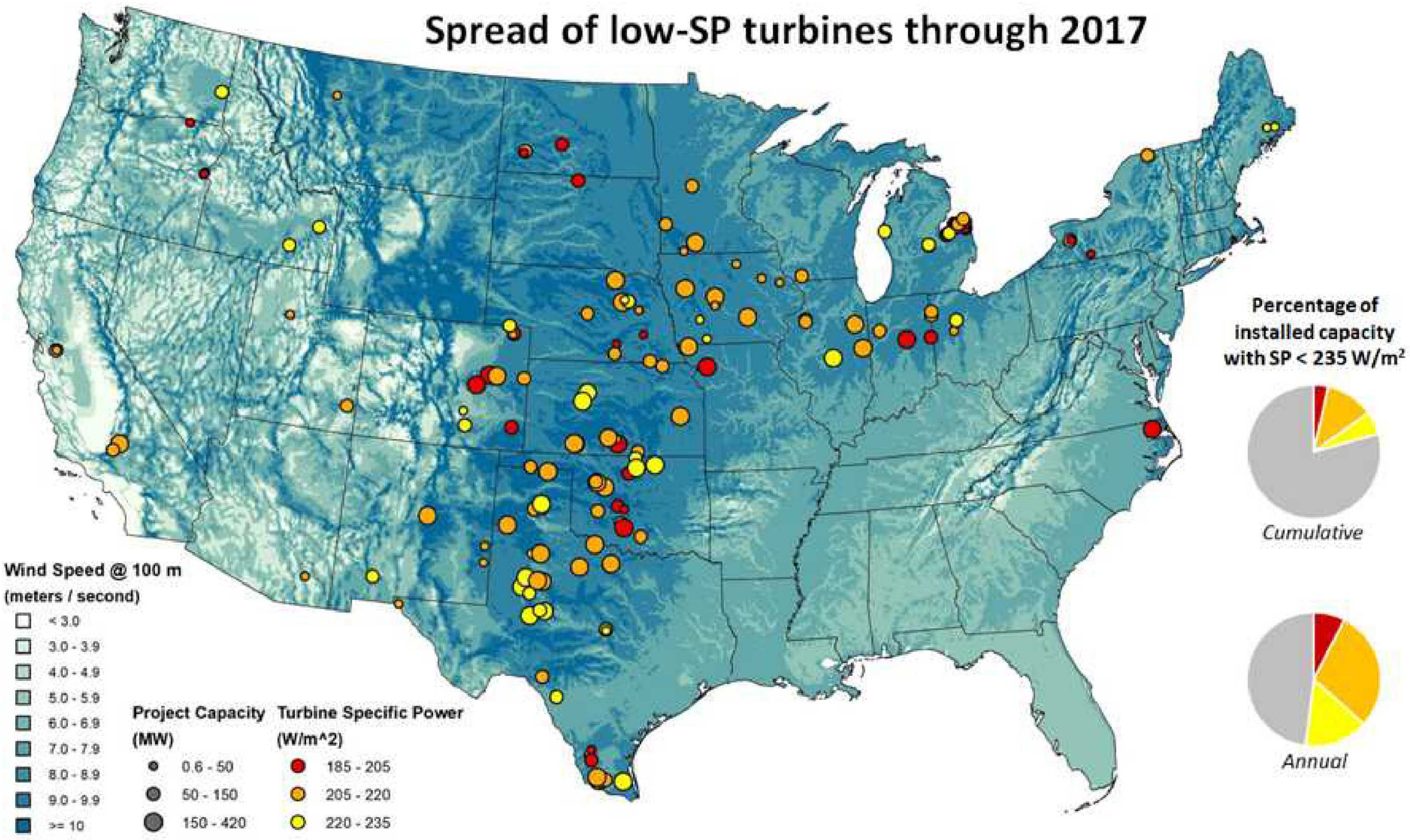


Wind Turbine Wake

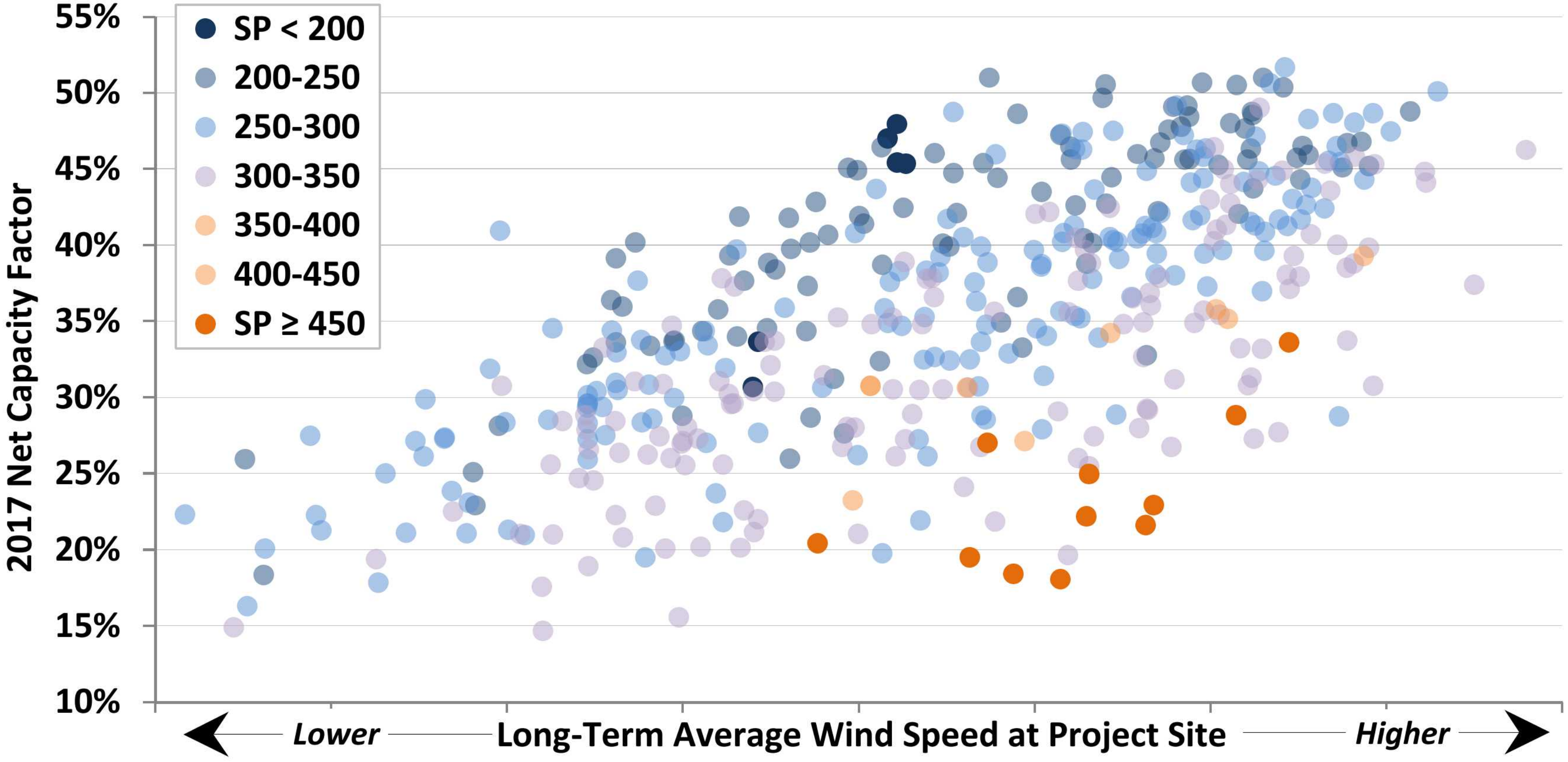


NRT Blade Design and Mold

Low-Specific Power Machine Trends

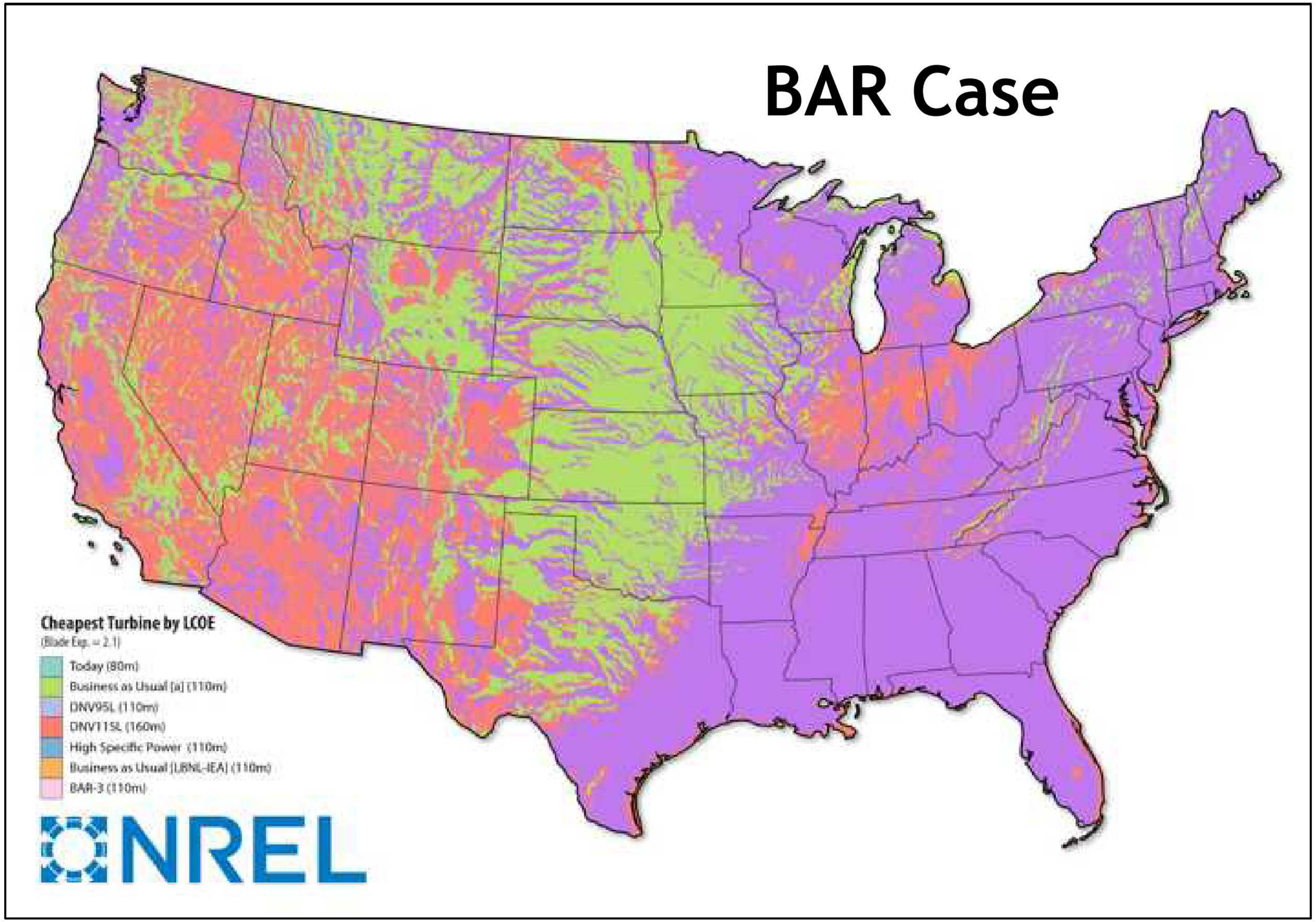


Capacity Factors



Main driver of low-SP turbines: Higher capacity factors

Impact of Large Rotors



Reliability

Further questions, please contact:

Josh Paquette, japaque@sandia.gov

Field Inspections

Quantify wind blade plant inspection technology

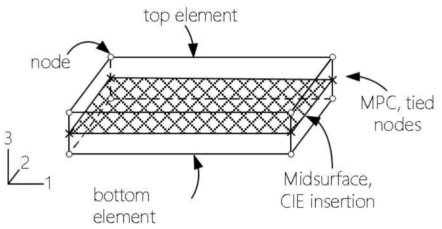
Develop autonomous inspection technology

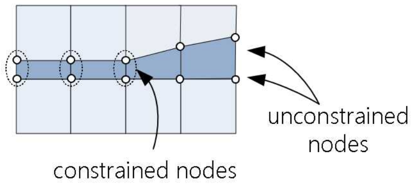
Reduce cost of advanced field inspection

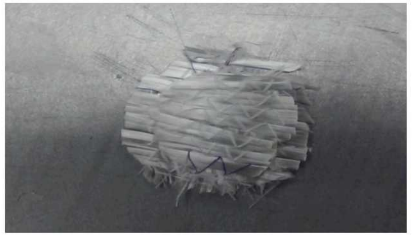
Defects and Repairs

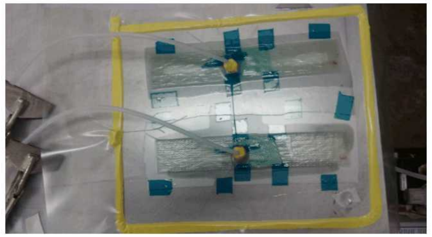
Manufacture and test repair specimens at coupon and sub-structure scale

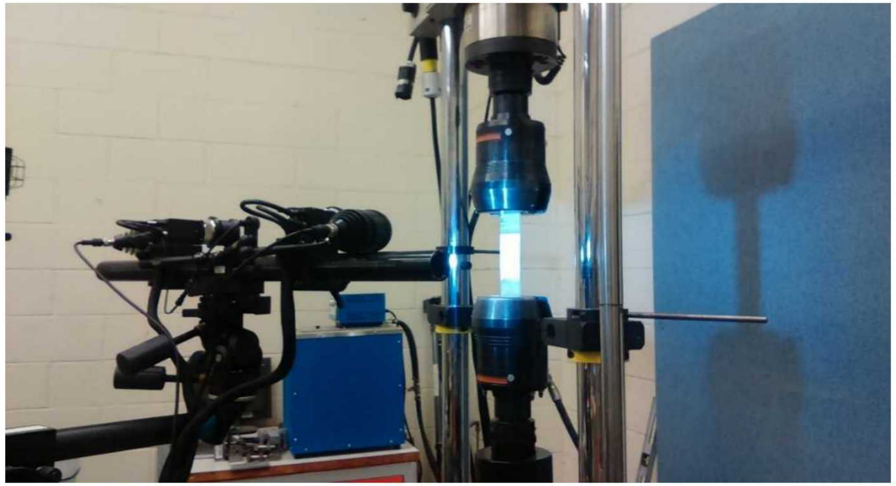
Interface with repair companies to produce realistic field repair conditions





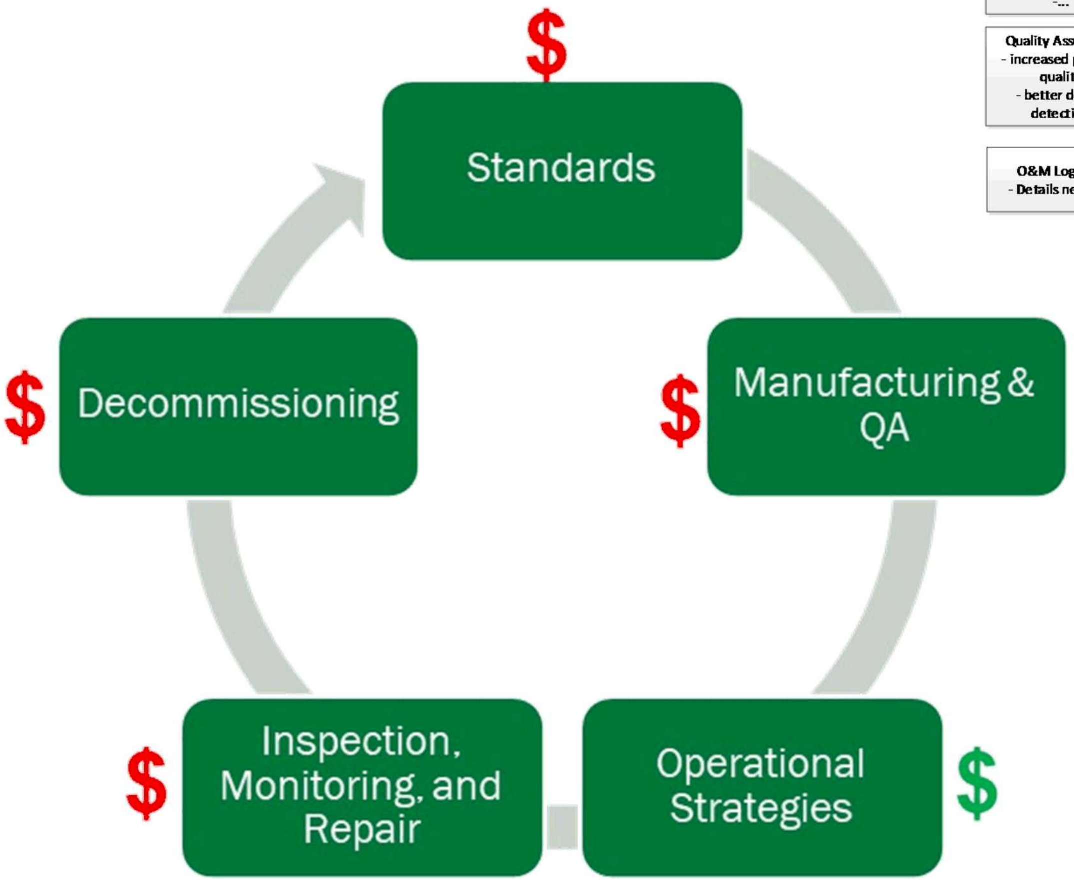


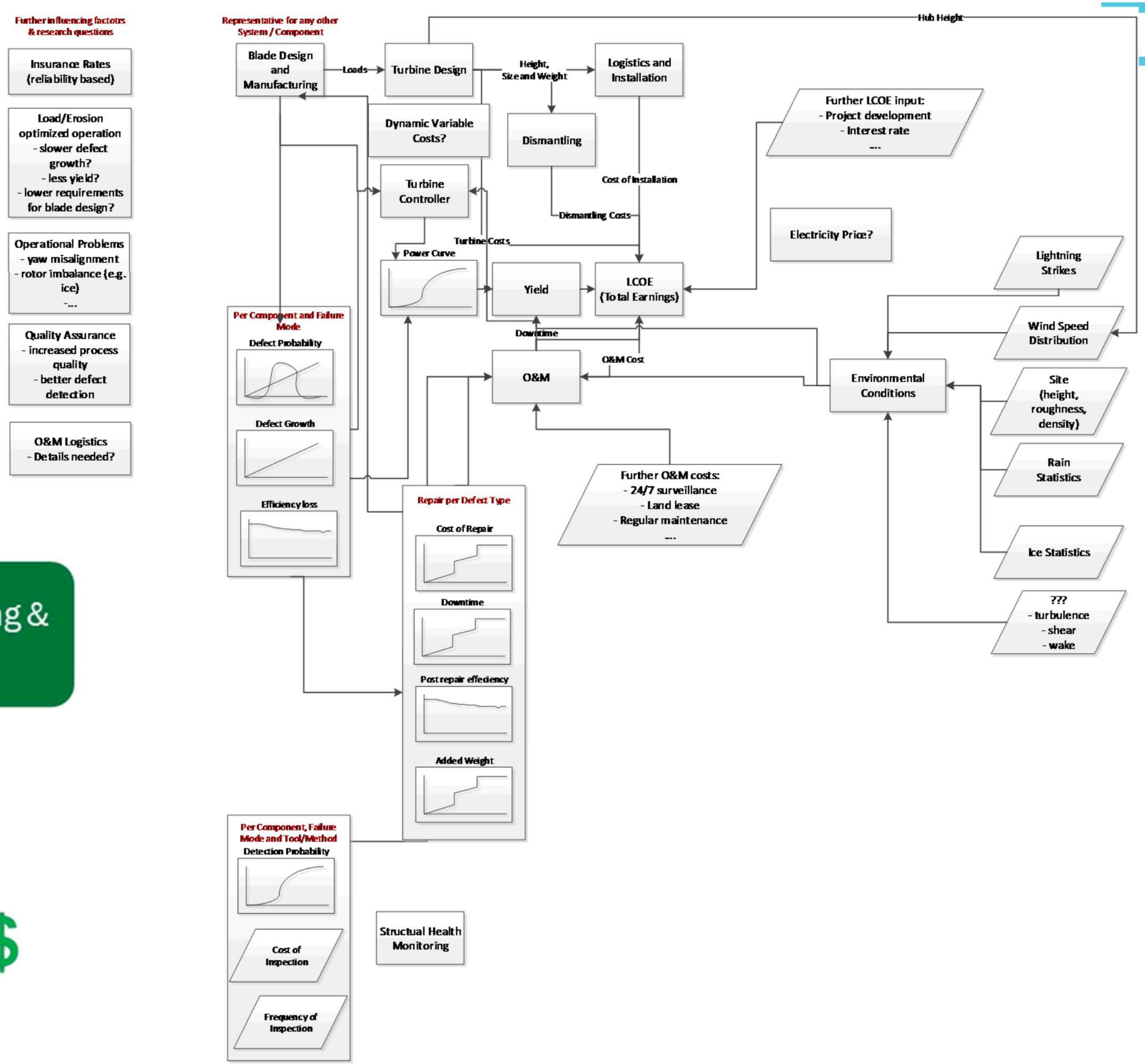




Blade Lifetime Value Model

Determine value proposition of changes to design and operations over blade lifetime



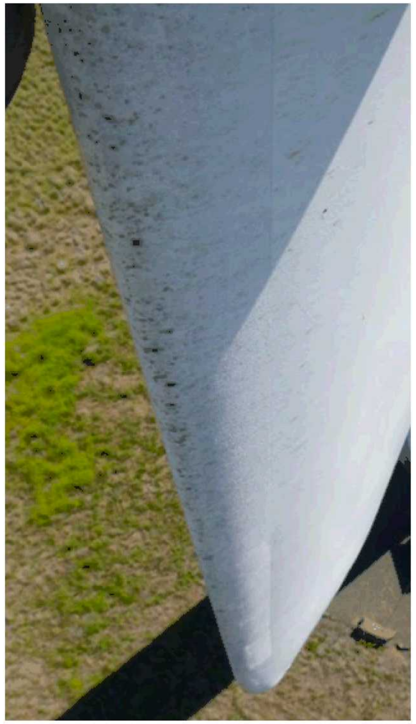


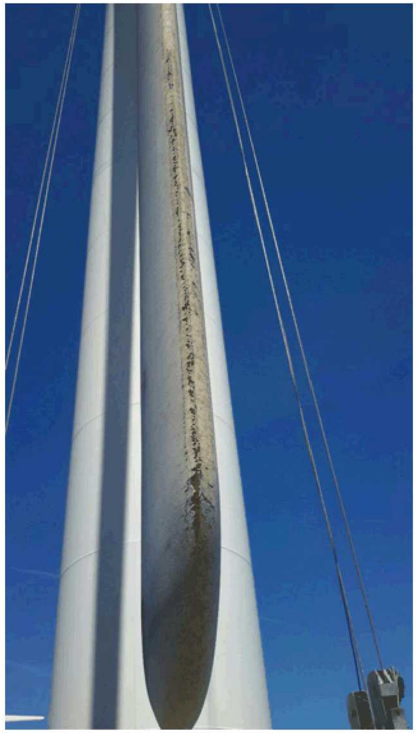
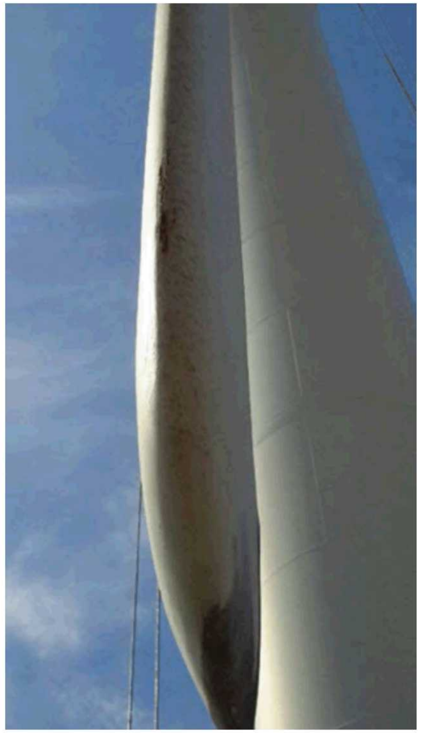
Leading edge impact review

Further questions, please contact:

Carsten Westergaard, cahwe@sandia.gov

Leading edge erosion – not necessarily the same on all 3 blades



Classification

Figure 2
Vestas' blade damage categorisation

Category 1	**Category 2**	**Category 3**	**Category 4**	**Category 5**
Cosmetic	Similar to cosmetic	Damage not serious	Serious damage	Very serious damage
No intervention needed	Intervention only done if there are other damages on the blade	Intervention done during planned WTG inspection within 6 months. Damage monitored at 3-months intervals. Repair time frame may be modified by blade specialist.	Intervention within 3 months. Damage monitored at monthly intervals. Repair time frame may be modified by blade specialist.	Immediate intervention required to prevent damage to the turbine, the surrounding area, or further damage to the blade.

Erosion Level	1	2	3	4	5
Same Blade Shown					Internals exposed Gaps / openings showing
Sectional Power Loss	+	+++ +++	++++ ++++	+++++ +++++	

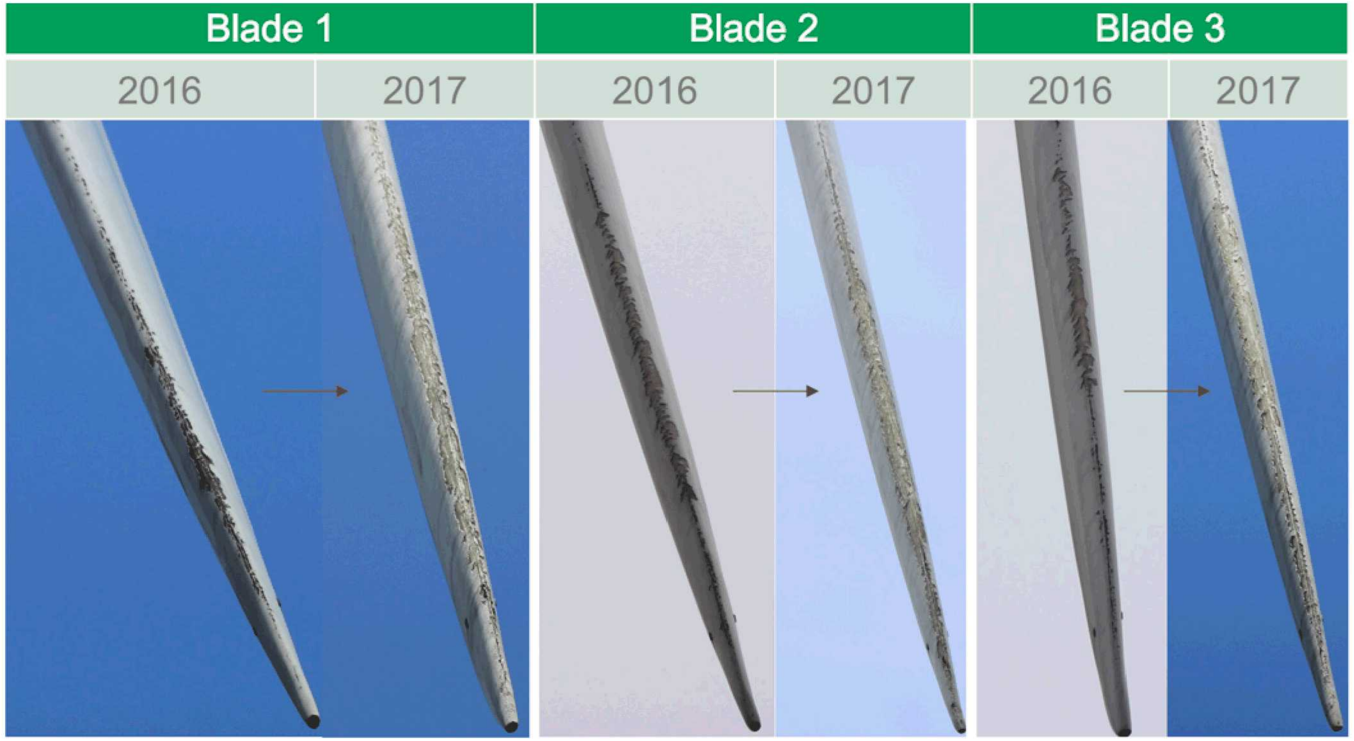
Source: Vestas and Siemens commercial brochures

Damage progression – perhaps faster than you like to see

Progression of erosion on all three blades of one turbine

Pictures taken one year apart

Location: Midwest



These examples shows a category 2 to 3 change in one year

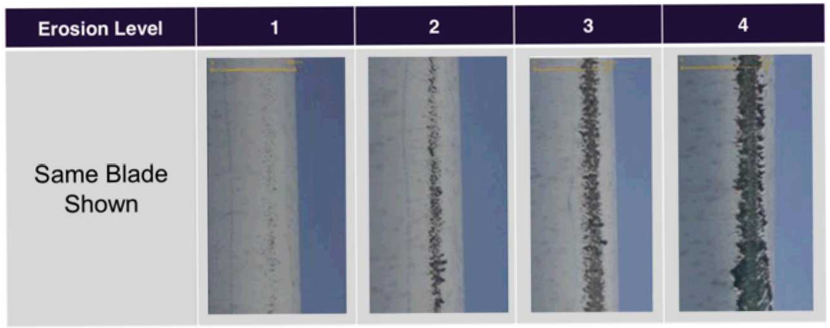
Source: Blade O&M USA: Blade Reliability
Katelyn Reynolds October 2018

AEP impact, 2 MW turbine example

Damage occur on outer 25% of rotor because of the very high tip speed sensitivity

Full span is calculated as "worst case" reference

Cat. 5 generally result in lost production due to other factors



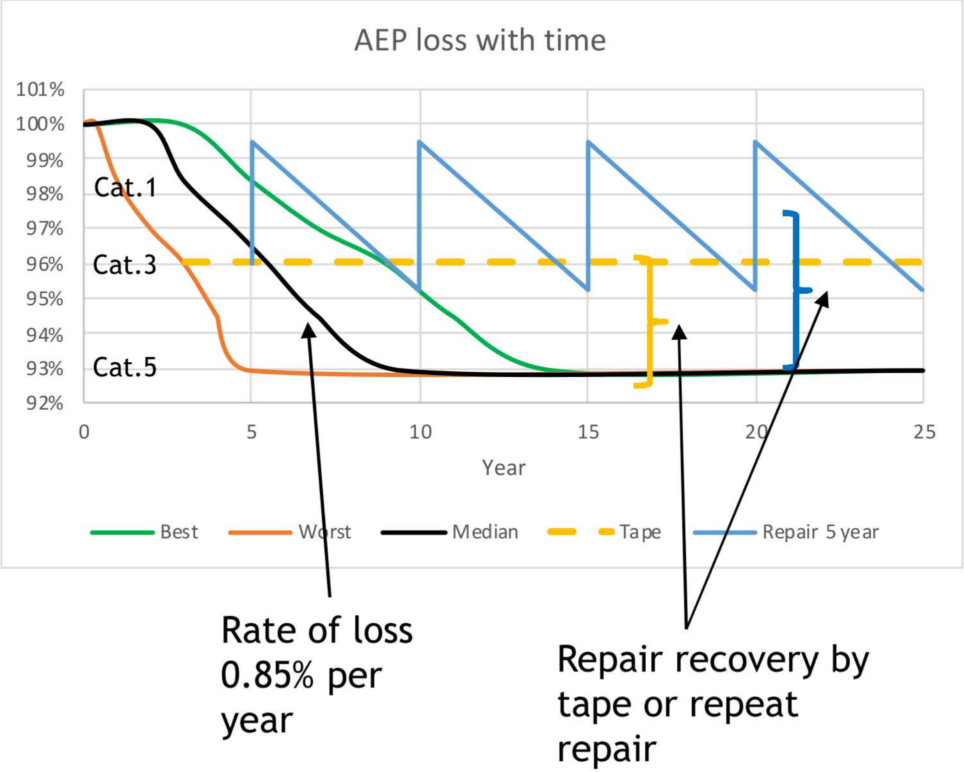
AEP loss at 7 m/s for 2MW turbine		
	Full span	1/4 span
Clean	0.0%	
Dirty	-0.2%	
Build LEP	-0.8%	-0.5%
LEP tape	-5.6%	-4.0%
Cat 1	-1.7%	-1.6%
Cat 2	-3.1%	-3.0%
Cat 3	-4.3%	-4.0%
Cat 4	-6.6%	-5.5%
Cat 5	-11.2%	-7.0%

Progression cost

- After the threshold is reached, the additional AEP loss is approx. 0.85% per year
- Assuming the damage does not resulting catastrophic damage tape style repair (25% length) recovers at least 3% AEP or at least $2,500* per year
- Initiating repair at cat. 3, a repeat repair every 5 years, recovers at least 4.4% AEP or at least $5,500* per year

* 2MW, 32% capacity factor,
$23/MWh (avg. DOE mid-west number)

Start	Progressed	Time (delta)
Clean	Cat 1	1 to 5 year
Cat 1	Cat 2	1 to 2 years
Cat 2	Cat 3	1 to 2 years
Cat 3	Cat 4	1 to 2 years
Cat 4	Cat 5	0 to 3 years



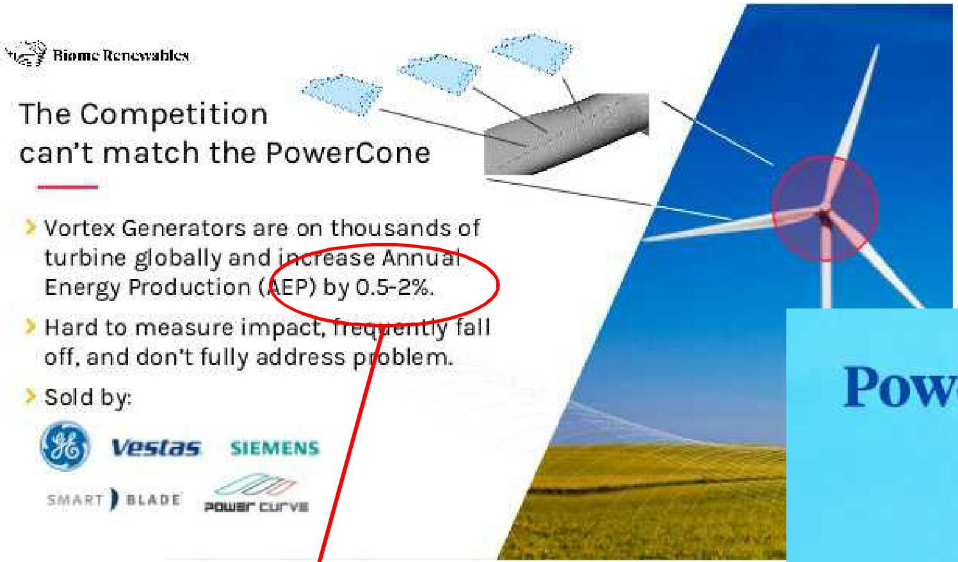
(Innovative) Performance enhancements

Further questions, please contact:

Carsten Westergaard, cahwe@sandia.gov

Power Cone, vortex generators and many other devices

** What is the base line, and what is the desired achievement ?*



Claim: 0.5%-2.0%*

Claim: 10%-13%*

Source: www.biome-renewables.com

Methods

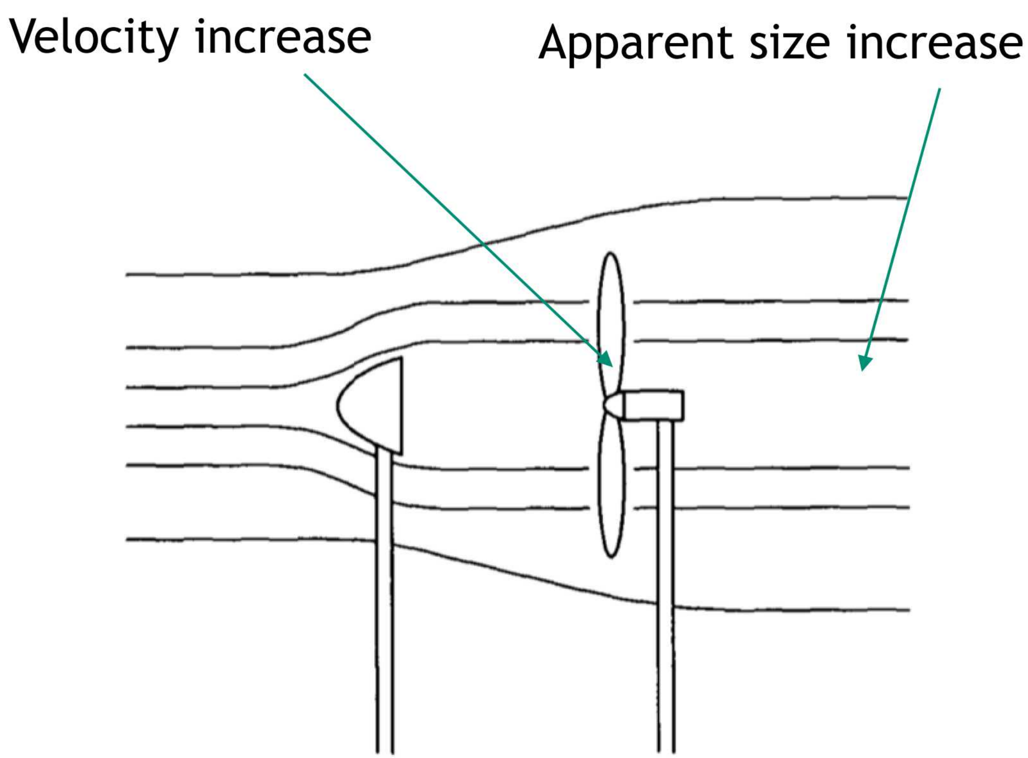


FIG. 4

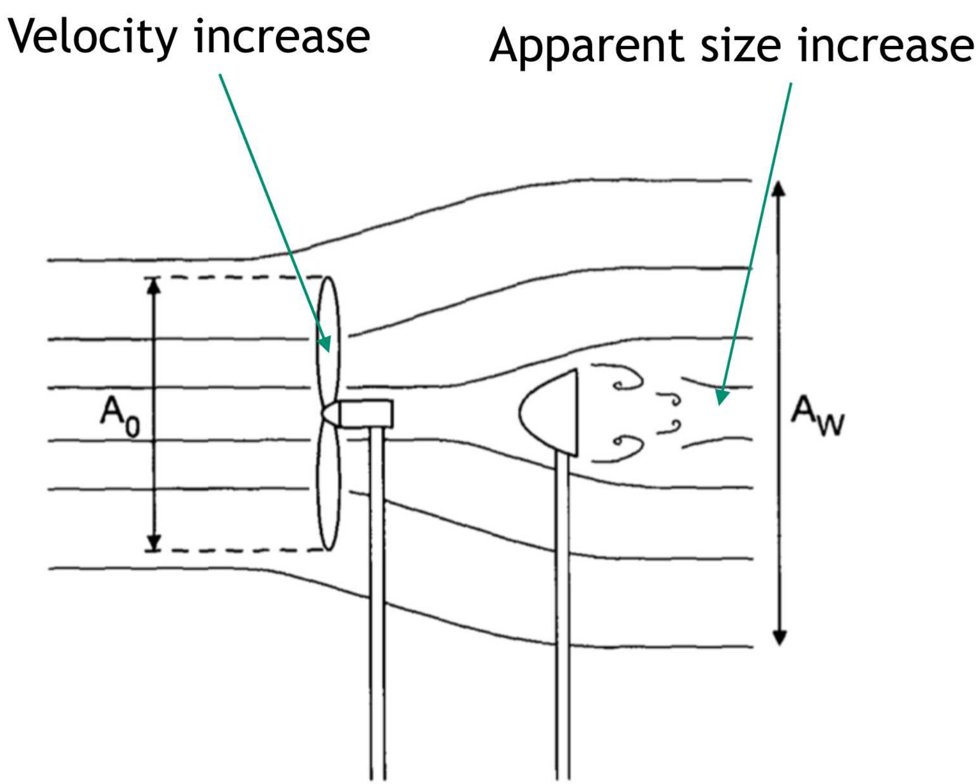


FIG. 3

Nose cone

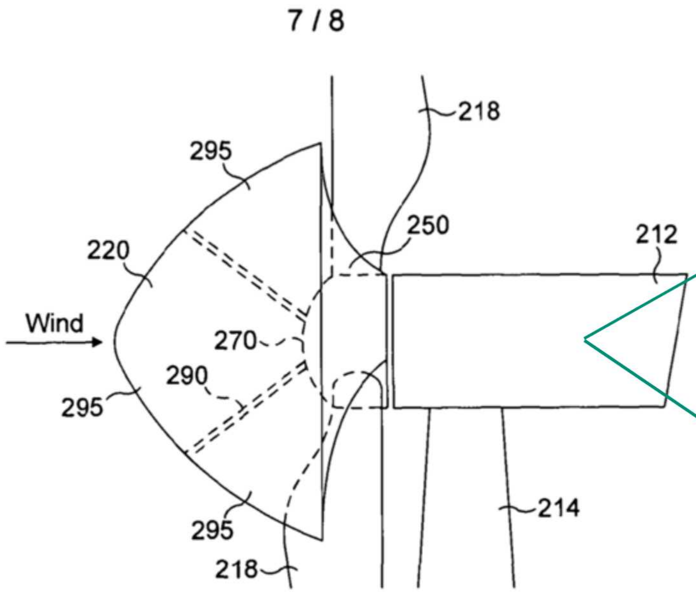


FIG. 13

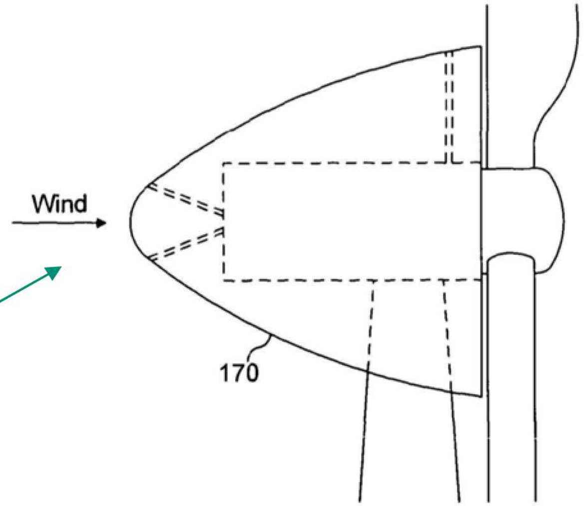


FIG. 10

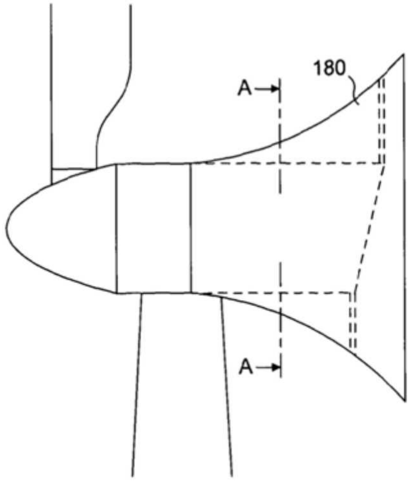


FIG. 11

Texas Tech University, Group NIRE, Sandia National Laboratories hybrid energy system research assets

Further questions, please contact:

Brian Naughton, bnaught@sandia.gov

Site overview

New power connection under development (est early 2020)

Schematic

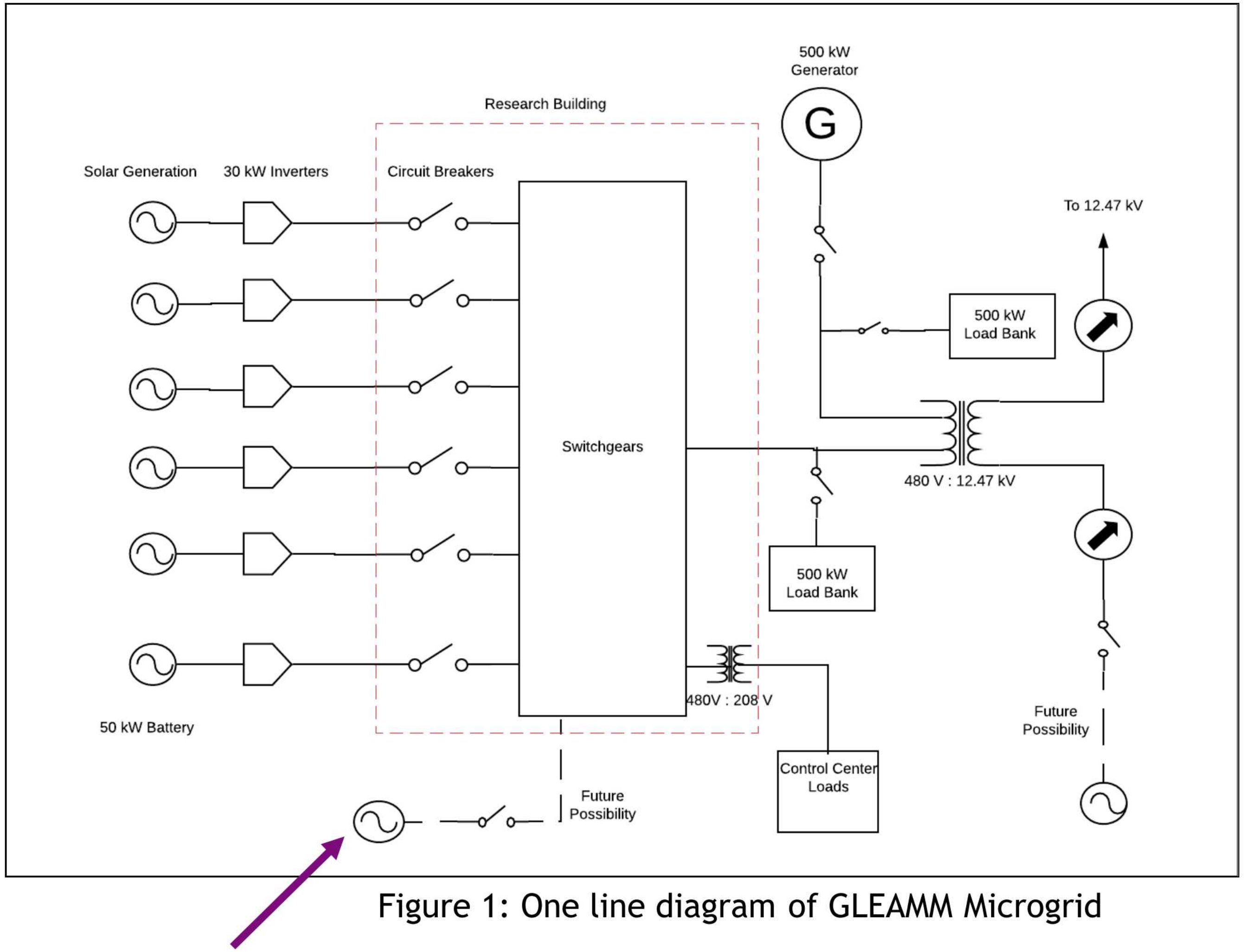


Figure 1: One line diagram of GLEAMM Microgrid

SWiFT turbines will connect here

Switch gear details

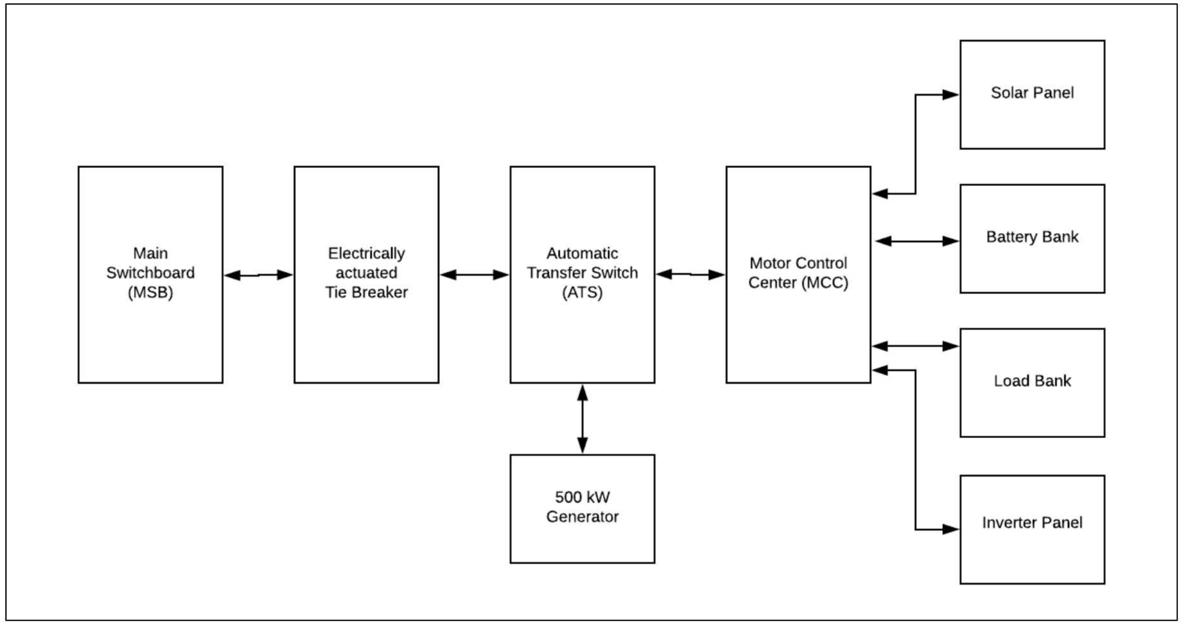


Figure 2: Switchgear block diagram

GLEAMM center

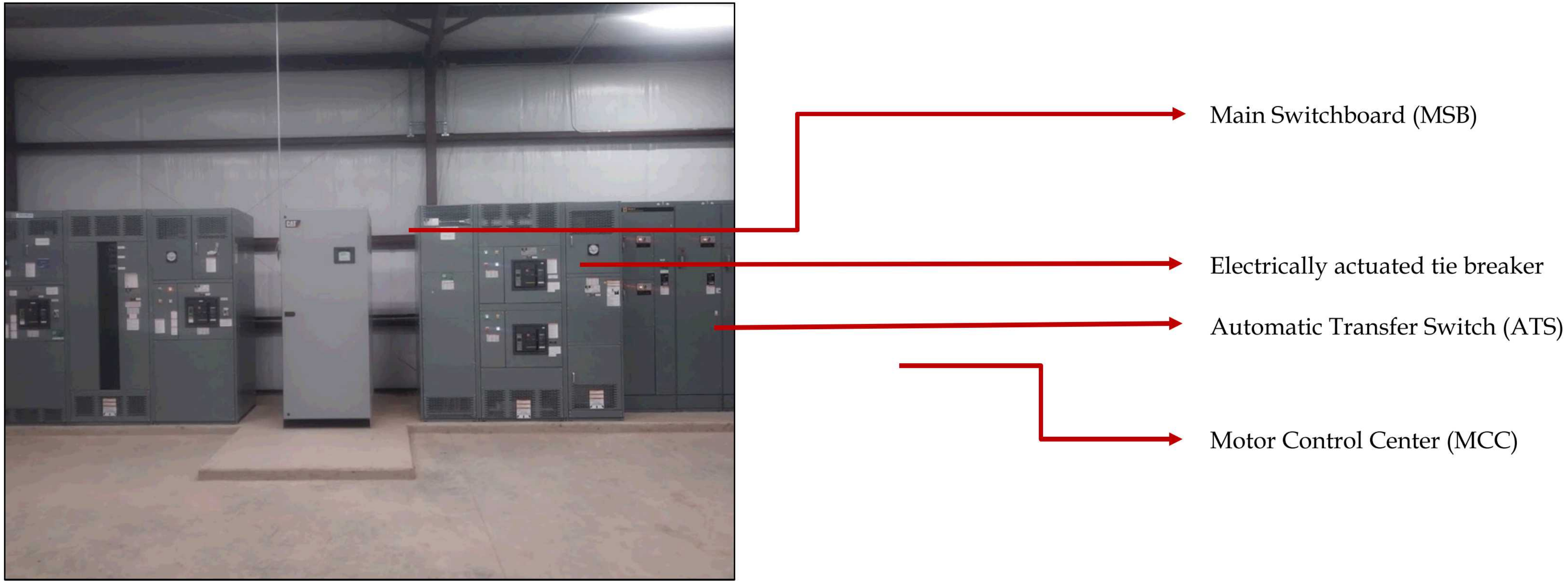


Figure 5: GLEAMM control center

Solar array

- Sunmodule SW 320 XL Mono Panels
- 320 W_p output power from a panel*
- Efficiency 16.04%*
- Maximum system voltage of 1000 V

*Under standard test conditions (1000 W/m^2, 25°C, AM 1.5)

Figure 3: 150 kW Solar Array

Solar inverter

- SMA Sunny Tripower 30000TL-US
- 5 inverters
- Nominal power 30 kW
- Rated MPPT voltage range 500 V – 800 V
- 98.6% efficiency

Figure 4: 30 kW Inverter

Grid generator

- US EPA Tier 4 diesel generator
- Maximum rating of 500 kW
- Operates at 480 Volts
- 1800 rpm speed

Figure 6: 500 kW Generator

Battery storage (small)

- Iron redox flow battery
- 8 hours capacity
- Peak power 50 kW
- Cycle life >20000 cycles
- Ambient temp.: -5°C to 50°C
- Roundtrip efficiency: 75% (DC-DC), 70% (AC-AC)

Figure 7: 50 kW Battery

Load banks

For each load bank:

- 500 kW capacity at 480 V AC
- Resolution of 5 kW
- 347.22 Amps Current at capacity
- Equipped with 30 inch panel fan for cooling
- Equipped with fork tubes for lifting

Transformer

- Transformer rating 1 MVA
- Common coupling transformer
- 480 V/12.47 kV step up transformer

More information

https://energy.sandia.gov/energy/renewable-energy/wind-power/wind_plant_opt/

https://gleamm.org

https://groupnire.com

Using Wind for Grid Stability

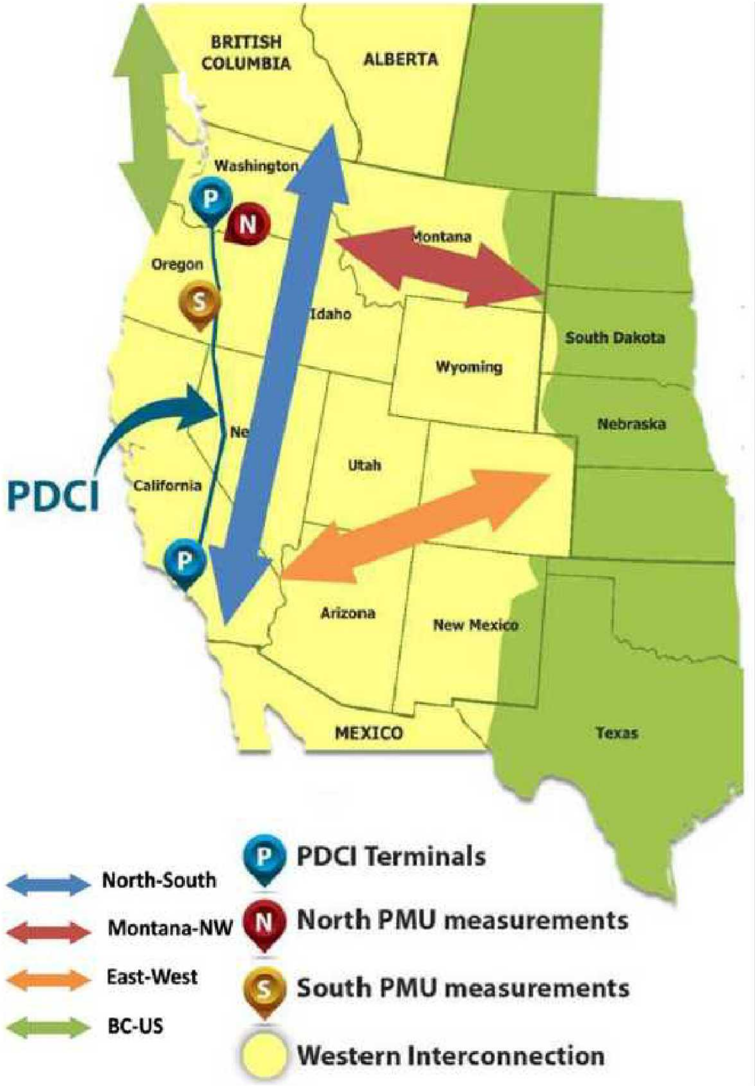
Wind energy displaces synchronous generation

Concern about decline of several grid-quality services inherent to synchronous generation

Wind turbines have high potential to contribute to grid services through inertial energy storage in the rotor

Control systems to utilize this require further development

Build upon prior work which used power modulation to provide damping of oscillation in the US Western Interconnection



From SAND2018-5248PE

Using Wind for Grid Stability

Establish controller in Sandia CONET* lab with necessary feedback control algorithms

Test power modulation on SWiFT wind turbine emulator to verify safe operation

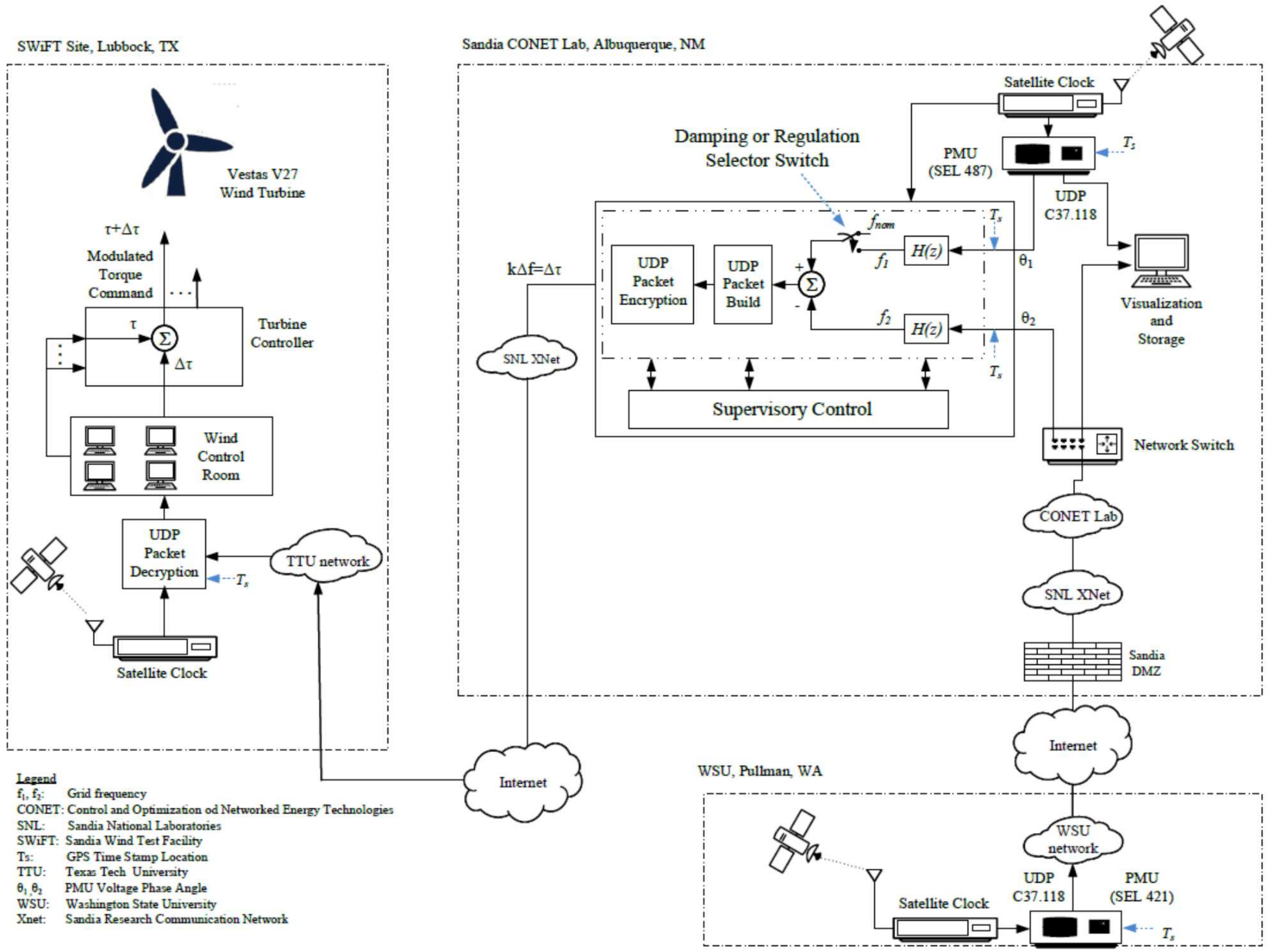
Establish network connectivity between SWiFT and CONET, characterize network quality (latencies, corrupted data, time stamps), and asses real-time feedback control performance.

Obtain streaming PMU data from two geographically-separated locations.

Determine system oscillatory mode(s) of interest and create feedback control test plan for wind turbine power modulation.

Obtain streaming SWiFT turbine data of power and time-of-arrival of CONET control commands.

Test and monitor feedback control of wind turbine power modulation



From SAND2018-7178

*Control and Optimization of Networked Energy Technologies

Hardening Wind Energy Systems from Cyber Threats

Further questions, please contact:

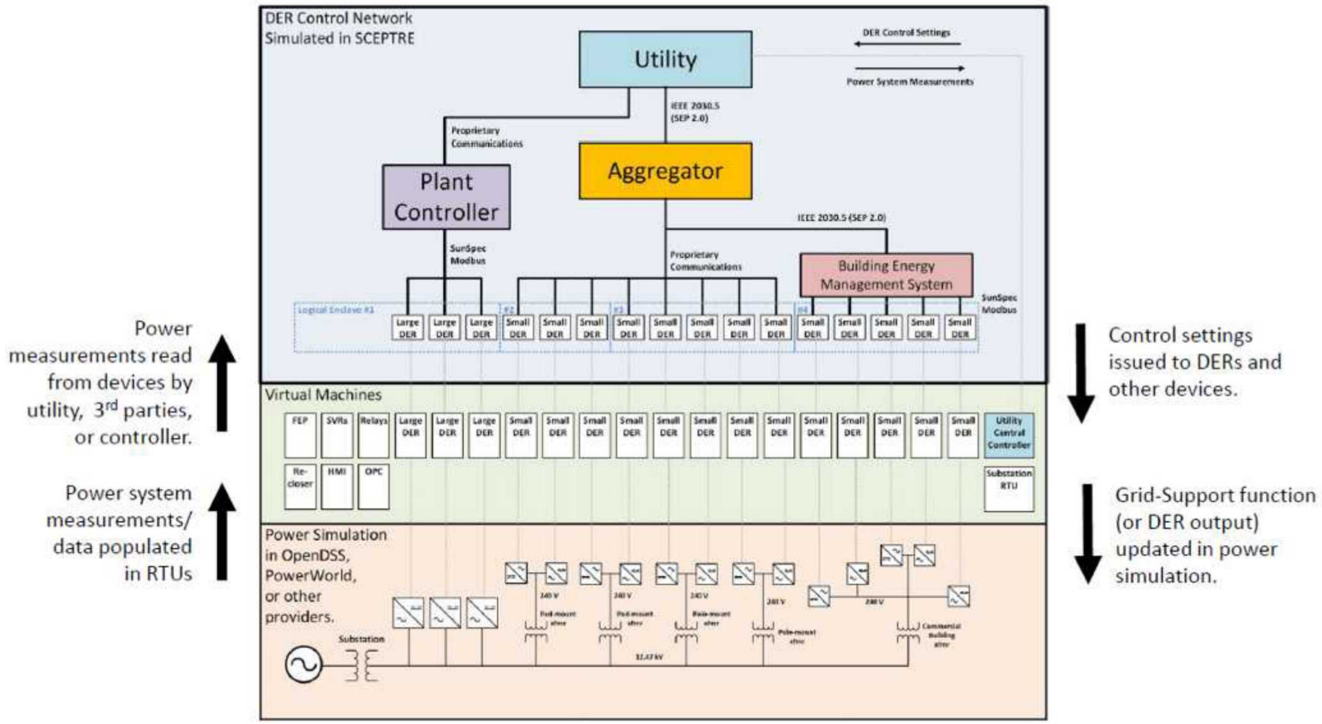
Brian Naughton, bnaught@sandia.gov

Hardening Wind Energy Systems from Cyber Threats
3-year R&D project at Sandia National Laboratories and Idaho National Laboratory

Goal:
The team will investigate wind network hardening and intrusion detection technologies to evaluate for performance and maintainability in wind-specific applications. Specific cybersecurity recommendations on reference architectures, including technology suitability, will be provided to the wind industry for appropriate adoption and incorporation in asset owner systems.

Outcomes:
- Co-simulation environment for wind plants with an industry representative utility-to-turbine communication network and power transmission simulation
- Cybersecurity assessments of wind system networks using red-teaming methodologies including impacts on power system.
- Assess performance of cyber intrusion detection system concepts for wind plants
- Cyber response system for coordinated wind plant systems and grid systems

SCEPTRE Control Network / Power System, Co-Simulation Framework



Industry Participation Opportunities

- Input on the controls and communications network for a wind plant (what are the most common topologies, protocols, etc.)
- Input on baseline/typical cybersecurity protection system and also any "state of the art" systems being explored.
- Typical communication and controls signals to/from plant. What does utility/grid operator need to send and using what protocol, what does plant operator send from remote control center, or locally at site.
- Visit to wind plant to see interfaces at control building and turbines
- Visit to control center to see interfaces with all turbines
- Input on biggest cybersecurity threats / concerns
- Input on what cybersecurity standards/products/services/resources are missing for operators