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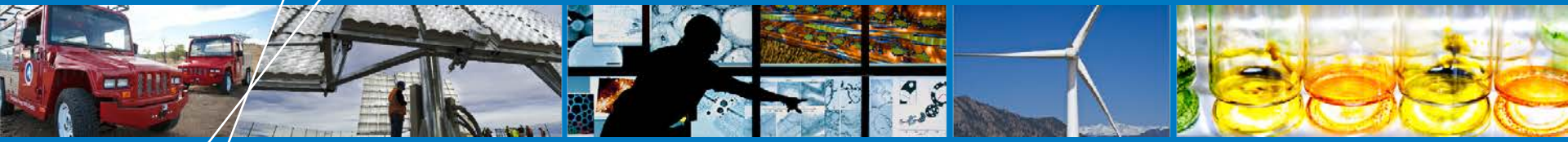
Gearbox Reliability Collaborative Update



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NREL/National Wind Technology Center

Wind Energy Operations & Maintenance Summit USA

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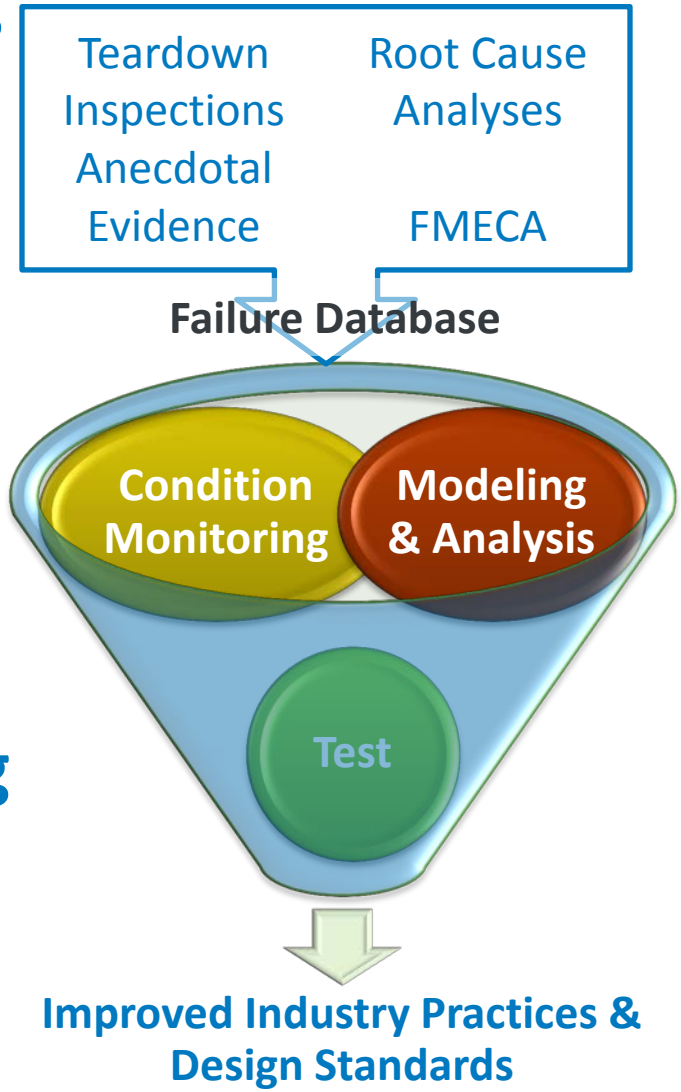
Why have a GRC?

- **Disparity between expected & actual gearbox life**
  - Widespread, not due to manufacturing issues
  - Critical elements may be missed in design process
  - Analytical tools may be insufficient
  - Design responsibilities, expertise, detailed information on failures are spread among many parties
- **Gearbox largest contributor to turbine downtime and costliest to repair[1]**
  - Most failures in bearings, not gears
  - Problems on small turbines still exist in MW designs

[1] WindStats Newsletter, Vol. 16 Issue 1 to Vol. 22 Issue 4, covering 2003 to 2009

GRC Objectives

- **Understand & isolate sources of gearbox failures**
- **Improve understanding of internal loads & response**
  - Normal operation & transients
- **Improve analysis tools to accurately simulate response**
- **Improve ability to reproduce field response in dyno testing**
- **Evaluate how CM augments design and O&M**



Outline

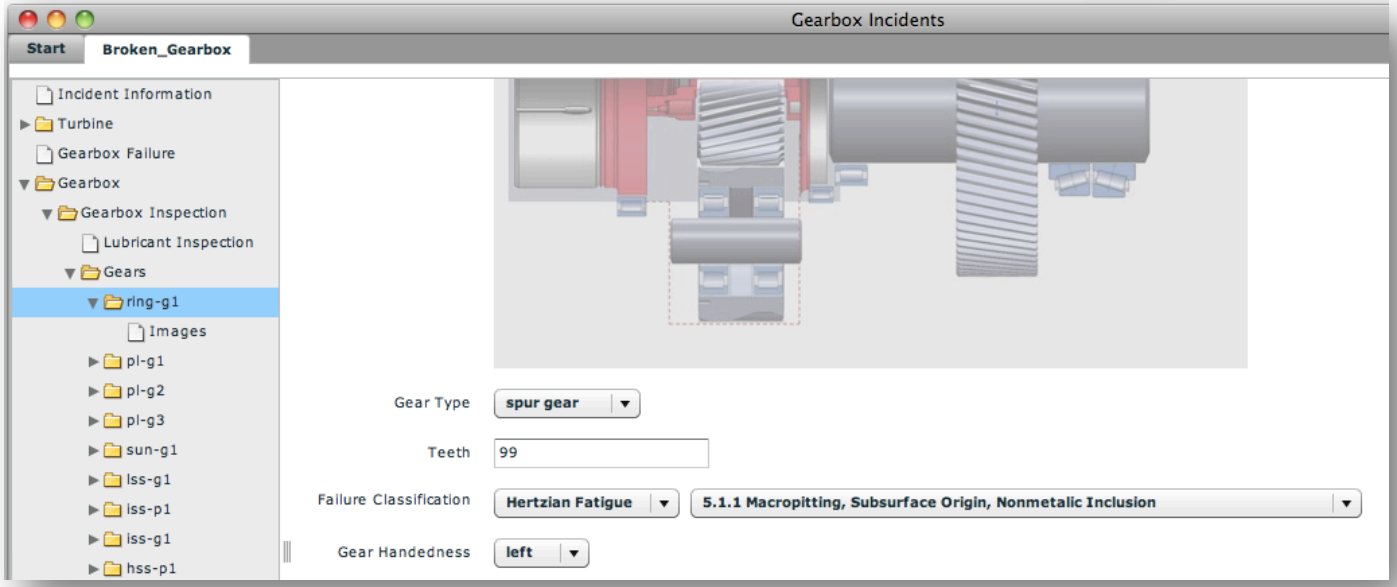
- **Gearbox Reliability Collaborative (GRC)**
  - Failure Database
  - Test, Modeling and Analysis
  - Condition Monitoring
- **Recent Activities**
- **Future Directions**

Failure Database

- **Understand gearbox failures**
  - Failure mode(s) and location(s)
- **Focus research accurately**
  - Aid root cause analysis and correction
- **Provide objective record of improvements**
  - Analyze and close loop when solutions found
- **Sanitized data shared among GRC members**
  - Contributors can view all their data

Failure Database Software

- **Collect information from gearbox rebuilds**
  - In shop and on tower
  - Existing data from papers, Excel spreadsheets
- **Structured data collection**
  - Navigation tree, visually oriented
  - Wireless image from camera to software fields



Results

- **The database contains 34 incidents**

	Incidents	Bearing	Gear
Total	34	23	15
Planetary	10	4	8
ISS	8	5	4
HSS	25	22	5

  - Bearing faults are concentrated in the high speed section; gear faults are concentrated in the planetary section
  - Top bearing failure modes: hardening cracks, abrasion (scratching of surfaces), adhesion (scuffing, welding and tearing of materials)
  - Top gear failure modes: fretting corrosion, high-cycle bending fatigue.

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GRC Test Gearboxes

- Two 750-kW wind turbine gearboxes
- 3-point mounting system
- One 3-planet stage with a floating sun and two parallel helical stages
- Pressurized lubrication for all but the planet gears and the ring gear
- Two speed generator

Photo by Scott Lambert, NREL/PIX 19222

Testing Summary

- **Phase 1 (300+ hours of data)**
  - GB 1 dyno test - 125+ signals
  - GB 1 field test
    - Oil loss event led to GB damage
- **Phase 2 (700+ hours of data)**
  - GB 2 dynamometer test - 150+ signals
    - Dynamic torque and some dynamic non-torque loads
  - GB 1 dynamometer test
    - Condition monitoring evaluation and GB teardown
- **Phase 3 begins FY12**

Apr 2009

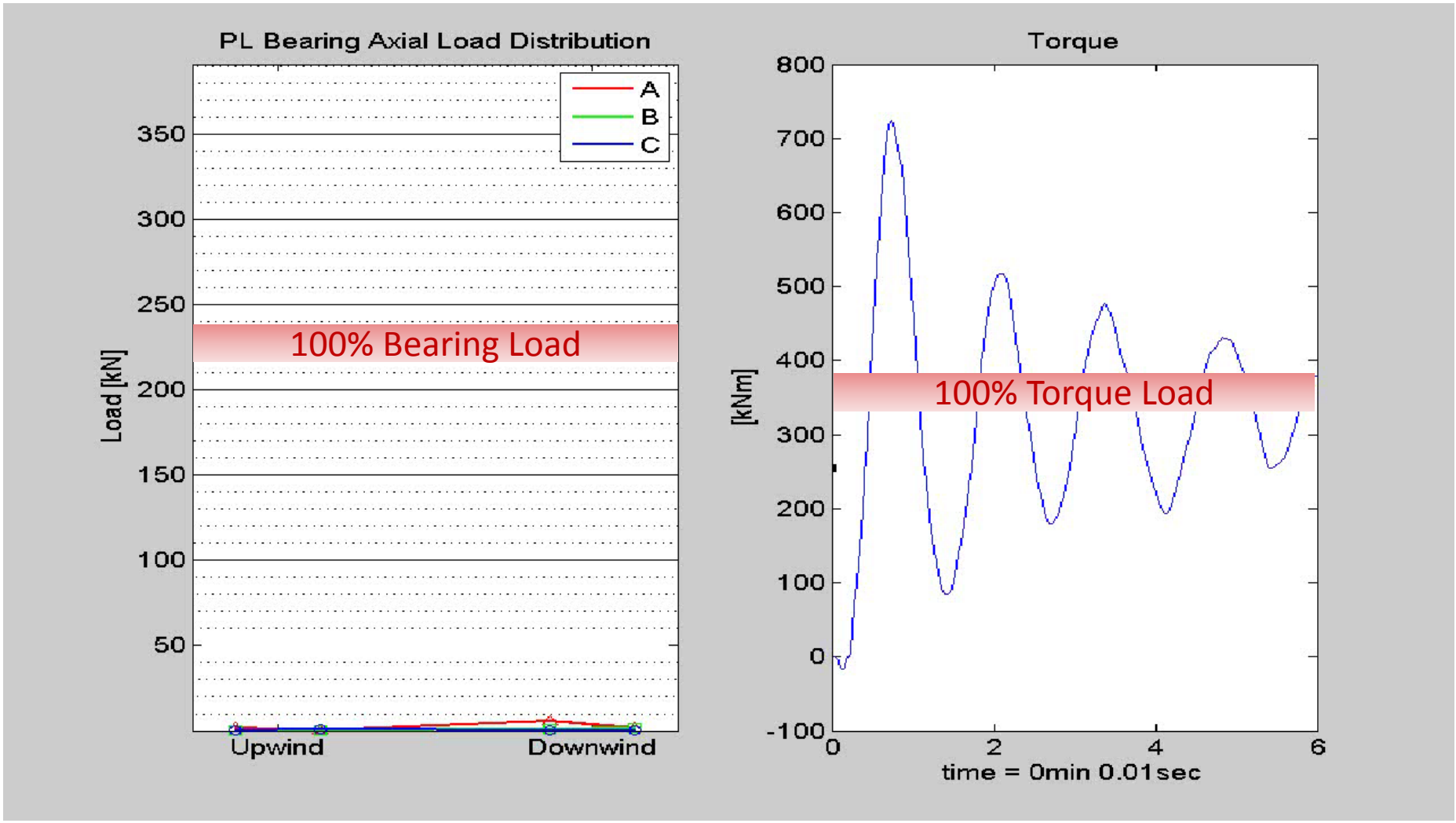
Oct 2009

July 2010

Nov 2010

Jan 2011

Transient Planet Bearing Response

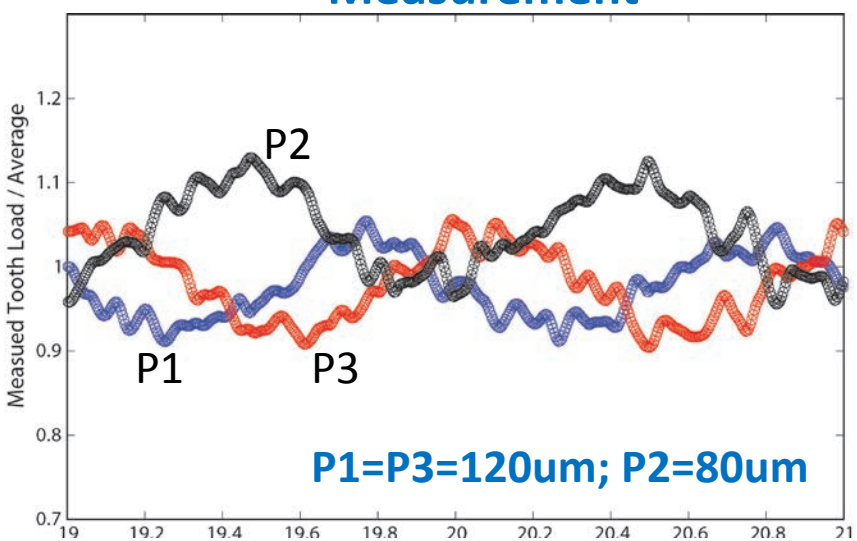


Planet C bearing loads 2x rated in transient

Model Validation

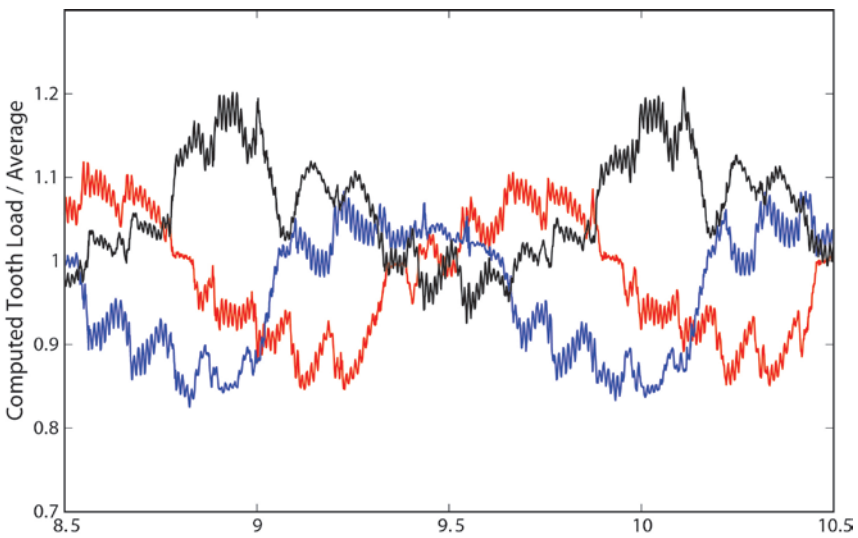
- **Multibody model evaluated**
- **Unequal bearing peak loads due to:**
  - Different bearing clearance
  - Pin position error

Measurement



Carrier Cycle

Model Calculation



Carrier Cycle

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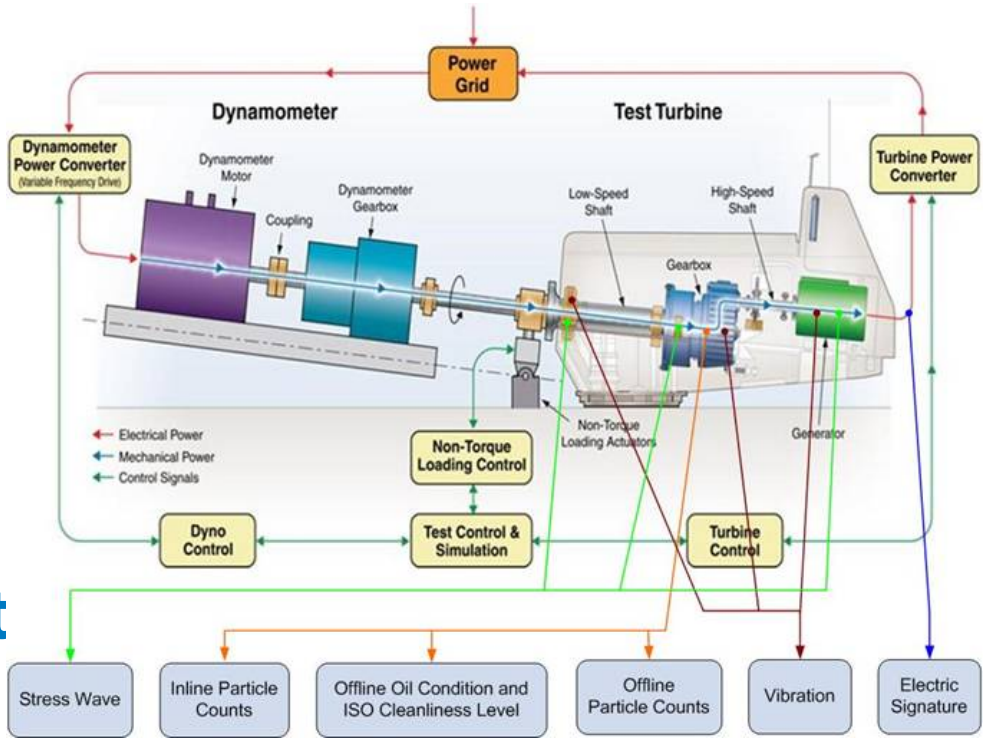
Condition Monitoring (CM)

- **Multiple CM systems used in Phases 1/2**
- **Various vendors and techniques (27 partners)**
  - Vibration
  - Stress Wave
  - Electrical Signature
  - Oil Condition
    - Particle count
    - Moisture/Quality
- **Compared capability to detect gearbox fault in dynamometer test**



CM Key Findings[3]

- **ISO cleanliness measurements could be used to monitor and control the run-in of GBs**
- **Recommend an integrated approach**
  - A combination of vibration or acoustic emission with oil debris monitoring techniques recommended
- **Similar trends in wear debris count obtained between offline and inline filter loops**
- **Round Robin report to be published**

[3] Wind Turbine Drivetrain Condition Monitoring During GRC Phase 1 and Phase 2 Testing, NREL TP-5000-52748.

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GRC Recent Activities

- **Meetings**
  - Condition Monitoring Workshop
    - 46 speakers, 11 sessions, and about 150 attendees
  - Tribology Seminar
    - 21 speakers and about 110 attendees
  - GRC Members Meeting
    - 22 speakers and 70 attendees
- **Continued Modeling and Analysis**
  - Model-to-model-to-test comparisons for dynamic data
  - Effect of carrier and planet bearing clearances and gravity on planetary section loads

GRC Website

www.nrel.gov/wind/grc

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Gearbox Reliability Collaborative

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Premature gearbox failures have a significant impact on the cost of wind farm operations. In 2007, NREL initiated the Gearbox Reliability Collaborative (GRC). The project combines analysis, field testing, dynamometer testing, condition monitoring, and the development and population of a gearbox failure database in a multi-pronged approach to determine why many wind turbine gearboxes do not achieve their expected design life—the time period that manufacturers expect them to last.

Read about:

- The Gearbox Reliability Collaborative
- Gearbox Reliability Collaborative Projects
- Gearbox Reliability Collaborative Research and Development
- Working with the Gearbox Reliability Collaborative
- Gearbox Reliability Collaborative Publications

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GRC Phase 3 Plans

- **Continue test, model and analysis campaign**
- **Re-Test GB2**
  - Dynamometer testing for dynamic and field representative loads
  - Test GB2 or another GB in field
- **Design, manufacture and test "new" GB3**
  - Incorporate lessons learned from previous GB tests
  - Demonstrate increase in GB life

“New” Gearbox 3

- **Re-use parts from GB1 where possible**
- **Contract award early Feb**
  - Conceptual design meeting Feb 9 (GRC)
  - Preliminary design review early April
  - Critical design review early July
- **Manufacturing & instrumentation plans**
  - Manufacturing review early August
- **Dyno testing Q1 FY13**
  - Repeat sequence of tests from GB2 and compare effect of design updates

Gearbox 3 Design

- **Possible design changes**
  - Preloaded TRBs for carrier/planets (current CRBs)
  - New, stiffer ring gear (current one damaged)
  - Optimized microgeometry and preloads
  - Review of high speed section bearings
  - Improve lube system

  Improve load sharing
- **Design variables**
  - Planetary carrier bearing clearance and preload
  - High speed pinion
  - High speed bearing configuration, clearance and preload

Thank You!

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Photo from HC Sorensen, Middelgrunden Wind Turbine Cooperative, NREL/PIX 17855