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Towards a more robust understanding of the uncertainty of wind farm reliability

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Status

- The wind industry has improved tremendously over the past decade:
  - Logistics and down time is handled more efficiently
  - Operational procedures and designs have improved
  - Downtime has been reduced and availability for new equipment can be in excess of 98%
  - O&M expenditures have increased
- Failure rates of 1% are in range for new equipment (excluding infancy issues), but certainly not for existing or aged equipment
- "Black Swan" unscheduled events carry the majority of reliability costs and remain a future threat, especially as the technology continues to evolve. Only through data sharing can these be quantified to a satisfactory level
- Both big and small events are not captured accurately by the envelope of the standards, and they are typically initiated by the unknown influence of:
  - Manufacturing flaws (acceptable and unacceptable)
  - Unexpected failure modes
  - Poor operational practice and documentation
  - Unforeseen events, frequency and nature of the events
- Existing design standards no longer support a growing industry at plant level and do not enable effective risk management methodologies
- New technology is constantly entering the market and will continue to do so - the role of DOE is to identify opportunities which can reduce existing uncertainty and preempt future uncertainty for owner/operators

Key Questions

- How do we accurately benchmark **technical** reliability data ?
- Is it meaningful to correlate technical and economical benchmarks ?
- Can we use historical data to predict the future ?
- How do we quantify the actual operating envelope and include:
  - Environmental conditions ?
  - Operational conditions ?
- Can we derive conclusions from data-mining SCADA data for both performance and reliability ?
- Can these data be used to improve design ?
- Can these data be used to control and/or extended the life time of a wind farm ?

Unplanned Reliability Events Estimates

Unplanned reliability cost, 2 MW @ 98% availability

	Lifetime cost per turbine (no including scheduled maintenance)	Annual failure rate of repairable items	Fraction of fleet which will experience major replacement in lifetime (20 yrs)
Blade	$ 150,400	16%	14%
Gear + bearing	$ 189,200	6%	42%
Generator	$ 112,200	3%	25%
Other	$ 44,120	39%	
Forced outage / resets	$ 20,645		
Total	$ 516,565*		
Unscheduled	$ 5.1 per MWh		
Here of replacement	$ 330,600		

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Preliminary crude numbers misc. collected data from workgroups, discussion and presentations

An insurance company's perspective on blades

Date	Capacity	Location	Yrs In Operation	Nature of Damage	Root Cause
December 2013	5 MW	Ireland	17 Years	Blade Break	Blade disconnection from the nacelle
January 2014	111 MW	Portugal	8 Years	Blade Break	Blade fell from turbine during storm
February 2014	75 MW	United States	2 Years	Blade Break	Blade snapped in half and was left hanging in the ai
February 2014	200 MW	United States	1 Year	Blade Break	Entire blade broken off, cause unknown
March 2013	110 MW	United States	2 Years	Blade Break	Defect arising from a spar cap anomaly
November 2013	112 MW	United States	6 Months	Blade Break	
November 2013	94 MW	United States	1 Year	Blade Break	
April 2013	101 MW	United States	6 Years	Blade Collapse	Lightning Strike
July 2013	206 MW	United States	6 Years	Blade Collapse	Lightning Strike
January 2014	300 MW	Canada	1 Month	Blade Damage	Blade damaged during construction - Human Error
January 2014	300 MW	Canada	1 Month	Blade Damage	Human Error
September 2013	36 MW	Portugal	8 Years	Blade Damage	Lightning Strike
November 2013	15 MW	Greece	6 Years	Blade Damage	Lightning Strike
February 2014	24 MW	Greece	7 Years	Blade Damage	Lightning Strike
January 2014	12 MW	Greece	7 Years	Blade Damage	Lightning Strike
October 2013	10.2 MW	Italy	6 Years	Blade Damage	Lightning Strike
March 2013	7.2 MW	Portugal	13 Years	Blade Damage	Lightning Strike
February 2014	114 MW	Portugal	8 Years	Blade Damage	Lightning Strike
March 2014	34 MW	Italy	3 Years	Blade Damage	Poor repair of previous issue caused blade to be delaminated
January 2014	201 MW	United States	1 Month	Blade Defects	Manufacturing Fault
February 2014	150 MW	United States	2 Years	Blade Failure	Mismatched Set
March 2014	80 MW	United States	2 Years	Blade Failure	Tower Vibration
April 2014	106 MW	United States	5 Years	Blade Failure	Crack in blade bearing - wind, poor maintenance and construction on several turbines
November 2013	106 MW	United States	5 Years	Blade Root	
April 2013	9.2 MW	United Kingdom	17 Years	Blade Throw	Gearbox rotor failure in high winds resulting in overspeed and loss of three blades
December 2013	10 MW	Ireland	1 Year	Blade Throw	High Winds
February 2014	13.4 MW	Germany	3 Years	Blade Throw	Highwinds/ technical failure - Unknown
April 2013	200 MW	United States	2 Years	Blade Throw	Adhesive bonding failure between pre-cast root segments and the fiberglass laminate of the main blade. The adhesive bonding failure was caused by insufficient surface preparation of the root segments
May 2013	58.8 MW	United States	6 Years	Blade Throw	
January 2014	12.6 MW	Denmark	1 Month	Blade Throw	Not available at time of print

Observations:

- Cost is known
- High level root cause is known, sometimes at a lower level
- Limited technical data on fundamental mechanisms
- Environment plays an important role

Source: GCube, September 2014

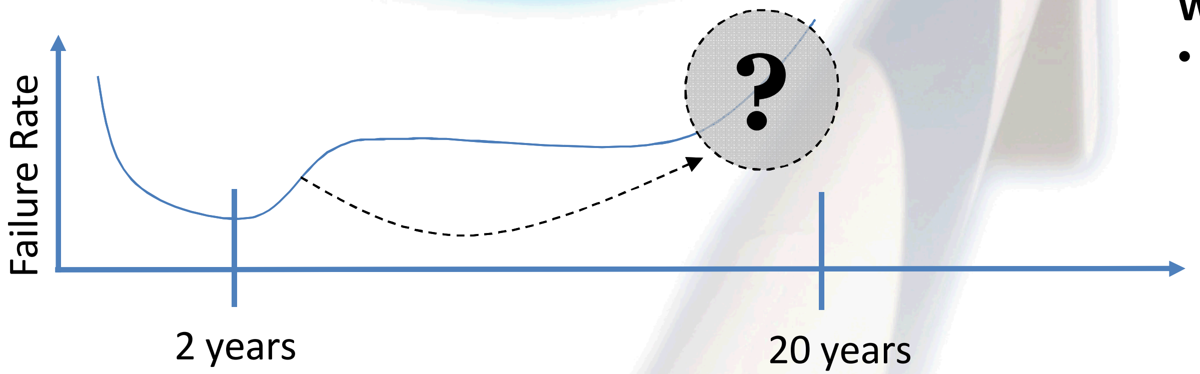
Environmentally induced Reliability Events

Failure induced by	Component	Annual failure rate of repairable items (number is relative to all component repairs)	Fraction of fleet which will experience major replacement in lifetime (20 years)
Lightning 35 days/year	Blade	3%	4%
	Other	High ?	?
Ice	Blade	?	?
	Other	Some, but low$	Some, but low$
Erosion	Blade	High	Almost none
	Other	None	None
Extreme wind w/wo vibration	Blade	?	6%
	Other	?	Unknown
Corrosion and surface degradation	Blade	?	?
	Other	?	?
Misc.	Blade	?	4%

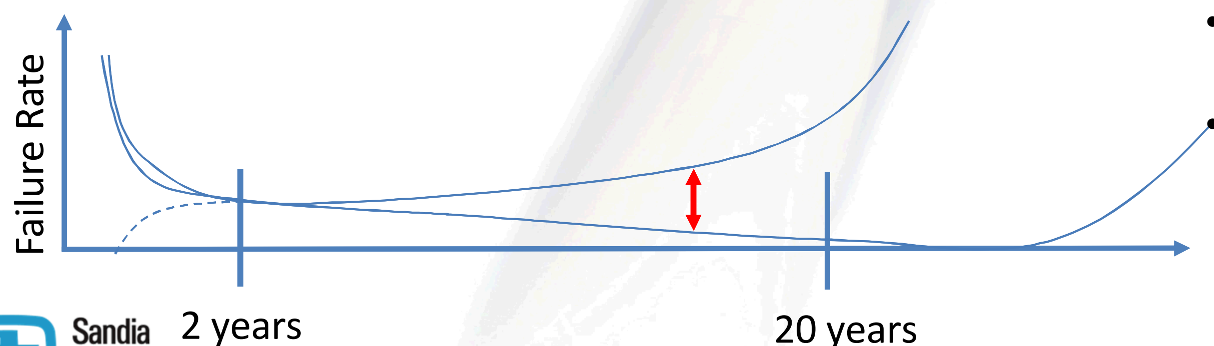
The data on environmental is not quantified at this stage and are fleet average. I.e. icing is a regional effect

The Life of Components in a Wind Farm

The expectation:
- Infant mortality
- Random failures at constant rate
- Opportunity for life extension



What we fear:
- "Black swan" events shorten life and prevent future opportunity



What we could achieve:
- Monitor and quantify remaining life + life extension
- Reduce quantifiable uncertainty by understanding failure and events

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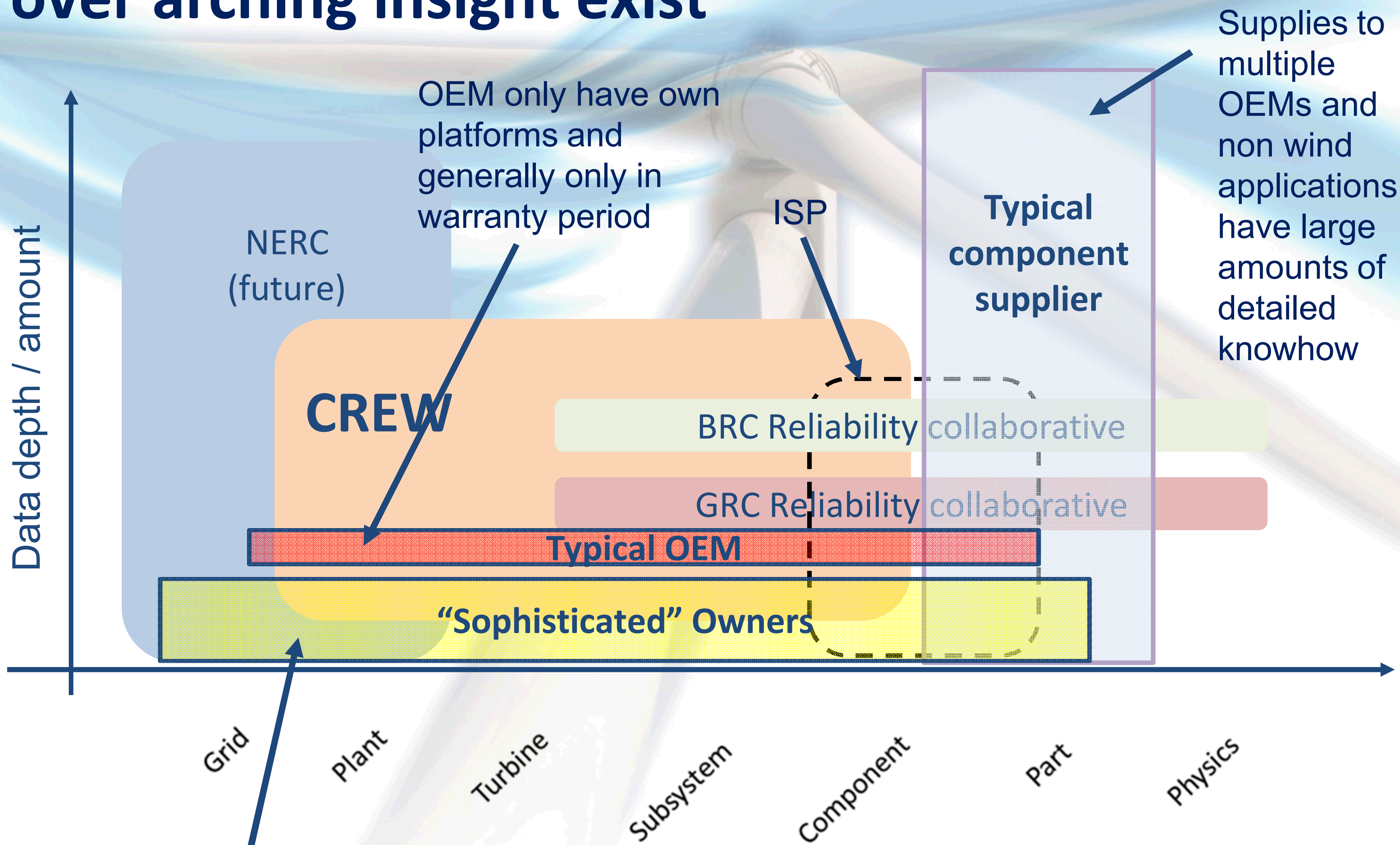
Stakeholders have different insights but no over arching insight exist



Owners have multiple platforms from multiple OEMs. Interact with suppliers and service provides for the entire life of their wind farms

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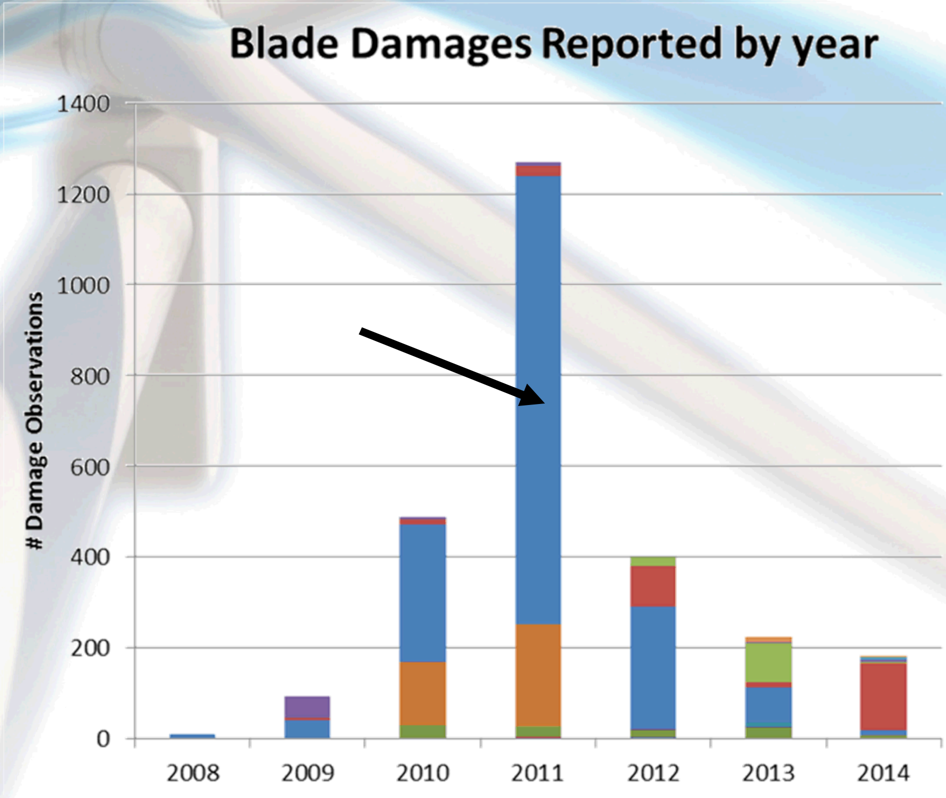
Example of discrete series of events which will bias an average unreasonably

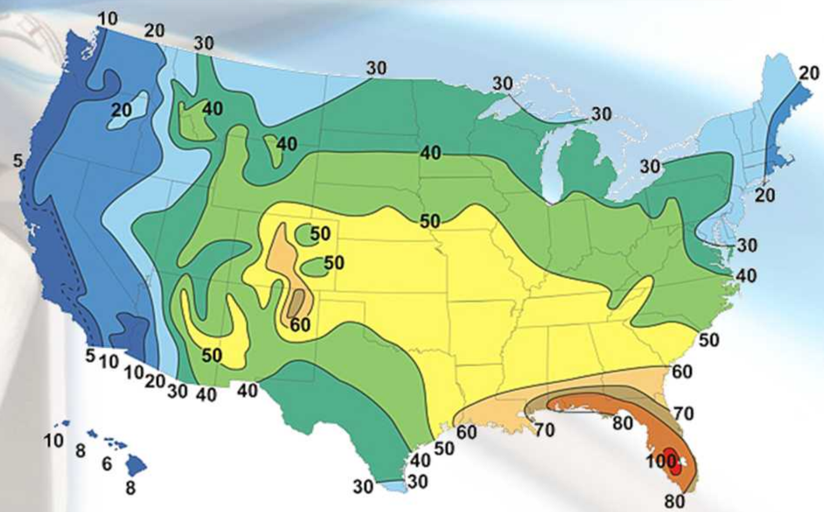
- Specific turbine in MW class has a peak of blade challenge(s) in 2011. Level normalized in 2013 and disappeared in 2014
- Relative young turbines, presumably an issue of proprietary nature and possible warranty
- Blade may only be inspected ever 2^{nd} or 3^{rd} year
- Sub-conclusion:
  - Including discrete (infancy) events will not support conclusion of future performance
  - Inspection methods and frequency will bias inter-annual results



Graph source: Coffey (2014)

Lightning: Regional Risk Variation

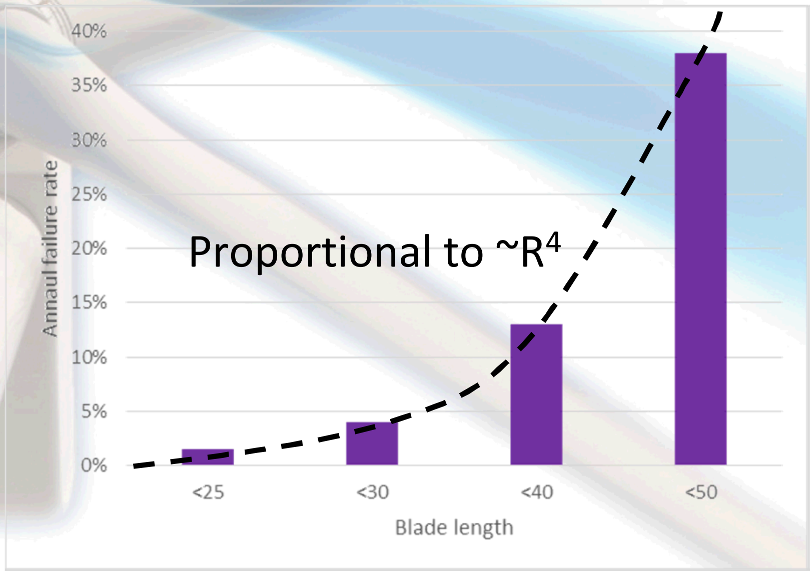
- Technical report IEC/TR 61400-24:2002
  - Based on data from 2800 “small turbines” in Northern EU (<15 days) and inner Germany (<35 days of thunderstorms)
  - Annual failure rate 0.4 to 1.4%
- US has 5 to 100 days of thunderstorms, 0.3% to 5%
- Midwest has ~55 day with an annual failure rate up to 3%
- Sub-conclusion:
  - Fleet average without considering regional exposure is fairly meaning less
  - A well document standard for normalization combined with a national fleet average could improve our understanding
  - Many US owners, has more accumulate experience than what the IEC standard is based upon



NOAA.gov, Cannata (2014), Coffery (2014), Nissam (2013), LM Wind power

Lightning: Technology bias and Size bias

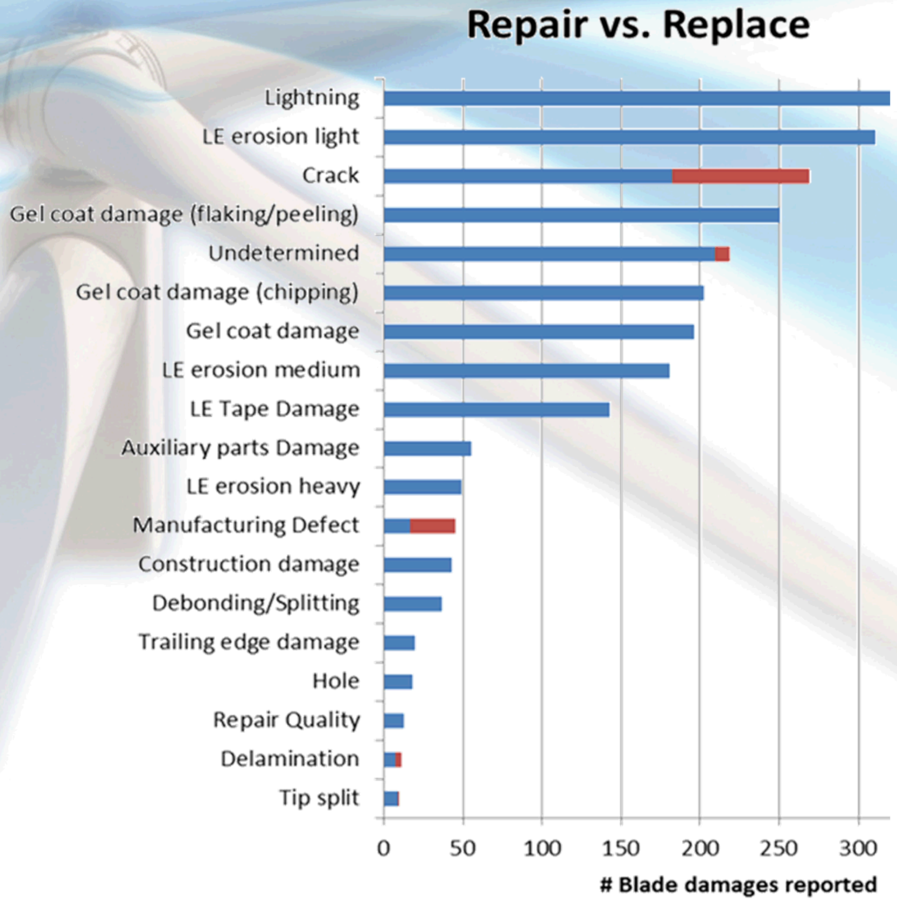
- Lightning risk, according to IEC61400-24 and ported from building code, suggest risk is proportional to height squared, including landscape topology
- Experience shows much higher height dependency ~R^4
- On the flip side, improved LPS systems are reported to have as much as an X10 improvement
- Sub-conclusion: Historical fleet average will not predict the future without significant considerations to technology and size correction



Cannata (2014), Coffery (2014), Green (2014), LM Wind power

Observations and Tagging

- Gear and generators have received a lot of attention
- Blades are receiving more attention. More frequent inspections are increasing awareness
- Lack of common naming and tagging makes direct comparison of technical data difficult
- New CREW objectives is to develop a common platform through an auditing process and aggregate these into a high level benchmark with more data



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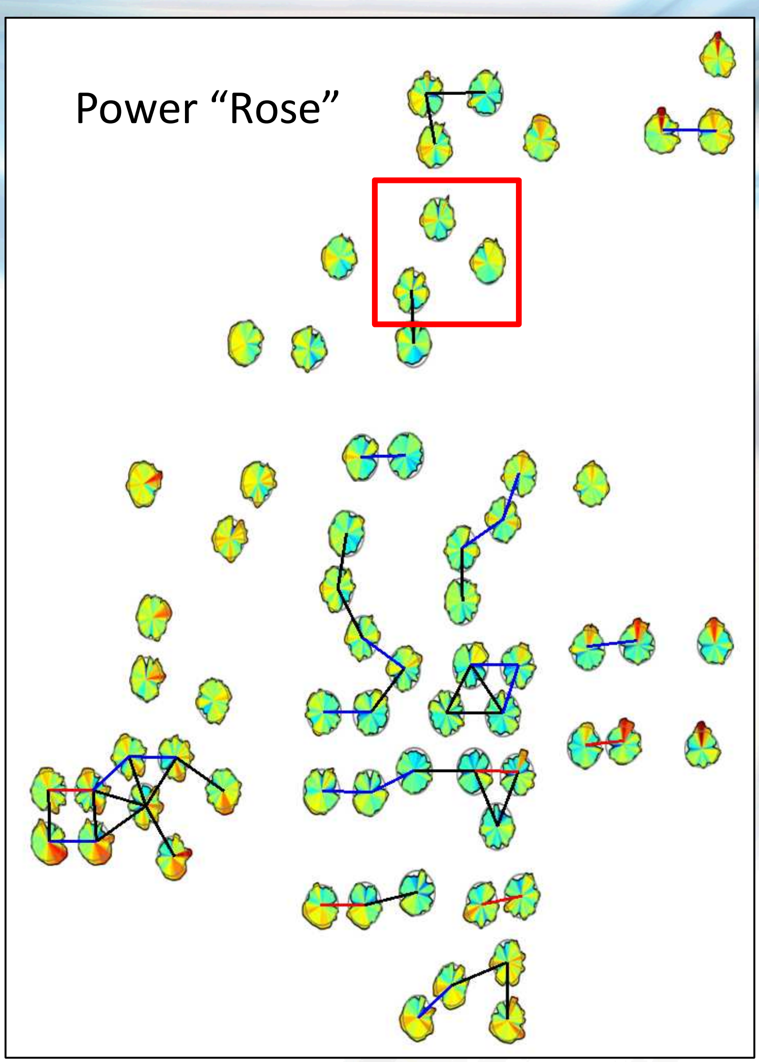
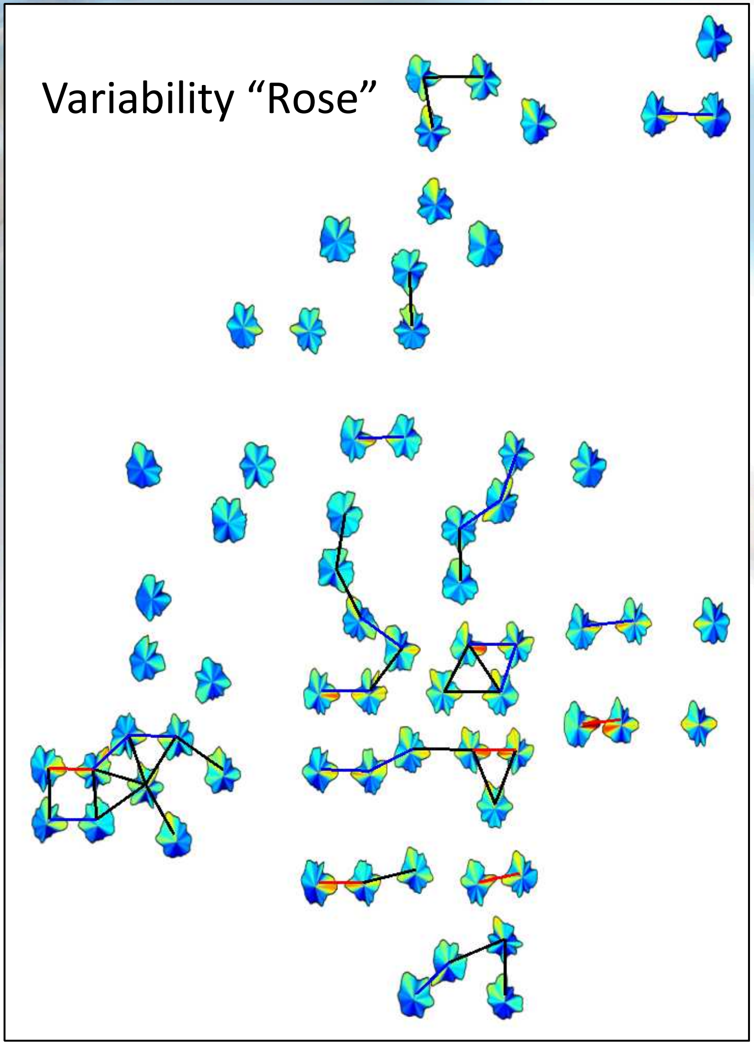
Directional analysis of SCADA data

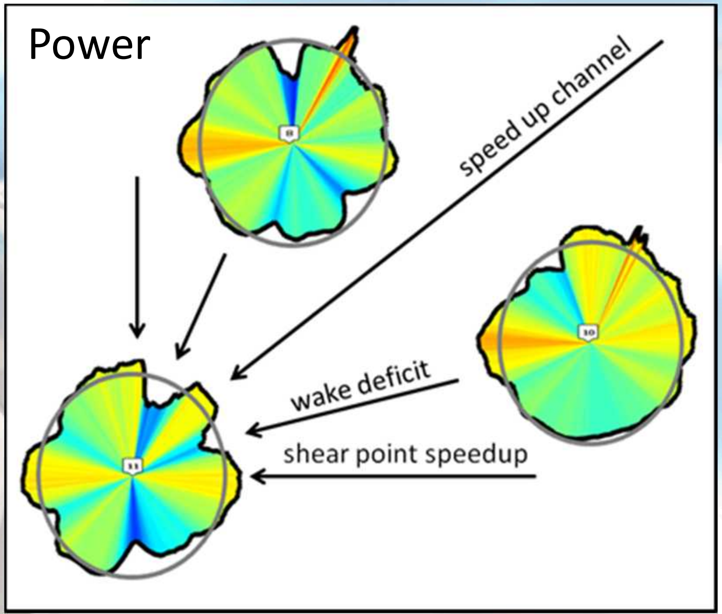


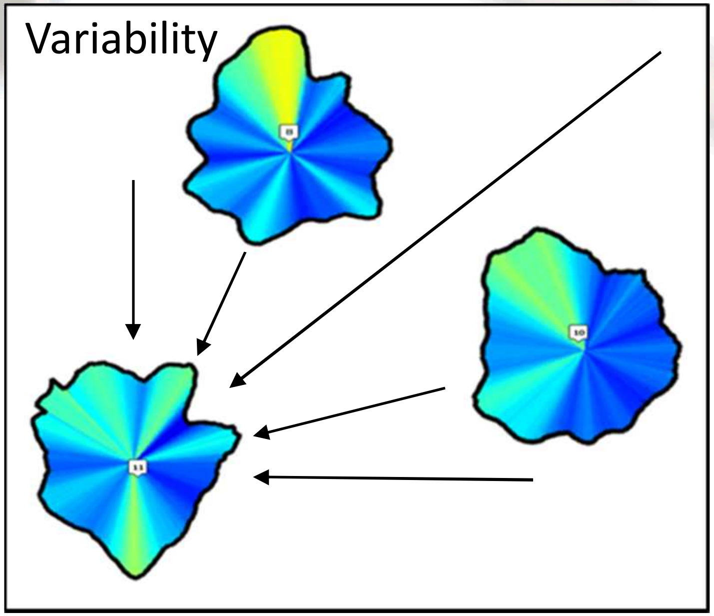


Operational quantification

- Observation: High power extraction relative to average performance occur with low variance
- If low variance equal low rates of fatigue and wear, then low rates of failure should be observed as a function of direction

- Working hypothesis: Direction plays a major role and is a simple way to quantify power and reliability
- Can we link data-mining of SCADA and apply a simple metric for reliability ?





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Conclusion

- Discrete events of proprietary nature needs to be isolated from technical benchmarking as it does not predict the future
- Environmentally induced reliability issues, originating from wind, ice, moisture, lightning, erosion, corrosion etc., are relatively undocumented – in part due to lack of attention and inspection methods
- Events are relatively rare so large amounts of data is required
- Uniform tagging across different datasets is critical
- Meaningful technical benchmarking requires normalization with respect to physical processes (technology, location etc.)
  - The semi-empirical relations could be developed from the benchmarking itself
- SCADA data analysis could enhance the relationships and give accurate lifetime performance (power and reliability) estimates
  - As a minimum data should be evaluated by directional consideration