Optimization of Wind Energy Converters

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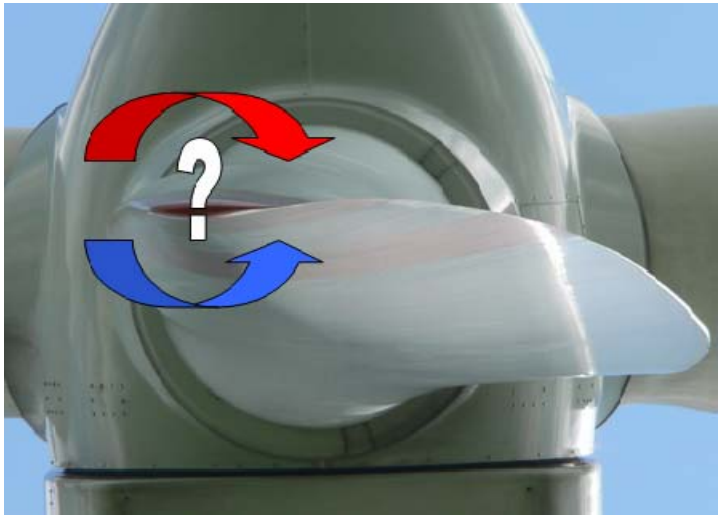
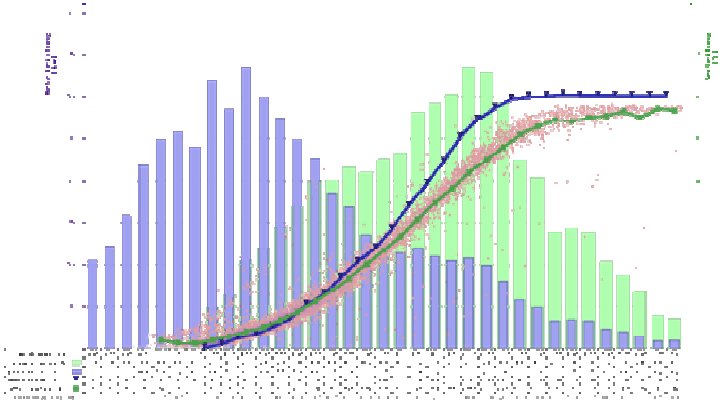
Reason for optimization

- Turbine settings often not set to optimum at individual wind farms: pitch angle, rotor speed (converter settings), pole switching
- At 10% of analyzed cases blade angles unequal which is a conservative rating
- Improper aerodynamics devices, like vortex generators, stall strips
- Turbine availability unnecessary low
- Reasons in general:
  - At installation of turbine no opportunity for detailed check of turbine settings
  - Optimization of turbine never done, because wind turbine is not sold anymore
  - Technical wind farm manager not skilled enough or too low financial resources for deep analysis

General Procedure

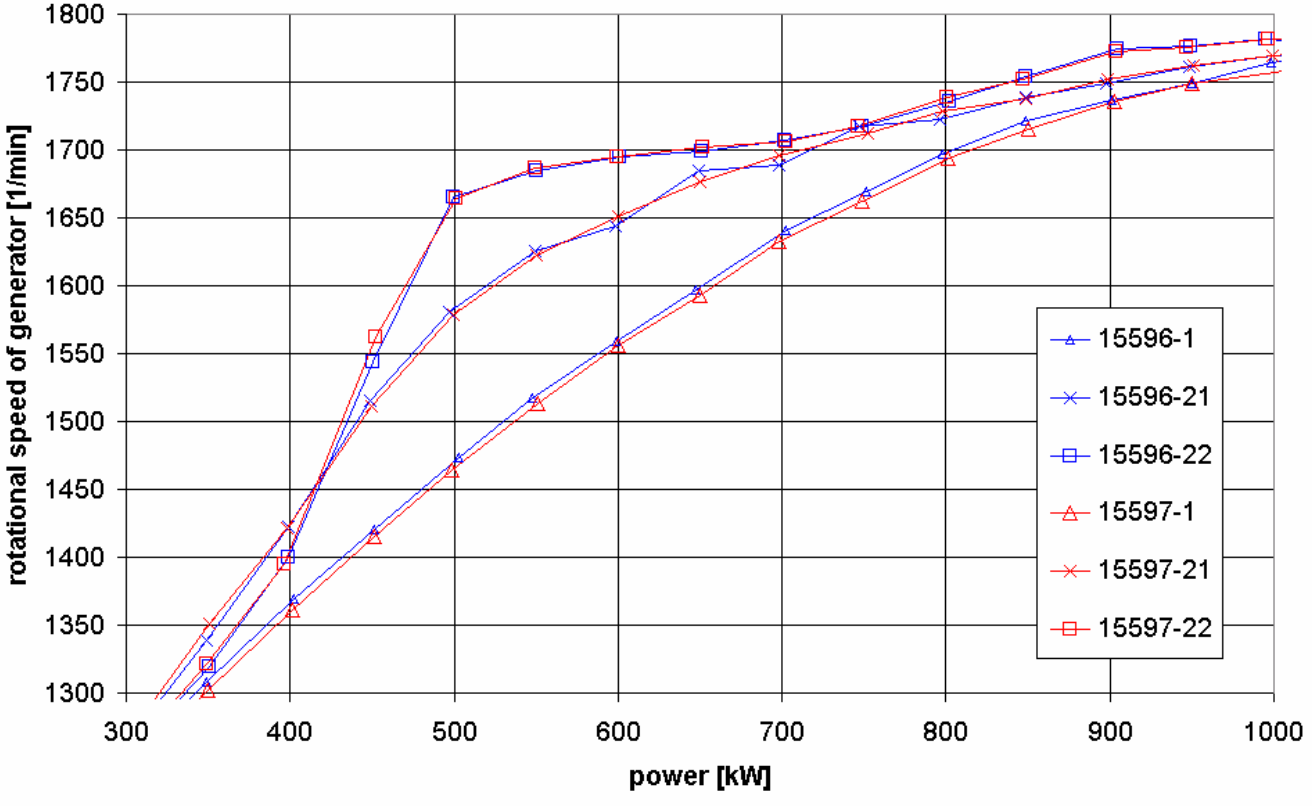
- Analysis of problem
- Development of improvements
- Verification of improvement





Analysis of pitch and rotor speed control

- Analysis of pitch angle and rotor speed control by SCADA-data

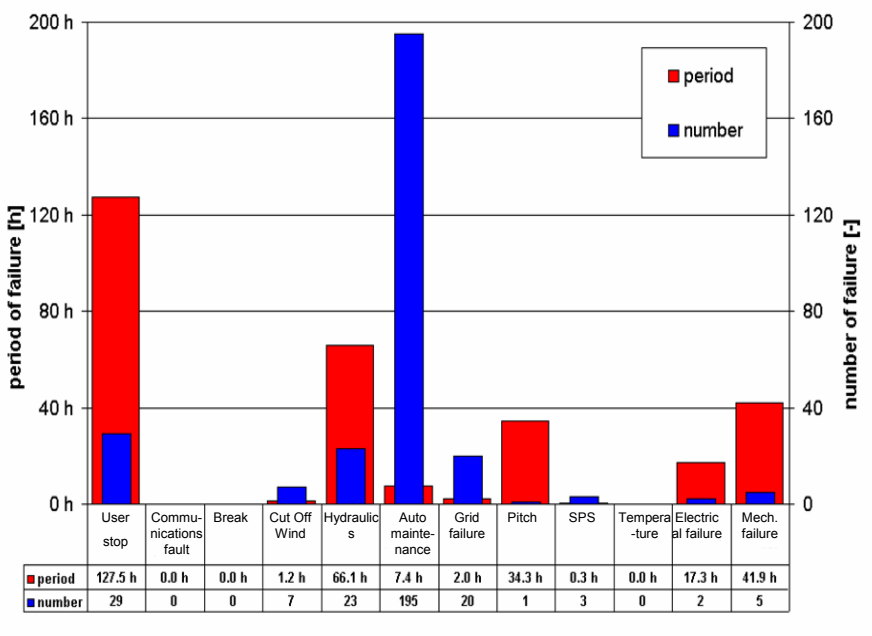


Analysis of rotor imbalance

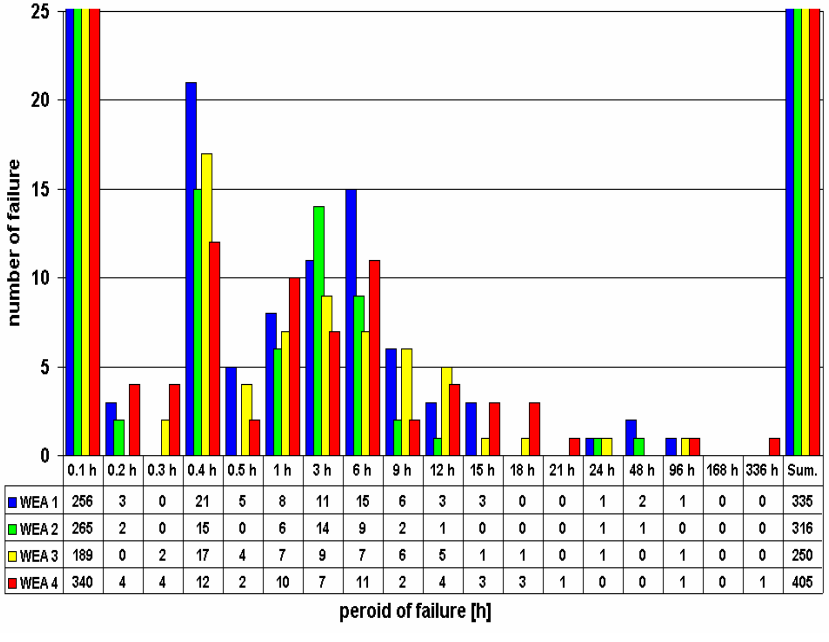
- About 20% of WEC show vibrations due to imbalances both aerodynamic (10%) and mass (10%)
- Turbines showing significant vibrations can be balanced
- Checking for erosion
- Measuring blade angles + correction
- Measure vibration level and calibrate by installing test counterweights
- Install counterweights calculated
- Vibration optimized operation

Analysis of SCADA Data

- Analysis of error causes and technical losses by SCADA-data



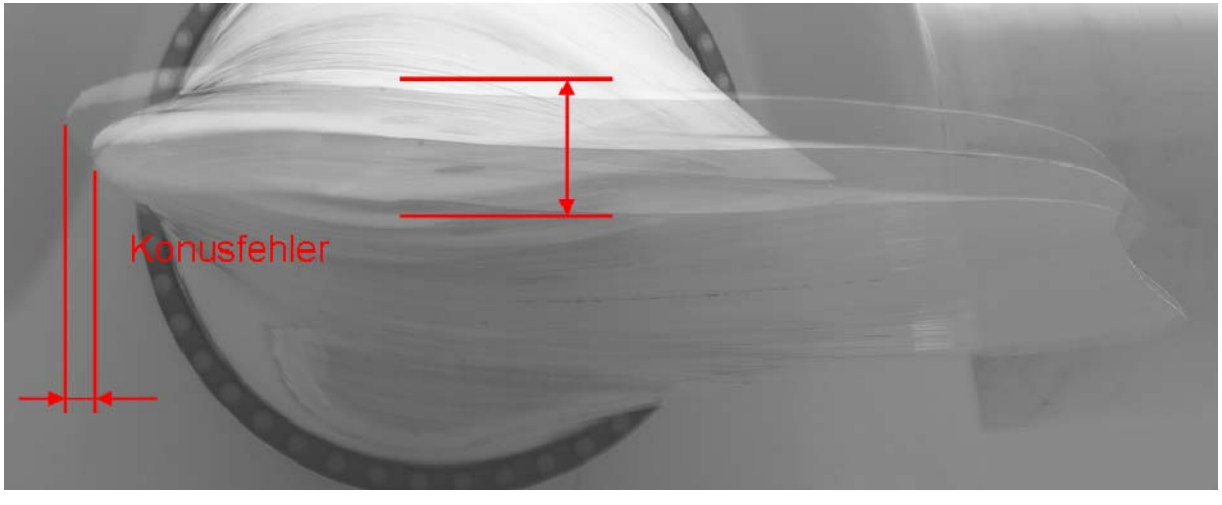
	User stop	Commu-nications fault	Break	Cut Off Wind	Hydraulics	Auto mainte-nance	Grid failure	Pitch	SPS	Tempera-ture	Electrical failure	Mech. failure
period	127.5 h	0.0 h	0.0 h	1.2 h	66.1 h	7.4 h	2.0 h	34.3 h	0.3 h	0.0 h	17.3 h	41.9 h
number	29	0	0	7	23	195	20	1	3	0	2	5



	0.1 h	0.2 h	0.3 h	0.4 h	0.5 h	1 h	3 h	6 h	9 h	12 h	15 h	18 h	21 h	24 h	48 h	96 h	168 h	336 h	Sum.
WEA 1	256	3	0	21	5	8	11	15	6	3	3	0	0	1	2	1	0	0	335
WEA 2	265	2	0	15	0	6	14	9	2	1	0	0	0	1	1	0	0	0	316
WEA 3	189	0	2	17	4	7	9	7	6	5	1	1	0	1	0	1	0	0	250
WEA 4	340	4	4	12	2	10	7	11	2	4	3	3	1	0	0	1	0	1	405

Analysis of blade settings

- Analysis of blade angles by optical measurements
  - Optical method to determine all blade faults
    - 1. Individual blade angles
    - 2. Rotor setting
    - 3. Damages at aerodynamic devices
    - 4. Improper angle division and cone angle errors



Improvements

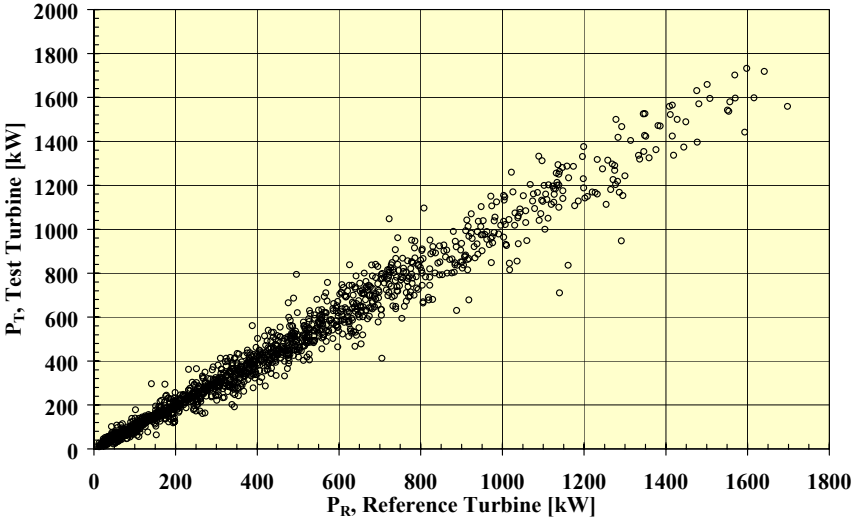
- Try and error for pitch settings, rotor speed, pole switching
  - Change only one parameter at once
  - Leave one turbine 1 unchanged, change one setting at turbine 2 to one direction and at the neighboring turbine 3 to the other direction within limits specified by manufacturer
  - Observe which direction was the right one, then change turbines 2 and 3 more in the right direction until optimum is exceeded

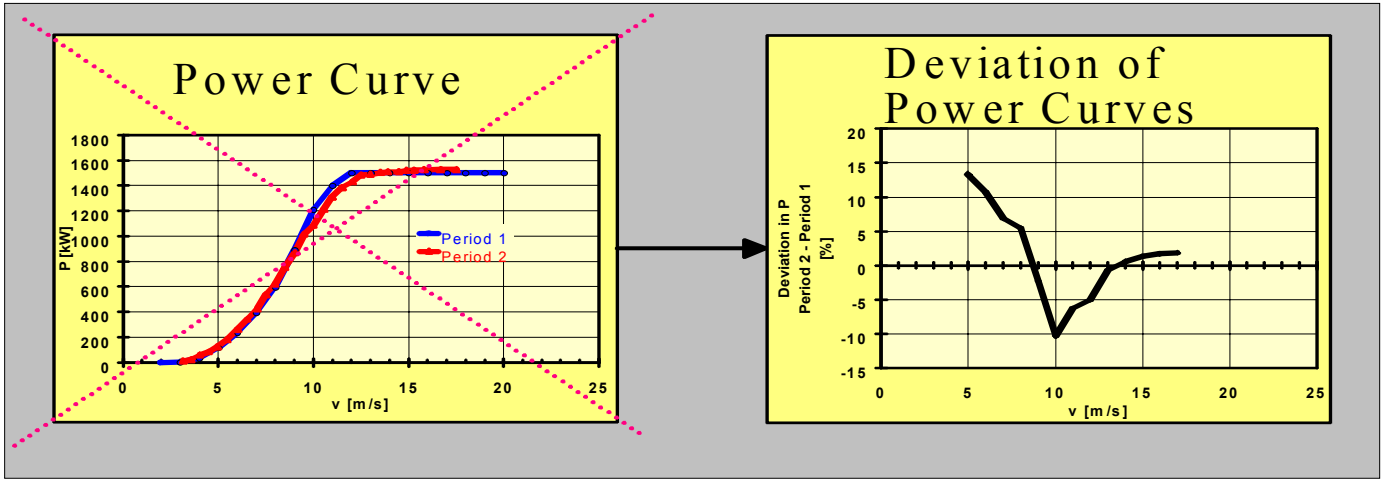
Improvements

- Set blade angles to same value
  - Repair of damages and aerodynamic devices (e.g. Vortex generators, stall strips)
- Solve origin of low technical availability instead of repairing the same fault time after time
- Get turbine back to operation after fault as fast as possible

Verification

- For power curve optimization:
  Relative Power Curve Analysis

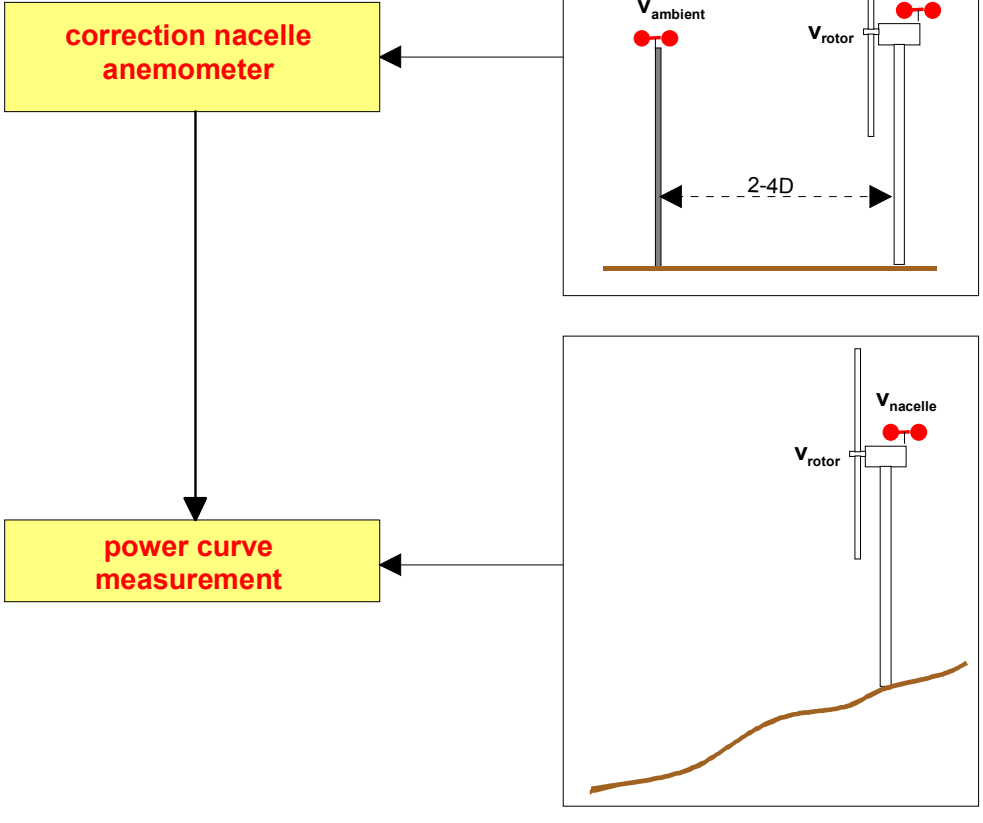




Relative Power Performance=
deviation of power curve between different periods of time

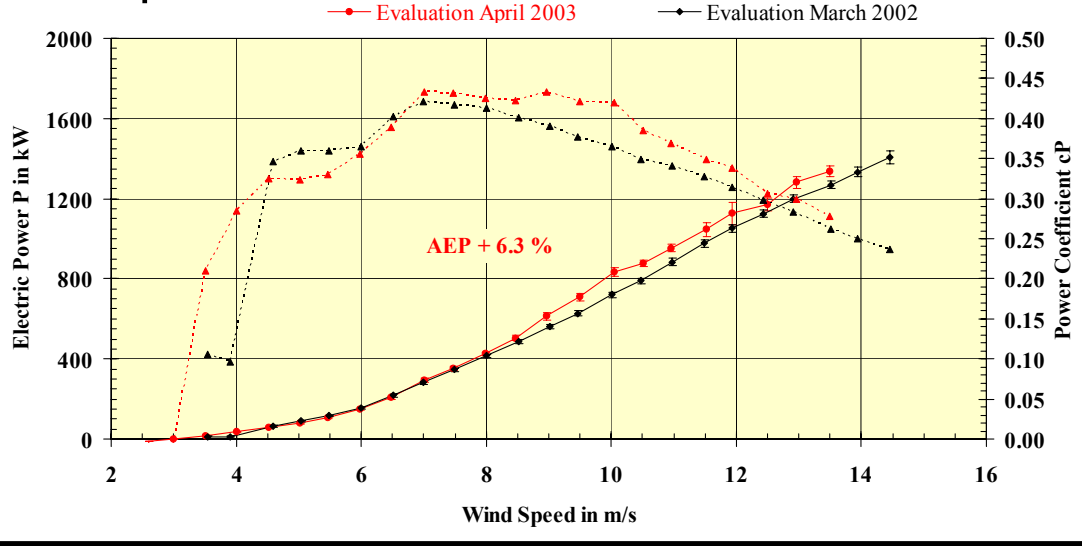
Verification

- Alternative: Advanced nacelle anemometry



Examples

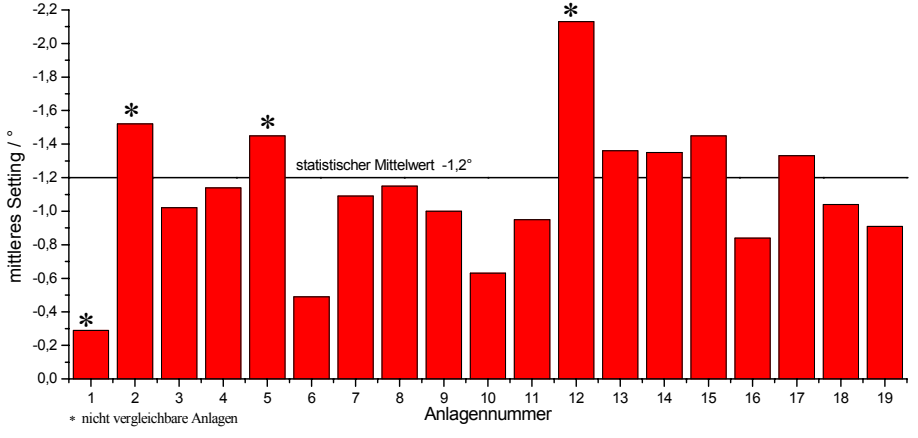
- Wind Farm A:
  - Analysis of availability problems
  - 5% Increase of availability after improvement
  - Try and error of power curve improvement with 5% improvement by small change of blade angle and dismantling of stall strips
  - Same nacelle anemometer power curve after improvements at all turbines, close to guaranteed power curve



Examples

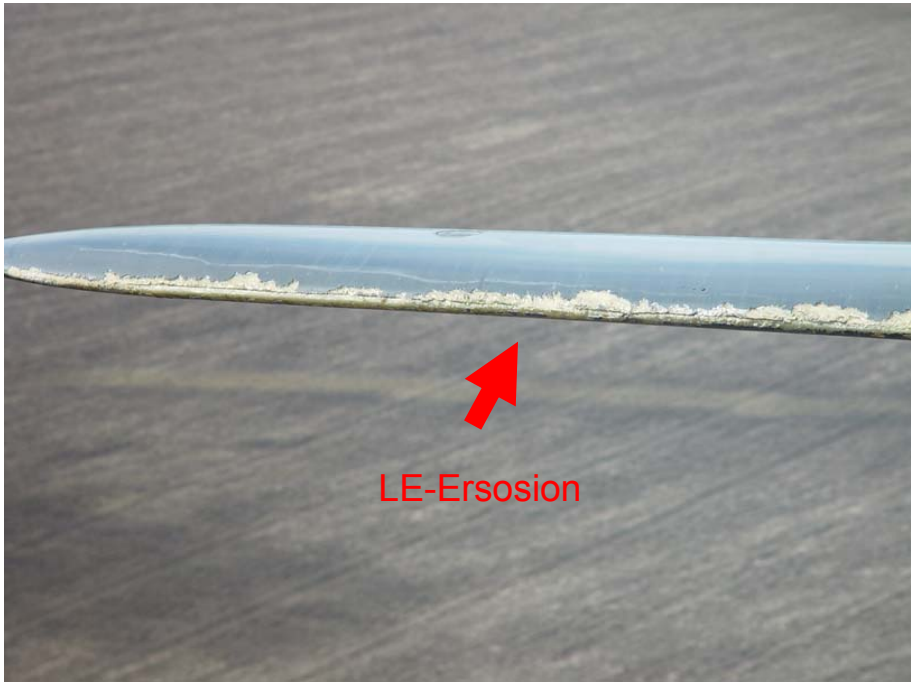
- Wind Farm B:
  - Arbitrary rotor speed settings at some turbines
- Wind Farm C:
  - Setting deviations, and massive damages at vortex generators, also different blade types

WEC	Blade 1	Blade 2	Blade 3			
	Tip degree	Tip degree	Tip degree	mean deg		deviation
480	9,38	9,47	9,02	9,29		<= 0,1°
481	9,24	9,58	9,3	9,37		> 0,1°
482	8,96	8,71	8,86	8,84		>0,3°
483	8,92	9,85	9,43	9,40		>0,5°



Examples

- Zond 750 kW:
  - Individual blade angles fault
  - setting deviations (some above 1 degree)
  - massive leading edge erosion (90% of turbines, up to 50% of blade length)
  - Imbalanced Rotors



Conclusions

- Analysis SCADA
  - 1000-2000 Euro per turbine
- Blade Angle Measurements
  - 500 Euro per turbine
- Relative Power Curve analysis
  - 1000 Euro per Turbine
- Example
  - 2MW machine
  - 2000 full load hours
  - 4000MWh/a
  - 0.06€/kWh
  - 320.000 € turnover/a
  - 0,9375 cost of analysis in percent of annual turnover
- Even small improvements pay of after only 1 year