

# Health & Performance Assessment

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# Romax Technology

- Gearbox and drivetrain specialists
- Established in 1989
- Approx. 220 employees globally, 120 in UK, 12 offices worldwide
- Work in a range of industries
  - Automotive, heavy industry, marine, aerospace
  - Wind energy

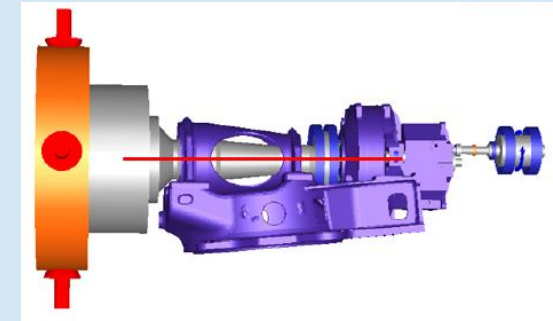
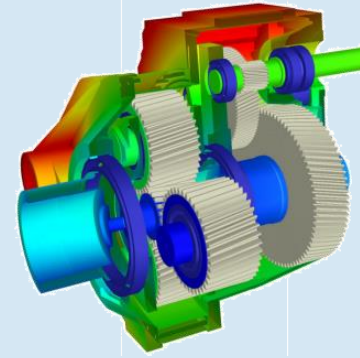


# Romax Technology – history in wind

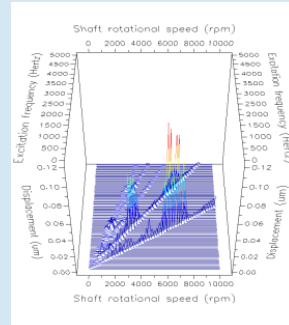
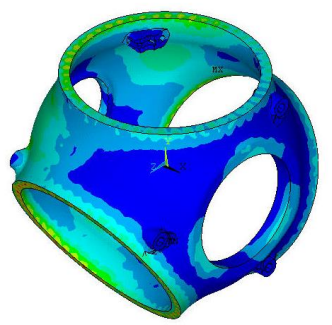
**Drivetrain and gearbox design**, worldwide no. 1 independent wind turbine gearbox designer; 39 certified gearbox designs to date



**Drivetrain simulation**, RomaxWIND virtual product development environment; dynamic analysis; gear and bearing simulation

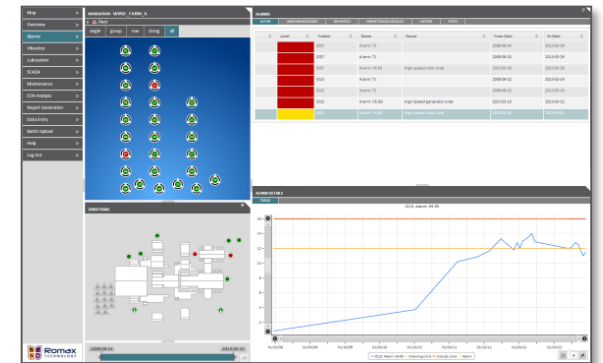
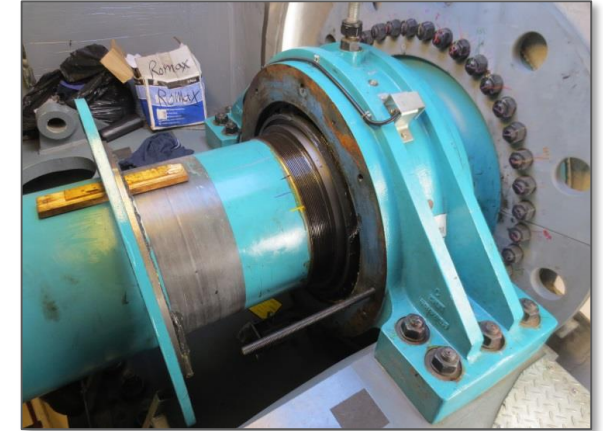


**Engineering consultancy**, analysis, inspection, certification support, testing, failure investigation, manufacturing support, etc.





# InSight – enabling predictive maintenance

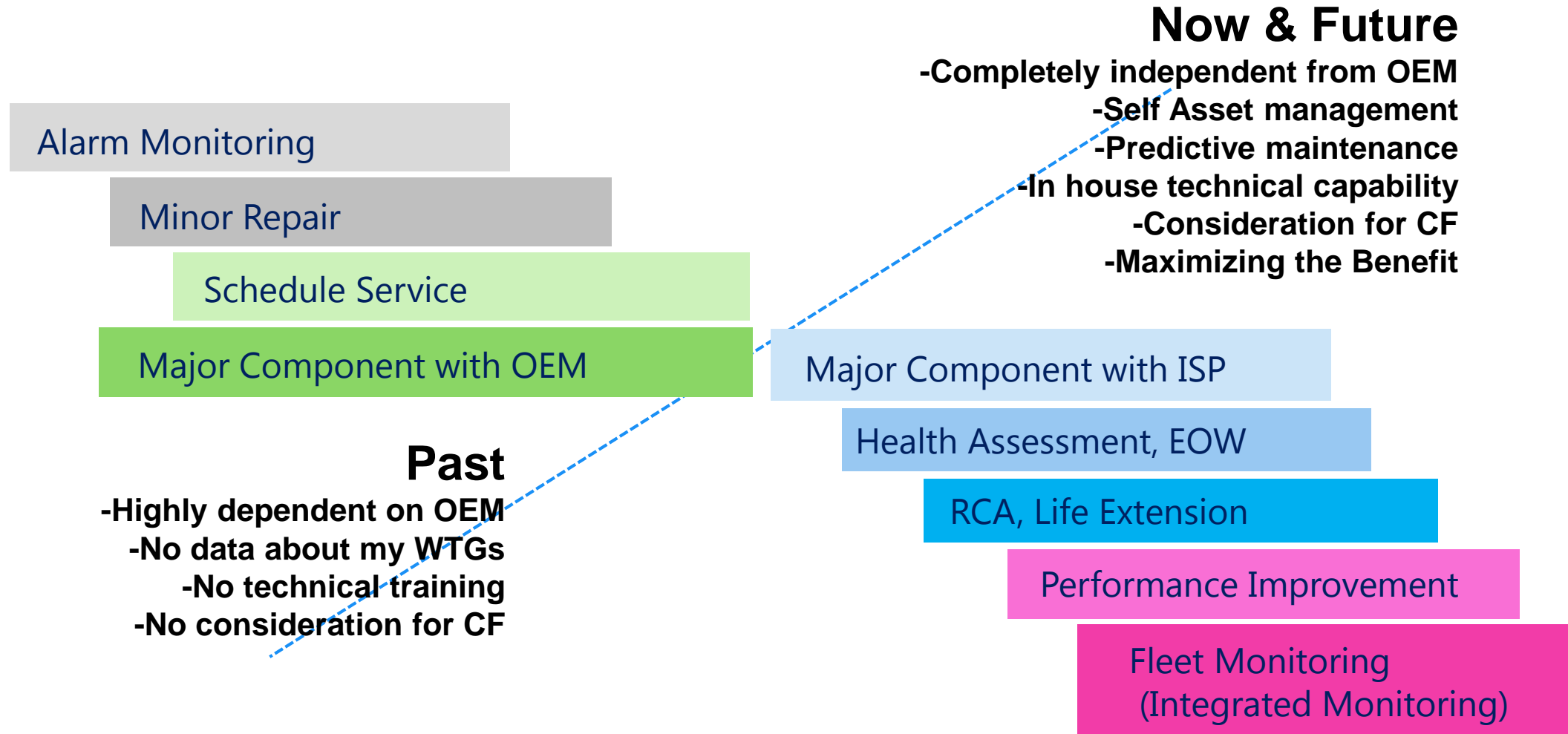


# Track Record

- **Over 5 GW** of inspections and health analysis to date
- **5GW** monitored and analyzed using Romax InSight
- Monitoring services to over **40%** of the UK offshore wind turbine fleet
- Experience with all major manufacturer's
- Supporting customers in UK, Europe, USA, Canada, Honduras, Nicaragua, Brazil, India, Korea and China



# Where we are and what we need ?



# 풍력발전기 건강상태 진단

- ***Asset Management***
- ***Predictive maintenance***
- ***Building the O&M strategy***
- ***Life expectation***
- ***Minimizing the downtime & Maximizing the benefits***
- ***Claim the warranty issues***

# What are the major risks in wind farm O&M ?

## **Risks affecting RoI and Asset Value**

### 1. Major Component Poor Quality or Damage

- Gearbox damage causes - 1 million USD cost / 6 months downtime

### 2. Wind Turbine Under-Performance

- Machine availability is high (>95%), but Power generation efficiency is not always high (80~90%)



# What are the major risks in wind farm O&M ?

## **Global trends to manage O&M risk**

1. Health assessment & expert inspection
2. Wind turbine Performance Improvement
3. Data-driven O&M using CMS / Field Mobile Tools

# List of recent projects

## Wind farm Health assessment, Year 2013-14

- UK offshore windfarm health assessment and monitoring for **316.8MWm** 3MW Class WT
- UK offshore windfarm health assessment and monitoring for **504MW**, 3MW Class WT
- UK offshore windfarm health assessment and monitoring for **270MW**, 3MW Class WT
- UK offshore windfarm health assessment and monitoring for **194.4MW**, 3MW Class WT
- US onshore windfarm health assessment and monitoring for NAES, **204.7MW**, 2MW Class WT
- US onshore windfarm health assessment and monitoring for **9MW**, **GE1.5MW**, Onshore
- UK offshore wind farm due diligence and health assessment for **30 x V80 WTG's**.
- US onshore wind farm **44 x 2.3MW** end of warranty inspection / health assessment.
- US onshore wind farm **74 x 2.3MW** end of warranty inspection / assessment.
- Asia onshore **155 x 1.5MW / 2MW** end of warranty inspection / assessment.
- Asia onshore **6 x 2MW** health assessment
- Asia onshore **3 x 3MW** health assessment
- 1.5MW turbine main shaft bearing failure analysis for a US wind farm.
- V47, NM52 WTG inspection and major failure repair for a Korean onshore wind farm.
- 2.0 MW onshore wind turbine gearbox failure analysis for a Korean wind farm.
- 1.5MW turbine main shaft bearing failure analysis & solution for Chinese onshore turbine farm.

# Sheringham Shoal – Offshore End of Warranty

- 88 x 3.6 MW, whole turbine inspections, CMS and SCADA analysis
- To date, **the largest Offshore End of Warranty Inspection in the world**





# Cannon Powr US Windfarm, Washington - End of Warranty

- 114 Wind Turbines (2MW Class), Full wind turbine inspection EoW
- Targeted inspection list based on CMS data



# List of recent projects

## Major Component Service, Year 2012-14



2MW gearbox  
refurbishment  
Taiwan  
Power  
Company,



Blade Onsite  
Repair Korea,  
Customer  
confidential



2MW gearbox  
replacement  
customer  
confidential



Blade  
assembly  
/disassembly  
customer  
confidential



Main bearing  
replacement  
customer  
confidential



Generator  
Replacement  
customer  
confidential

- 1.5MW gearbox full refurbishment
- Gearbox/Mainbearing/Generator replacement
- Gearbox HSS bearing replacement in situ
- Gearbox oil replacement and Flushing in nacelle
- Torque arm / suspension bush changes in nacelle
- Service crane repair and replacement in nacelle

- Generator damper (mounting) change and alignment in nacelle
- HSS Brake Pad change and Brake disc refurb.
- Heat exchanger (cooling system) upgrade
- Main bearing and Seal replacement
- Generator Bearing / Slip ring changes
- Hub flange bushing replacement
- Hub nacelle assembly

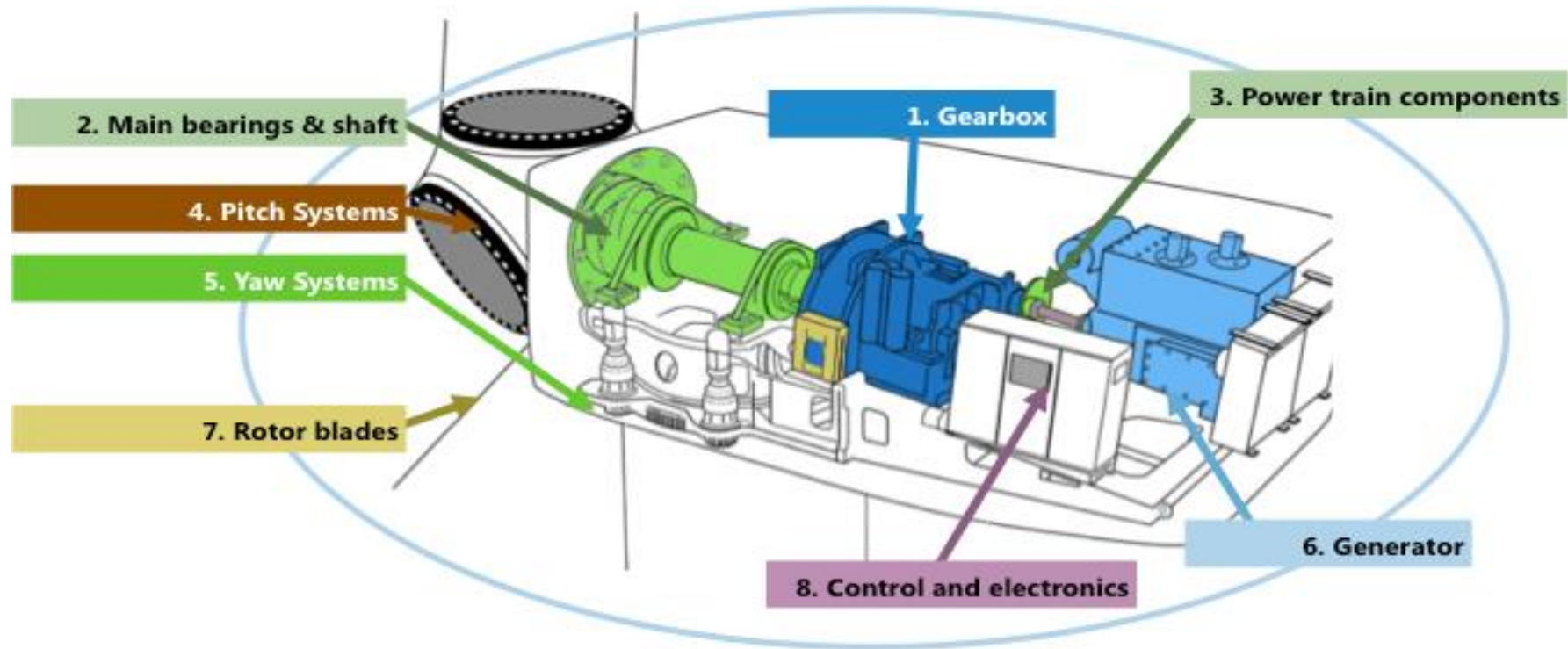
- Hub, nacelle, blade replacement
- HSS Coupling change
- Main shaft shrink disc change
- Blade in situ repair
  - Repair of surface and structure
  - Edge separation
  - Crack
  - Lamination damage
  - Lightning protection system damage



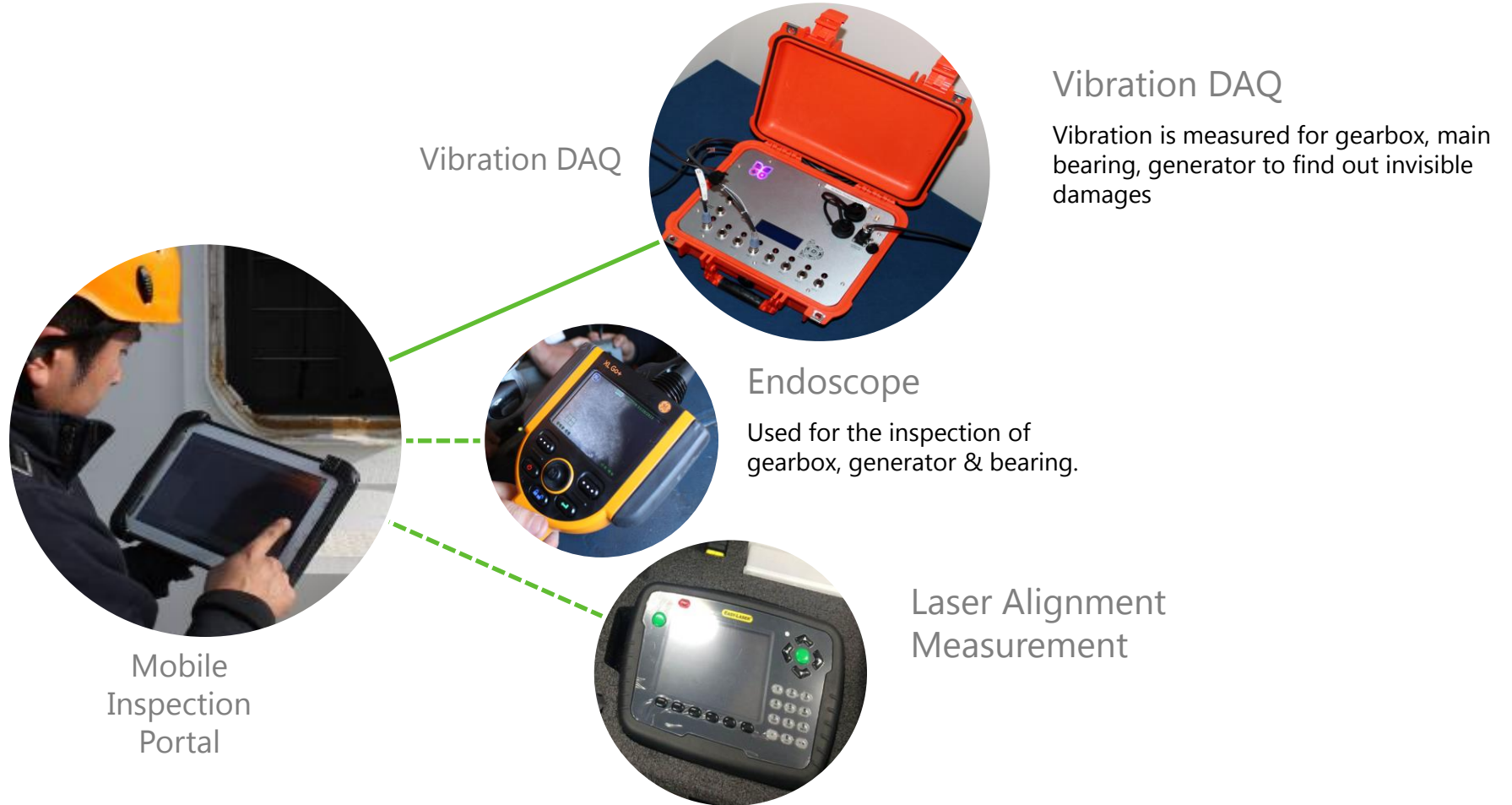
# EXPERT INSPECTION & HEALTH ASSESSMENT

# What to inspect?

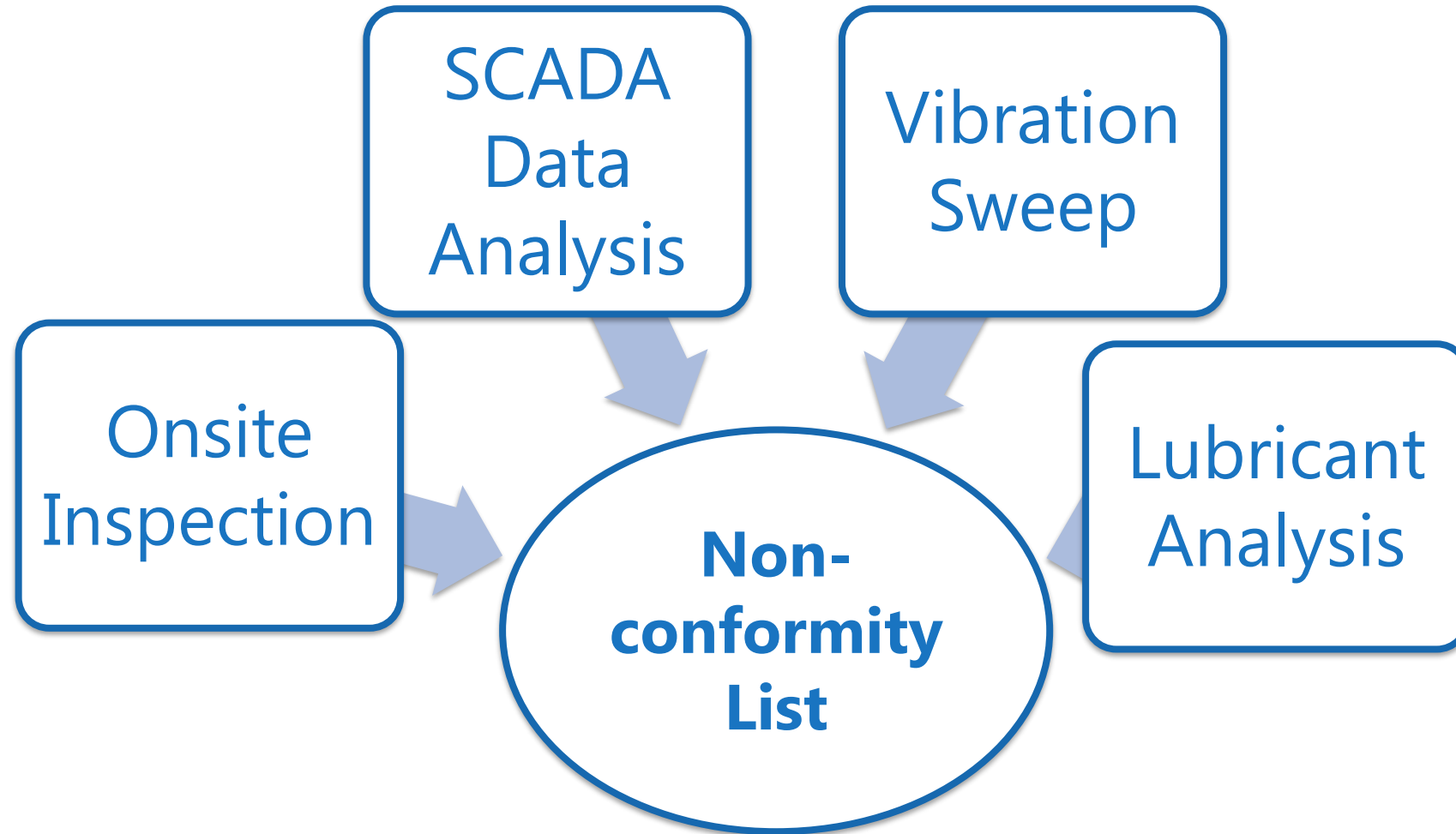
- All major component shown above needs to be assessed.
- Especially, drivetrain ( gearbox, main bearing and generator ) is the key inspection item.



# Special tools & analysis required for inspection?



# What analytic method used for inspection?



# What SCADA Data Analysis can find out?

## Common issues from Romax Experience

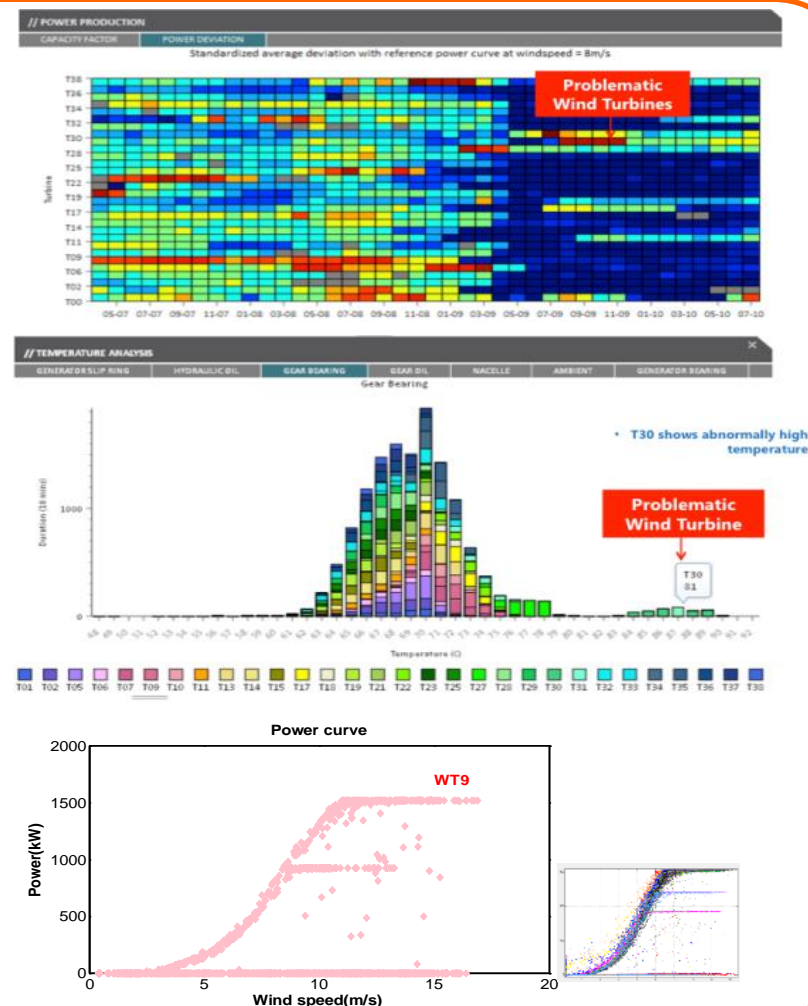
**SCADA data contains key information about wind farm performance and health condition. Past 2~3 years SCADA data of entire wind farm should be analyzed to assess following aspects**

- Wind turbine efficiency
- Site wind condition
- Health condition of gearbox, bearing, generator
- Wind turbine sensor condition
- Alarm record

### Top 5 Problems from Romax SCADA Analysis

- Wind turbine efficiency loss
- Poorly done maintenance that didn't address the root cause of alarm
- Gear and bearing failure symptoms that needs attention, although it didn't yet triggered controller alarm
- Yaw and pitch malfunctioning
- Hydraulic system malfunctioning

**!** SCADA data analysis report provided by wind turbine maker focuses on performance side of wind turbines, because it's major purpose is proving that contractual availability condition is met. It usually doesn't highlight if there's any 'efficiency loss' or 'potential health problems'. However, according to Romax's experience, if "Existing SCADA data" is analyzed with proper diagnostic expertise, provides huge information about farm health condition.





Here's the 'target suspect list'  
that field inspection team should focus.

	VAR300	VAR217	VAR216	VAR209	VAR208	VAR205	VAR204	VAR203	VAR110	VAR109	VAR108	VAR051	VAR050	VAR040	VAR039	VAR038	VAR037	VAR030	VAR029	VAR028	VAR027	VAR026	VAR024	VAR023	VAR022	VAR019	VAR018	VAR016	VAR015	VAR010	Turbine
Power - performance	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Main Bearing Temp.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Gearbox IMS-DE Temp	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Gearbox IMS-NDE Temp	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Gearbox HSS-DE Temp	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Gearbox HSS-NDE Temp	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Generator DE Brg. Temp	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Generator NDE Brg. Temp	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Pitch Performance	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Pitch Conv. Temp	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Pitch Battery Voltage	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

**Targeted Endoscope Inspection at Onsite required**


# What Vibration Analysis can find out?

## Common issues from Romax Experience

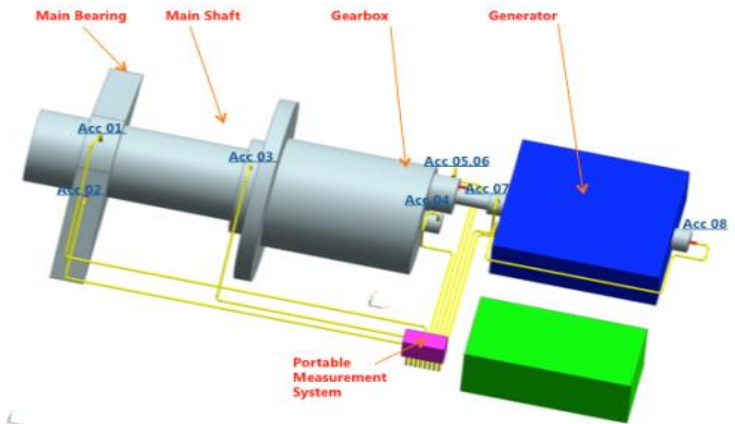
Portable vibration measurement kit, specially developed for wind turbine, can be installed easily in an hour and take measurement for several hours under good wind condition, which can reveal much of potential problems that are not visible to eye inspection.

### Top 5 Problems from Vibration analysis

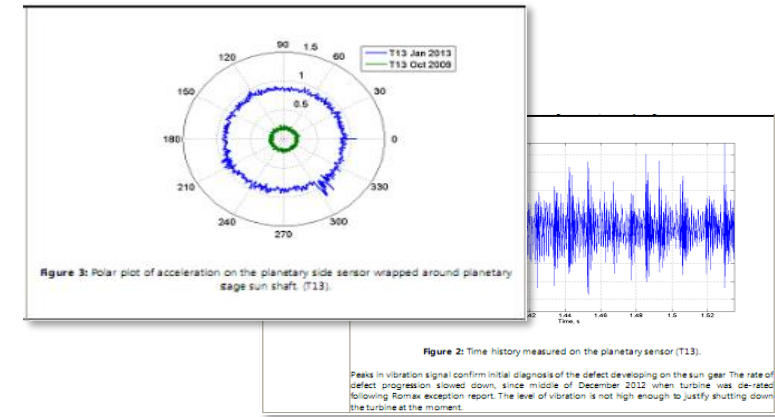
- Generator bearing damage
- HSS bearing pitting
- Main bearing pitting
- HSS and IMS gear tooth cracks and pitting
- Generator soft foot and misalignment

 Vibration analysis requires in-depth expertise of drivetrain design and dynamics, in order to make it truly useful for maintenance. Merely judging overall vibration level based on ISO or VDI standard, and arguing if overall vibration is high or not isn't sufficient. The analysis should address if which component is causing the abnormal symptoms, what is the progression of damage, and what is the recommended maintenance action.

Example of vibration sensor locations

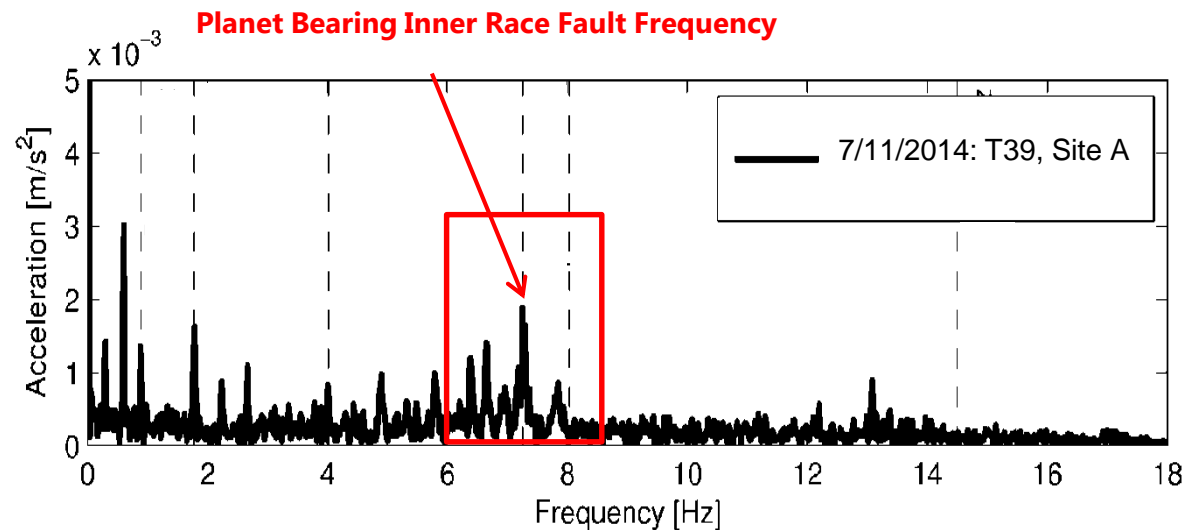


Vibration analysis result



# Targeted inspection based on vibration result

- **Vibration indicated:** Inner race damage
- **Inspection found:** Inner race macropitting



Borescope inspection



**Warranty Claim: Gearbox replacement**

*"The ability to know which turbines to target has meant that we have a much better process in place when it comes to managing inspections and maintenance."* Mike Cookson, **EDF RS**

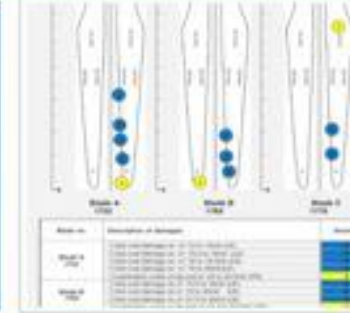
# What Onsite Inspection can find out?

## Common issues from Romax Experience

### Top 3 Blade Problems

- Blade edge separation
- Blade crack and Lamination damage
- Lightning protection system damage due to lightning

⚠ Often internal layer damages are hidden under surficial damage, which is not observed by telescope inspection. Close up visual inspection by expert is required for complete recovery.



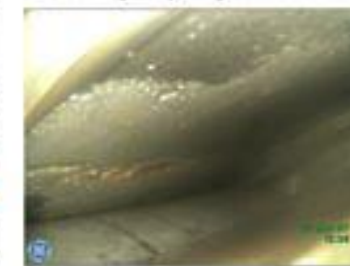
### Top 5 Drivetrain Problems

- Gearbox gear and bearing wear, pitting, crack
- Main bearing pitting
- Contaminated gearbox oil and main bearing grease
- Oil leakage at hollow shaft seal, HSS shaft seal
- Shaft misalignment

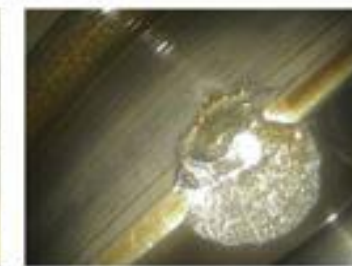
⚠ There are more than 30 failure symptoms of a typical wind gearbox, and some of them are fast-developing critical failures while some are trivial damage. Expert judgment is critical not to miss the important symptoms.



HSS bearing GS spalling IR



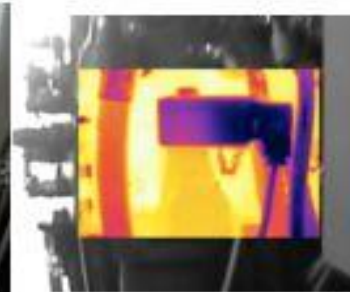
Gear failure



### Top 5 Gen, Controller, Converter Problems

- Generator bearing damage
- Controller, CT module malfunctioning
- Winding insulation deterioration and excessive heat
- Skii pack overheating or overcurrent
- Generator foundation (damper) problem

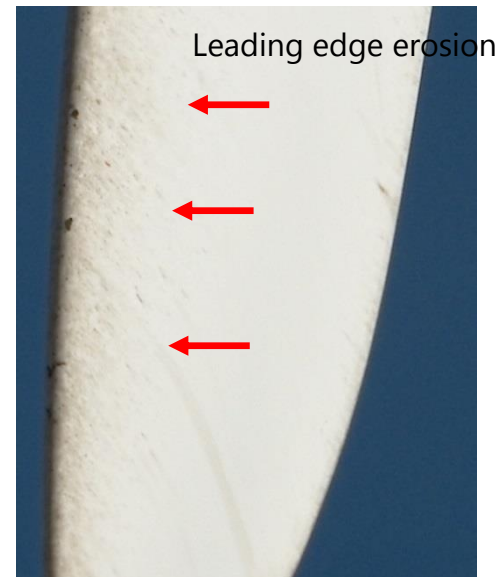
⚠ Effective use of special tools are required. Such tools include thermal image camera, endoscope, laser alignment device and various measurement tools





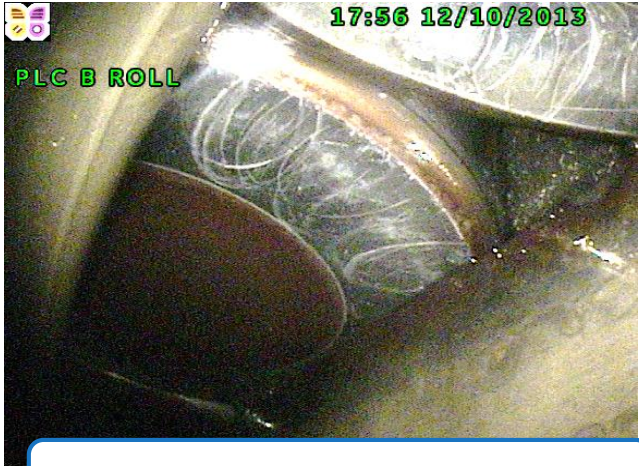
# Blade inspections

- Zeiss Photoscope - 45x Optical zoom with 7 MP Camera onboard
- Inspect entire blade surface (LE, TE, SS, PS, Tip and root)
- Inspection by rope access is sub-contracted, recommend at least 10% of turbines on site be inspected this way

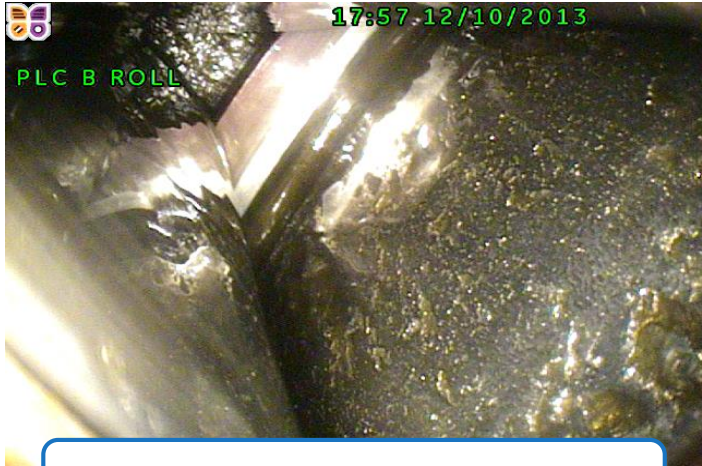




# GE XL GO 5mm Borescope image examples



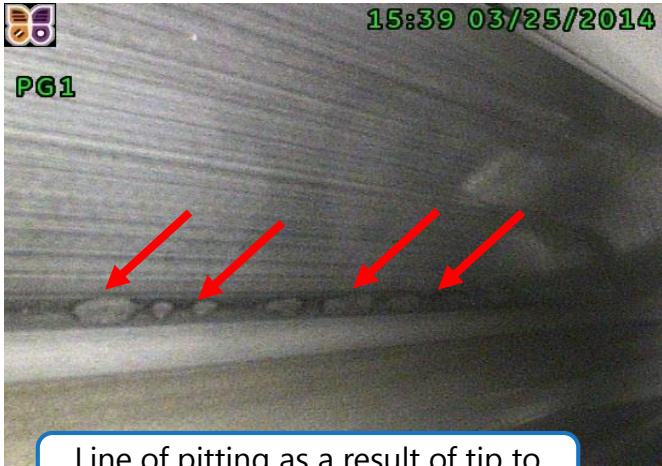
Roller end with abrasive wear



Bearing inner ring macro pitting



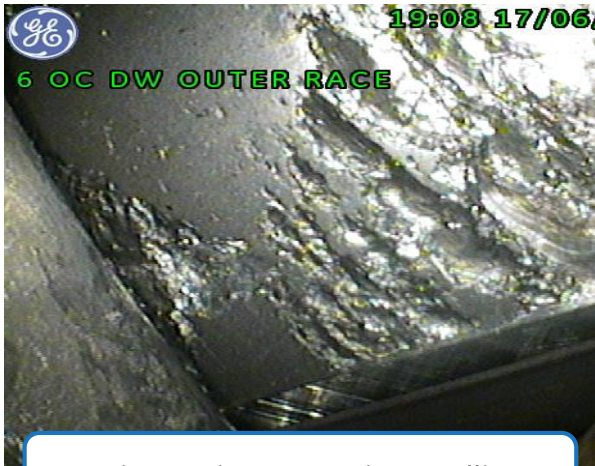
Close up of sun gear micropitting



Line of pitting as a result of tip to root interference



Planet bearing spalling



Main Bearing outer ring spalling

# What is the final outcome of Inspection?

## Non conformity report with evidences

The most important output from expert inspection is inspection summary and maintenance action report.

- Report should summarize all SCADA, Vibration and oil analysis result
- Report should contain actionable maintenance plan
- Report should have categorize rating, indicating how critical the damage is, and how urgently action should be followed.

Turbine	Rating			Comments
	Bearings condition	Oil sample analysis	Vibration analysis	
1	4	2	3	Inspection of HSS RS bearing is recommended within next 6 months. Possible inner race defect on the generator bearing.
2	3	1	5	Immediate inspection of HSS GS bearings is recommended
3	3	1	2	Healthy
4	3	1	3	Further investigation of high bearing temperature.

Severity	Definition
Accept[1]	1 - No damage observed (accept)
Reject[2]	2 - Non-conformity, minor issue, progression unknown, add to watch list (reject)
Reject[3]	3 - Non-conformity, early stage damage observed. plan for elevated monitoring to establish progression. (reject)
Reject[4]	4 - Non-conformity, major damage observed. plan for repair or replacement (reject)
Reject[5]	5 - Non-conformity, stop turbine, repair or replace immediately (reject)

### MAINTENANCE SUGGESTION

#### Major Maintenance Item

- ☐ Gearbox HSS bearings(UW,DW) replacement
  - Gearbox suspension replacement
  - Gearbox flushing and gear oil & filter replacement
  - Generator alignment after HSS bearing/suspension replacement
- ☐ Service crane to be replaced

#### Regular Maintenance Item

- ☐ Check and replace disc springs of gear suspension
- ☐ Generator Coupling alignment/replacement
- ☐ Remove corrosion and feed new grease to yaw bearing
- ☐ Gearbox flushing and gear oil & filter replacement
- ☐ Rusted surfaces to be cleaned/ an Anti-corrosive paint(gearbox, nacelle)
- ☐ VRCC Electric cable replacement
- ☐ Desiccant breather

ine No.6

# 풍력발전기 출력 효율 평가 및 개선

- *Maximize the Capacity Factor and Turbine Performance*
- *Asset Management*

# PERFORMANCE LOSS

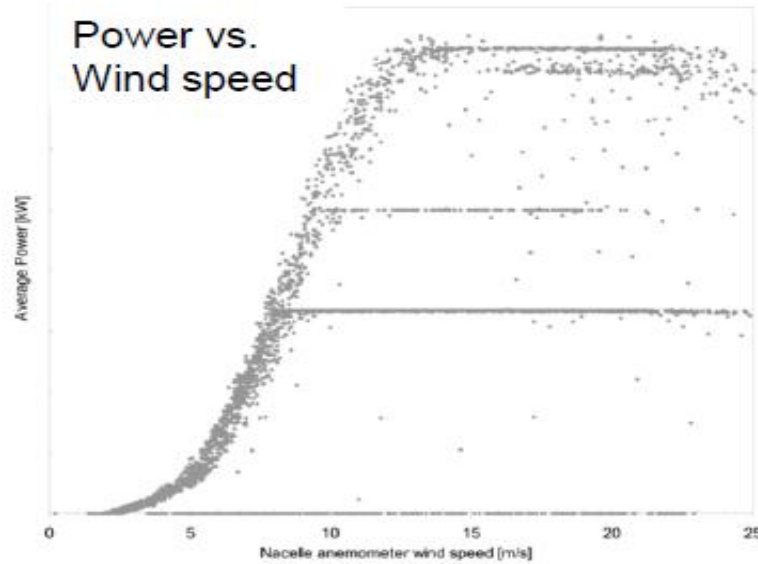
What causes the loss?



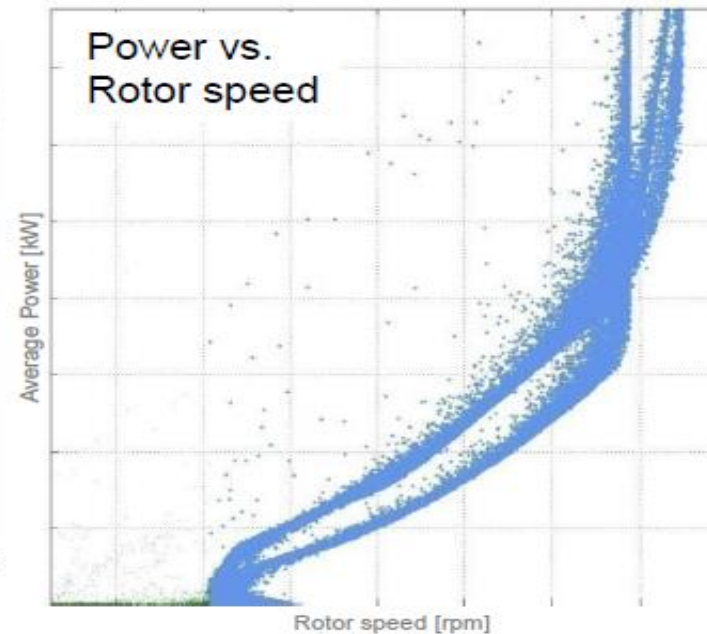
# What causes 'Under Performance'?

## Non-optimal installation, control setting, operation

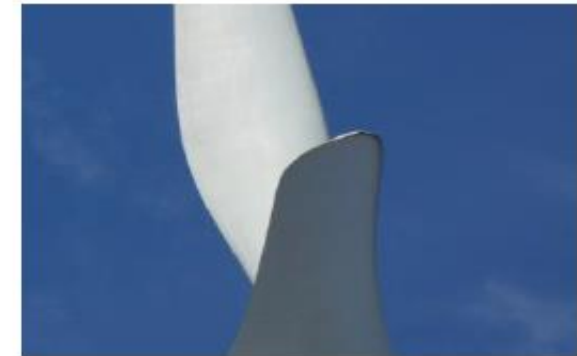
1) De-rating



2) Non-optimal controller settings



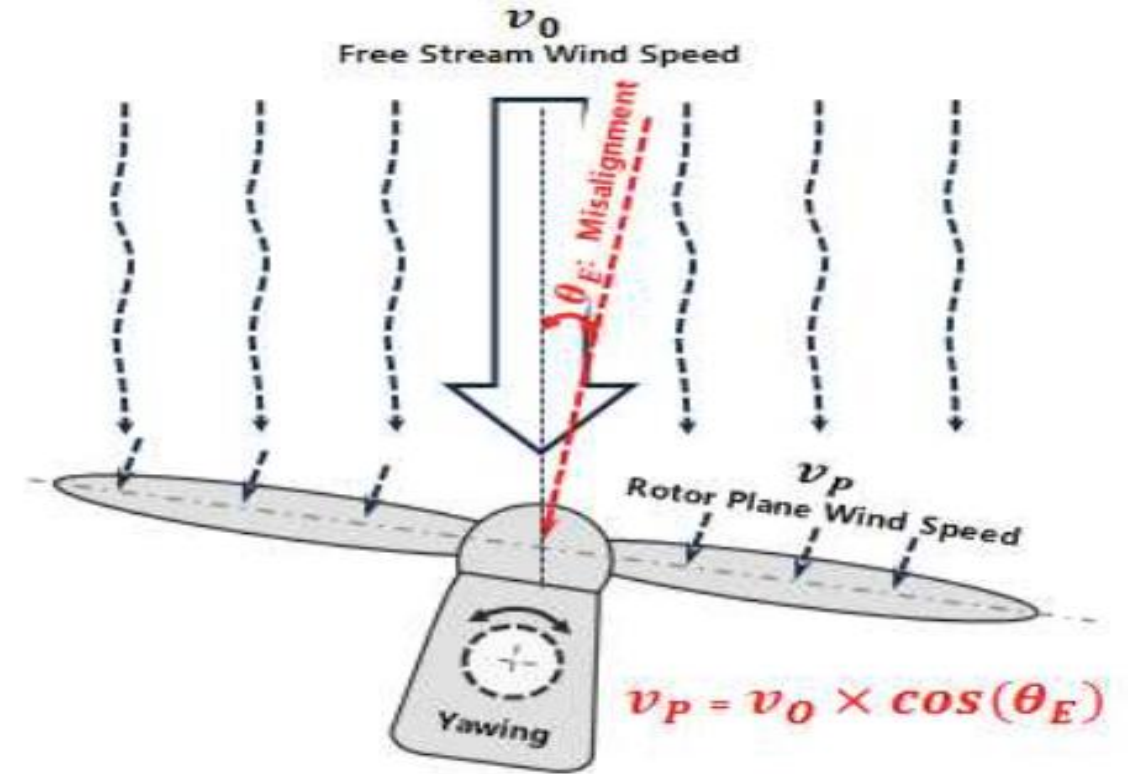
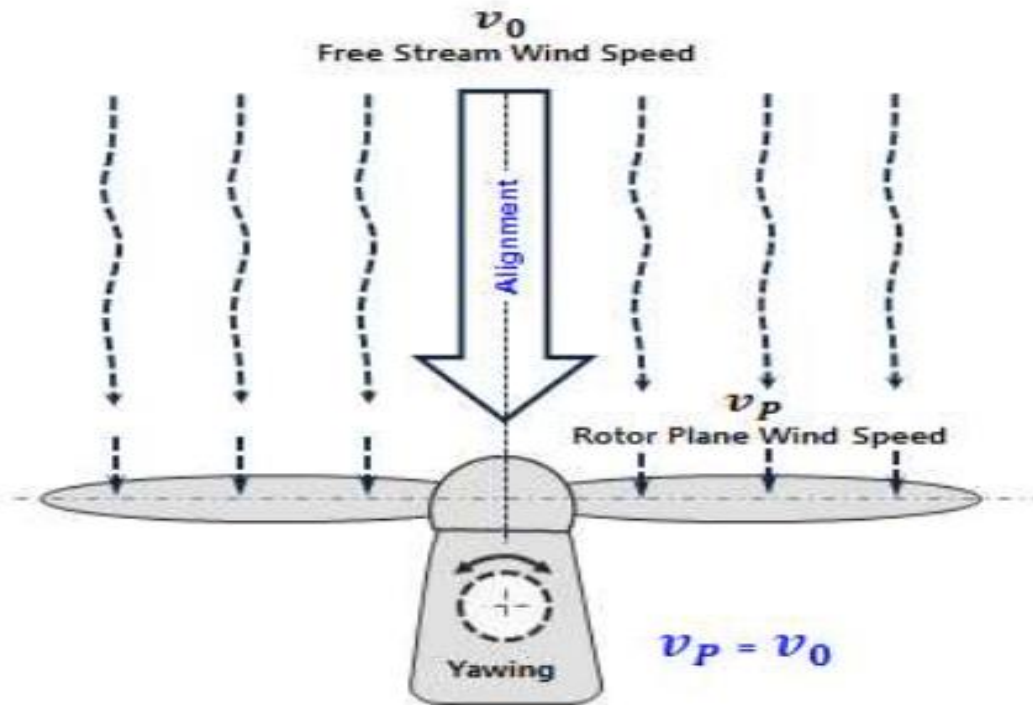
3) Component misalignment / Sensor error





# Possible reasons for deviation

## Yaw Misalignment

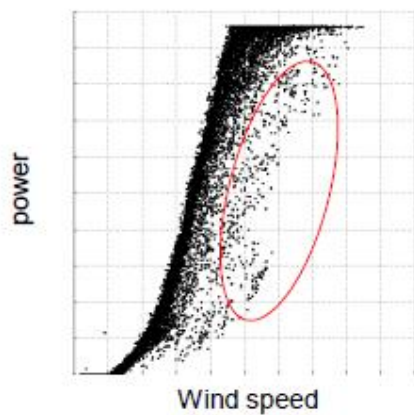
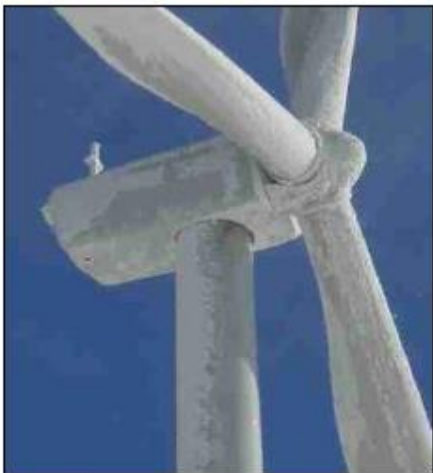


# Possible reasons for deviation

## Blade issues

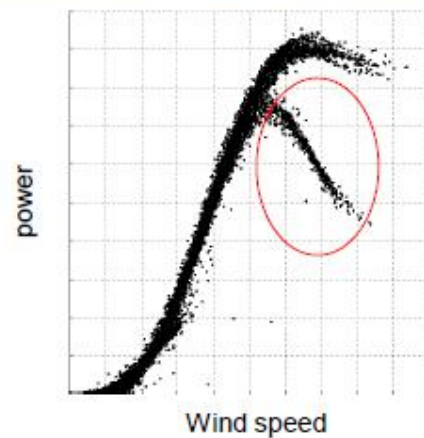
### Icing

High impact on some sites



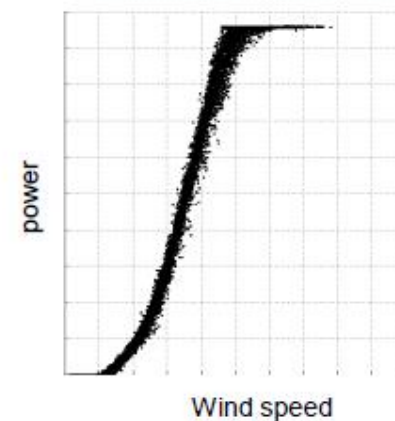
### Bugs

High impact for short periods



### Dirty blades

Subtle impact but persistent



# Possible reasons for deviation

## Wind Condition

The power curve is impacted by:

- Flow inclination
- Turbulence intensity (TI)
- Shear profile

Air density Influenced by:

- Atmospheric stability (TI, shear, density)
- Complex terrain (flow inclination, TI, and shear)
- Forestry (TI and shear)



Source : [2]

CONFIDENTIAL  
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# Power Performance Tolerance

Category	Typical range of loss(-ve)/gain(+ve) (nominal energy %)	Median (nominal energy %)
1. Generic power curve performance	-5% to +3%	-1% (model specific)
2. Mechanical sub-optimal performance	-5% to +0%	-1% (operator specific)
3. Environmental	-3% to -0.2%	-0.5% (region specific)
4. Wind conditions – turbulence intensity, shear and flow inclination	-5% to +1%	-1% (site specific)

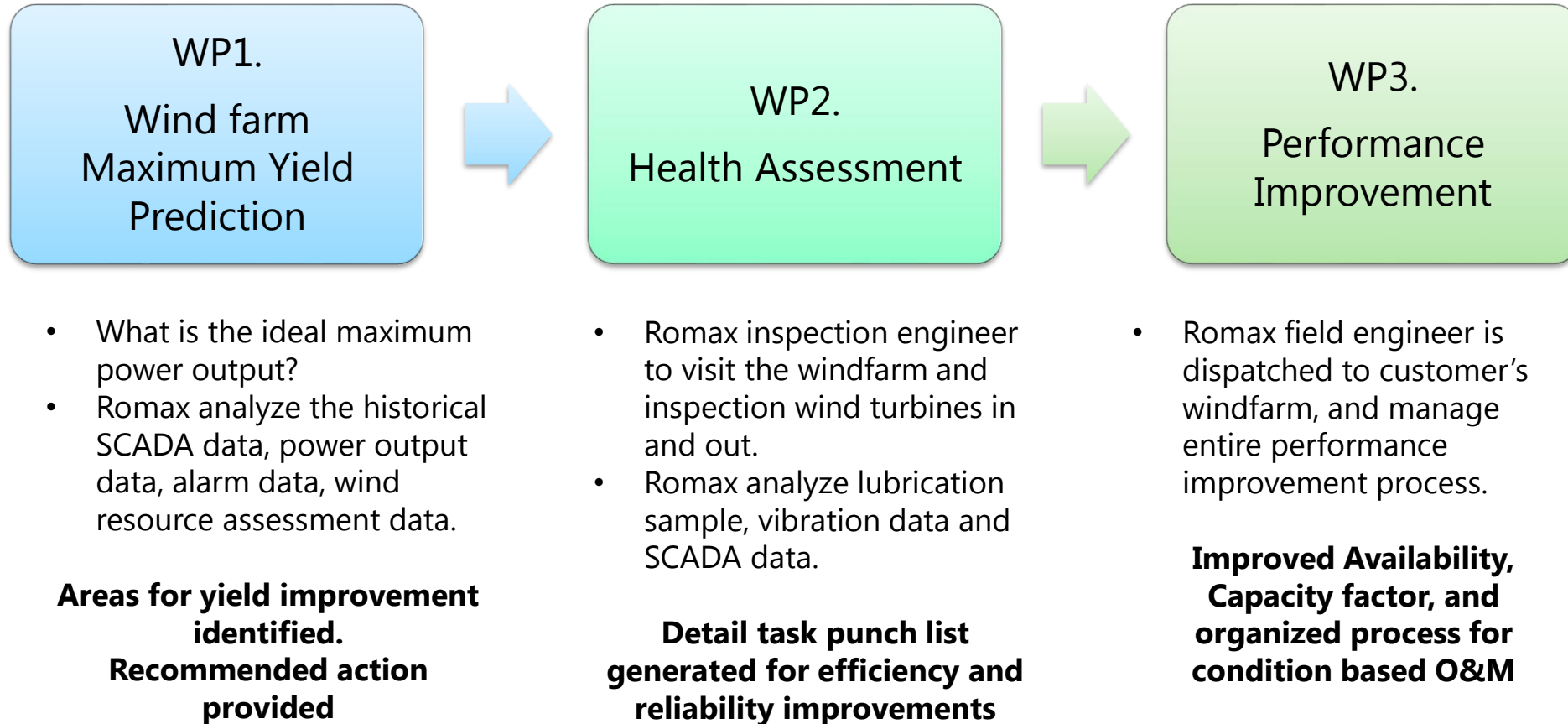


# APPROACH TO PERFORMANCE IMPROVEMENT

Data driven approach

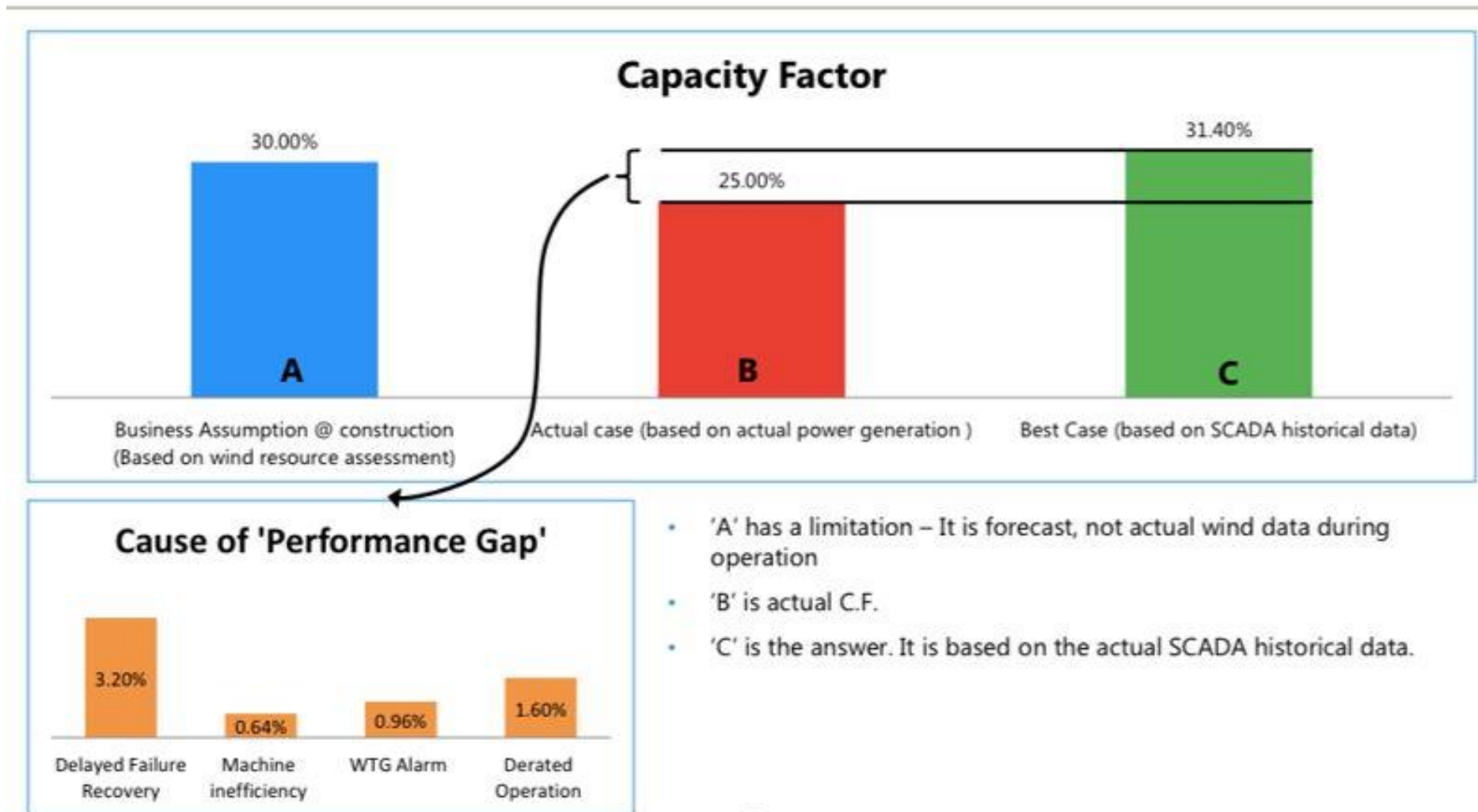
# Underperformance Wind farm

## How to improve C.F.?



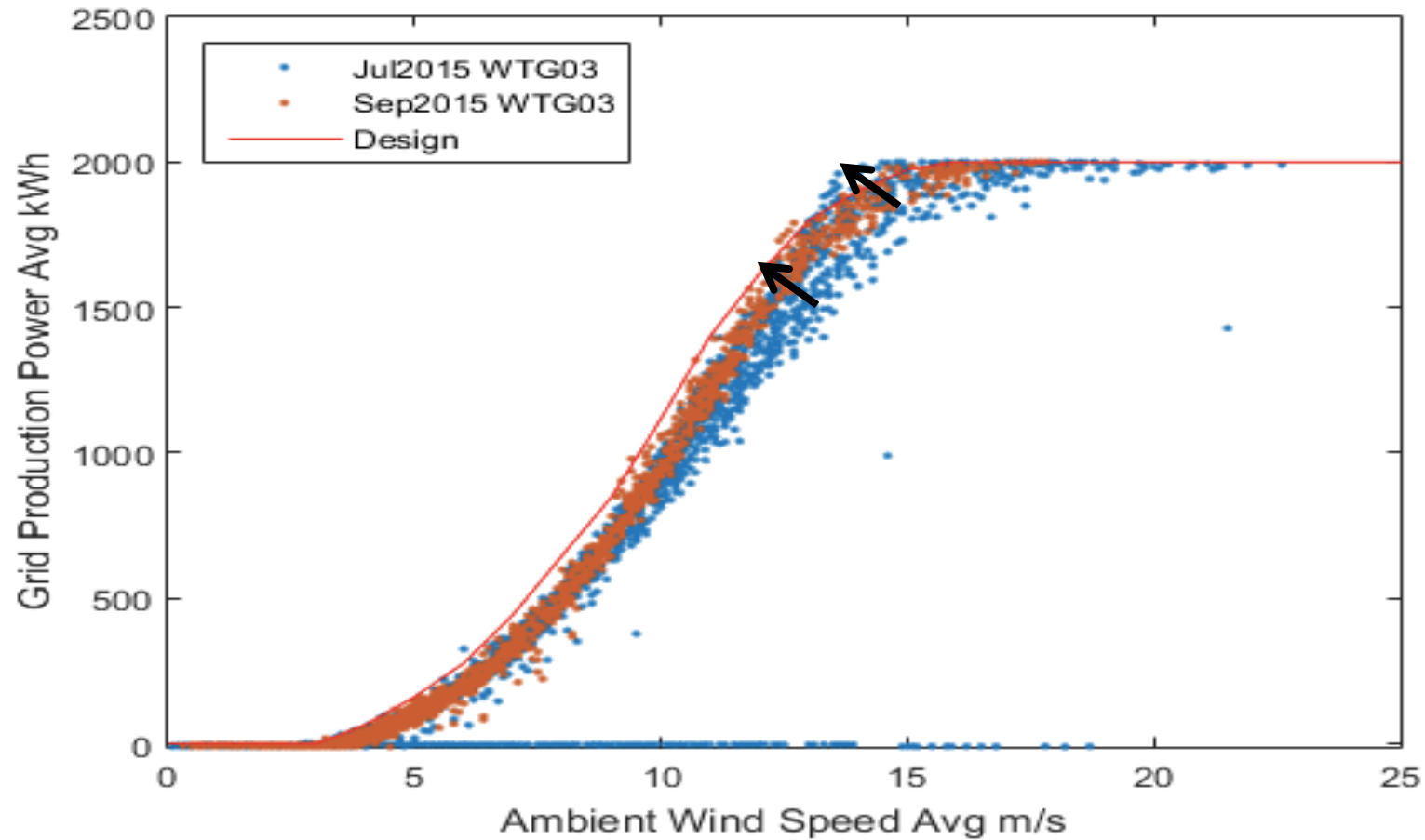
# What's the ideal maximum power output from my wind farm?

## What's the causing the performance GAP?



# Case for Improvement

## Eurus Taegisan – Power Curve





# Case Study

## Performance Improvement after acquisition of the wind farm

### Haengwon & Shinchang wind farm, Jeju, South Korea

- Under performing asset acquired by JEC in late 2012.
- Frequent breakdowns & unexpected alarms
- Wind farm under performance

### 3 phases of trouble-shooting strategy

Expert  
assessment

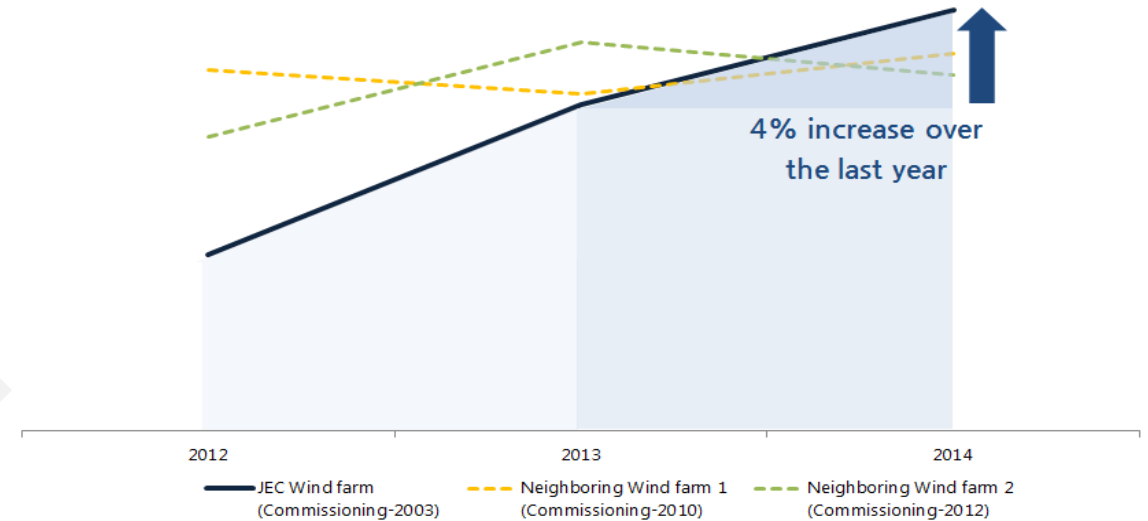
Data-driven O&M  
action planning

Turnkey field  
O&M service

### Benefit to Jeju Energy Corporation(JEC)

- **239 non-conformity issues** found by expert inspection and Data analysis & Corrective actions done to the wind farms in accordance with the priority level of the tasks.
- **The machine net-availability**(including service time) increased by **10%** at the end of the project.
- **The annual capacity factor** increased by **4%** over the previous year.

### Comparison of Annual Capacity Factor



### Availability of Haengwon & Shinchang wind farm

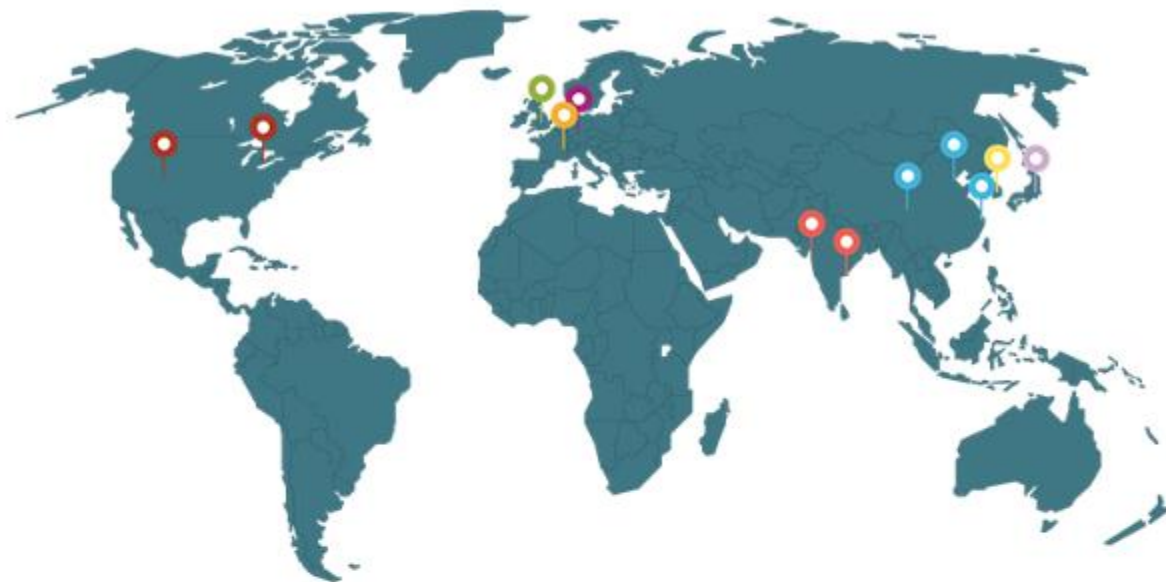


# Conclusion

## Starting from inspection (Data & On site)

		Focal Point	Meaning
I	Inspection ; to know what status WTGs are on	Diverse Methods & Diverse factors	Weapon
S	Solution and Scheduling	Cost Effectiveness	
O	On site action ; Repairing, Replacing....etc	Expertise For on site works	Target
I	Improvement of Performance	Expertise For the analysis	

# *Solutions to drive business and sustainability*



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