



## Condition Monitoring : multidisciplinary is a must-have

NI days Belgium 2014

2014, X. Jaspar



## Laborelec in a nutshell

# Laborelec, multi-disciplinary experts

## ■ Technical competence centre and laboratory

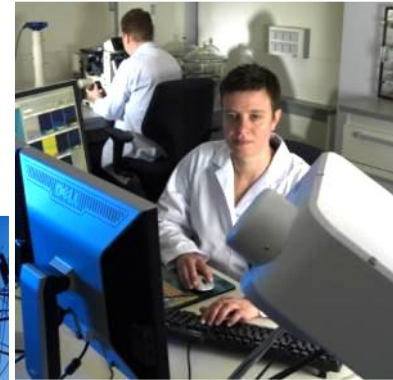
- Multidisciplinary Experts in Electrical Power and New Energy Technology
  - Generation, Transport, Distribution and Energy End-Use
- 240 researchers and technical specialists
- Offices in Belgium, The Netherlands, Germany and Chile
- Since 1962 (more than 50 years)

## ■ Applied research and technical expertise support

- Turnover € 48 M
- Contract research (35%) and services (65%)
- For shareholders (75%) and third-party customers (25%)

## ■ Shareholders

- GDF SUEZ, ORES Assets, SIBELGA, Tractebel Engineering, Cofely Services , Intermixt



# Expertise and Innovation Creating Customer Value

## ■ Protecting the Value of Investments

- Inspection, Monitoring, Troubleshooting, RCA
- OEM Counterweight
- Guaranteed access to expertise

## ■ Improving Asset Performance

- Increasing Energy Efficiency
- Reducing OPEX and CAPEX
- Increasing Availability and Life-Time

## ■ Driving Innovation

- Continuous Improvement with Best Available Technologies
- De-Risking introduction of New Technologies
- Preparing for Disruptive Changes

# Laborelec Key Services

## Competences

### Sustainable Process Technology

Water Chemistry, Biology and Treatment  
Combustion and Emissions  
Process Performance and Automation

### Structural Integrity Assessment & Monitoring

Power Plant Materials Technology  
Destructive and Non-Destructive Testing  
Vibrations & Mechanical Equipment  
Remote Monitoring and Diagnostics

### Electricity Grids and End-Use

End-Use Energy Efficiency  
Electrical Power Systems  
Electrical Equipment & Machines  
Monitoring and Metering  
Lighting Technology  
Electromagnetic Fields & EMC  
Oil Analysis

## Services

On site measurements

Laboratory analysis

Trainings

Health Checks

Technical Consulting

Trouble shooting

Root cause analysis

Inspection

Monitoring

## Customers

### Generation



### Transport & Distribution



### End-use



## Value

Availability

Performances

Capex

Opex





## Active Around The World

**Missions 2012-2013**

# Innovation also means discovering New Frontiers ...



Laborelec built the break-through smart micro-grid energy system  
for the zero-emission research station  
Princess Elisabeth at Utgrunden, Antarctica



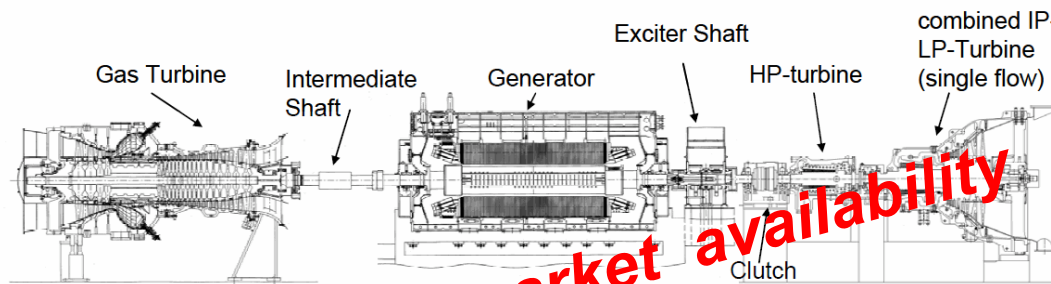


Today's challenges in Condition Monitoring  
Multidisciplinary top expertise is a must-have



# Today's power generation, grid and industry landscape

- An international competitive market with continuously changing market drivers
- Boost of renewable energy generation
- Flexibility required in thermal power plants
- Flexibility wished from (industrial) consumers → “demand-side management”
- Distributed power generation and smart grids
- Faster time to market of (complex) technologies → child sicknesses



**market availability**  
**flexibility**



**reliability**  
**availability**

# Condition monitoring process

## today's solutions

## today's challenges

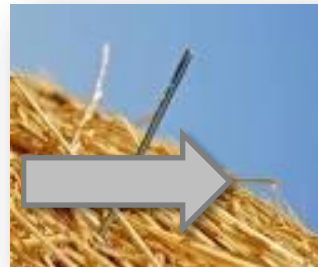
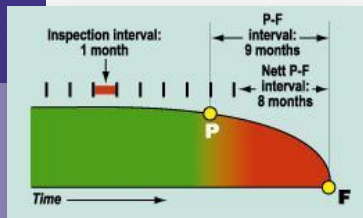


Can I detect the problem in due time ?

What is happening ?

Where is it happening?

Why did it happen ?



- Tool for O&M management
- Permanent monitoring
- Alert for every anomaly
- Understanding of an event

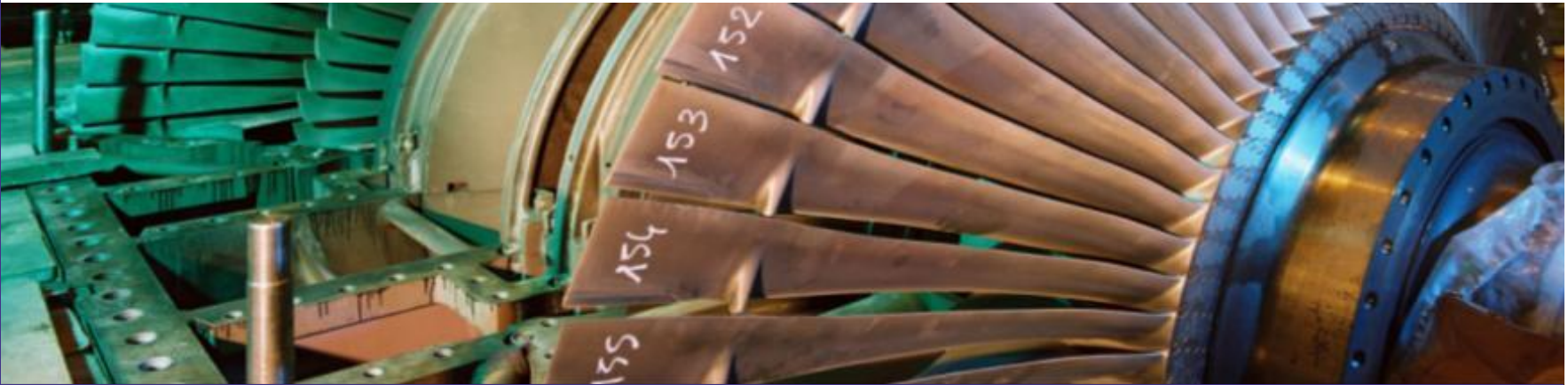
- Tool for Life Time Management
- Survey & predict evolution
- What time to intervention ?
- Prevention of future events

**How to tackle this ?**

**Future condition monitoring will need to consider  
the coupling between assets, between systems**

(and big data won't solve everything...)

**→ Multidisciplinary is a must-have  
multidisciplinary teams  
multidisciplinary CM tools**



## Three concrete system examples (1/3) LVMS, vibration monitoring



## Online vibration monitoring – LVMS 30 years of experience and evolution



# Online vibration monitoring – LVMS 30 years of experience and evolution



...recent technology evolution...

smaller, smarter, more robust,  
standard hardware from NI,  
less cables & easier installation,...



# Online vibration monitoring – LVMS 30 years of experience and evolution

- Continuous vibration monitoring of gas and steam turbines
  - Acquisition station in the plant for data processing and alarming
  - Online remote visualization and data analysis
  - Automated remote data backup facilities
- Worldwide implementation of 90 systems, monitoring over more than 130 shafts, ranging from 5 to 1200MW...
- 24/7 online remote consulting facilities by vibration experts
- Field measurements with **mobile LVMS equipment**



## LVMS in a few features

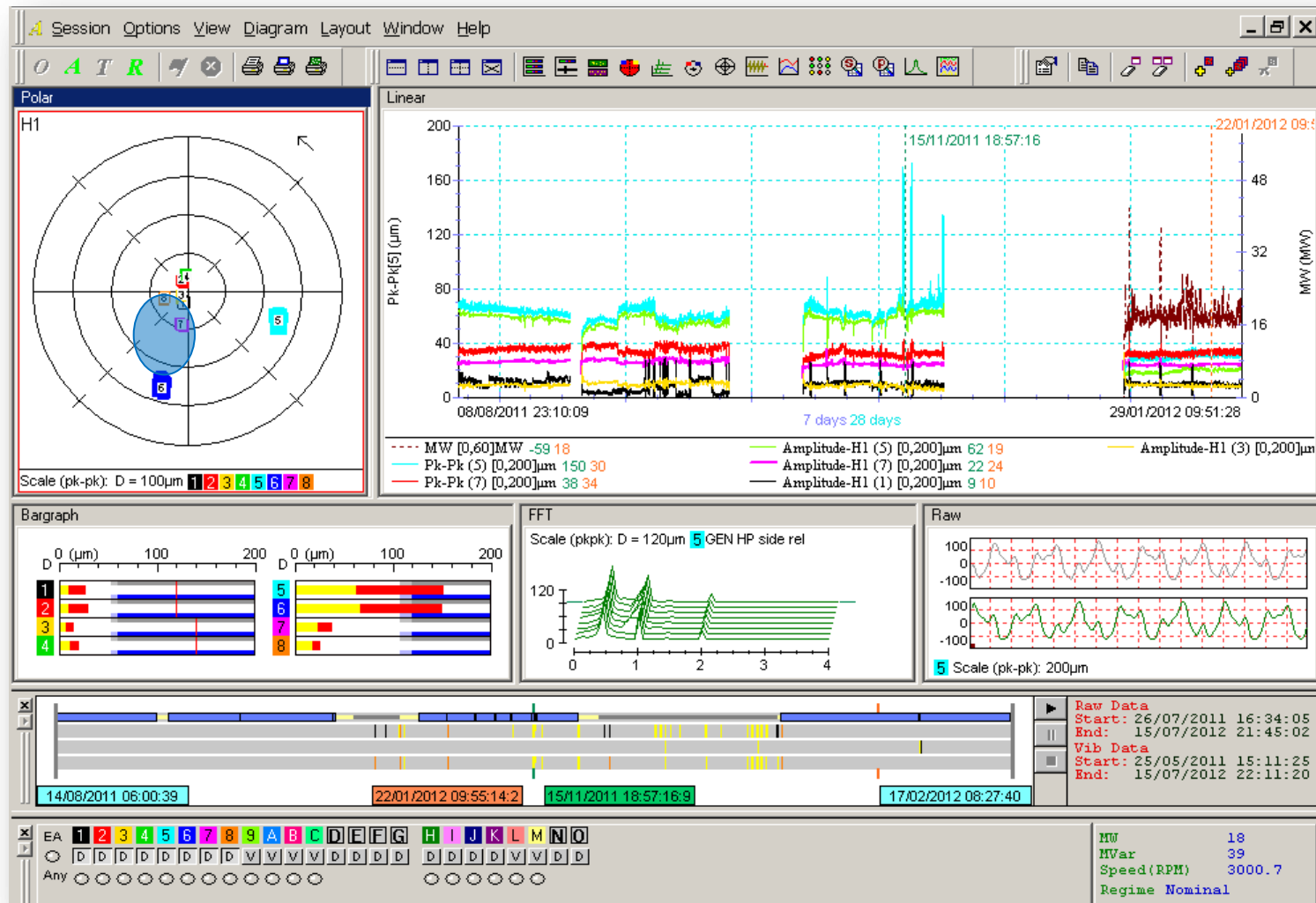
### Efficiency! Get to the right conclusions within 15 minutes!

- Key feature of LVMS = **efficiency for the end-users**.  
How?  
Designed by end-users for end-users...  
**Designed by our vibration experts who use it every day...**
- Intelligent alarming for early detection of developing problems
- Smart storage triggered by alarms
- Order-tracking
  - Phase stable using phase reference pulse
  - RPM tracking & anti-aliasing filters
- Fast and easy to use graphical user interface for analysis of large datasets (1+ years)



# LVMS in a few features

## Efficiency! Get to the right conclusions within 15 minutes!



## Customer benefits

- Increase the reliability & availability → increase profits  
Reduce unplanned stops and related penalties → reduce costs
- Helps plan and prioritize maintenance interventions,
  - by identifying elements that require special attention,  
by urgency level (e.g., as soon as possible or at the next planned stop)
  - by avoiding unnecessary interventions on elements that perform correctly
- Independently of your OEM and service provider
- Helps minimize downtime during a major overhaul,  
by thorough analysis of all vibration signals beforehand
- Helps evaluate the impact of maintenance actions,  
by analysis of historical archived data (before and after the maintenance)
- and our experts can help customers remotely to solve complex situations

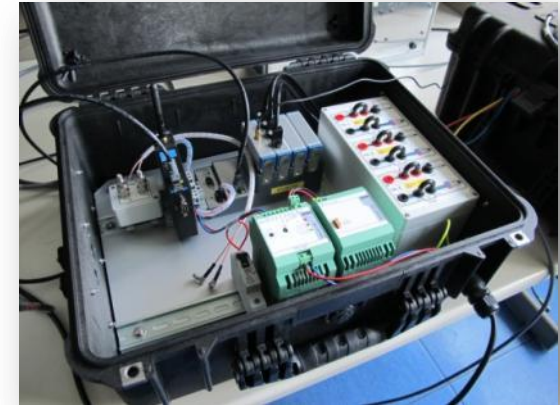


## Three concrete system examples (2/3) EPMD, enhanced phasor measurement device

# Enhanced Phasor Measurement Device (EPMD)

## Power Quality recorder & analyzer, fault recording & monitoring

- Power quality recorder & analyzer (3 voltages, 4 currents): frequency, phasors, true RMS, RMS12, (inter)harmonics, unbalance, power measurements...
- Phasor measurement unit features (PMU)
- Highly accurate time synchronization between equipments
  - Absolute time accuracy  $< 10\mu s$
  - Relative time accuracy (between equipments)  $\sim 1\mu s$



### Distinguishing set of features:

- Recording of the whole waveforms, continuously or on faults/transients
- Both short term and long term campaign (even permanent)
- Fault detection and recording



- Easy to transport, install and configure
  - Full remote control, online data transfer, e-mail reporting
- = ... evolution ...





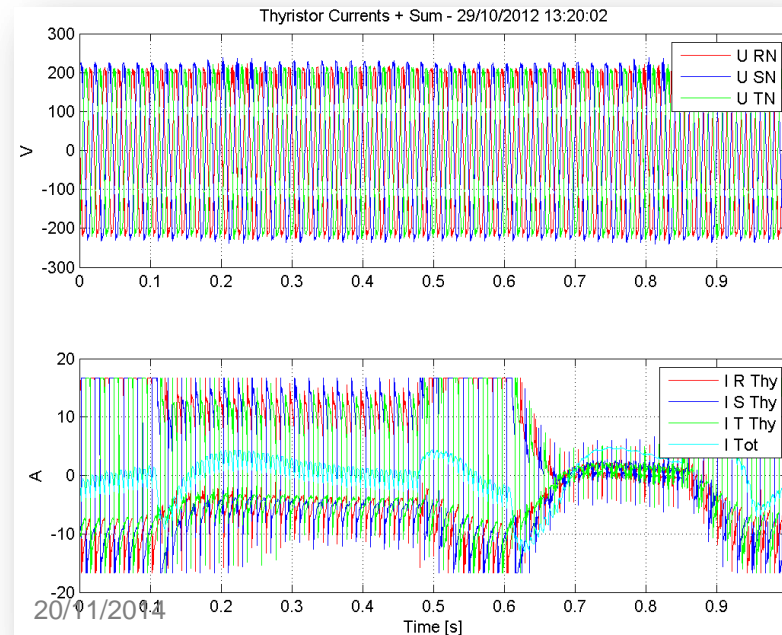
# Enhanced Phasor Measurement Device (EPMD)

Ch ref	Channel in use	Channel name	Channel unit	Channel offset (Volt)
Ur	<input checked="" type="checkbox"/>	Ur	Vac	0.005087
Us	<input checked="" type="checkbox"/>	Us	Vac	0.008249
Ut	<input checked="" type="checkbox"/>	Ut	Vac	0.006264
U1	<input checked="" type="checkbox"/>	U1	Vac	6.5E-5
U2	<input checked="" type="checkbox"/>	U2	Vac	5.2E-5
U3	<input checked="" type="checkbox"/>	U3	Vac	8.6E-5
U4	<input checked="" type="checkbox"/>	U4	Vac	6.7E-5

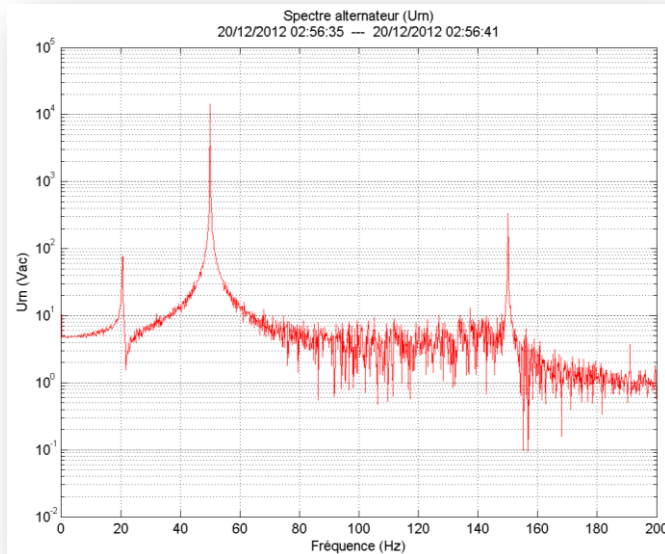
Un : 230 Vac  
flagging Uref < : 10 % Un

Easy configuration,  
even remotely

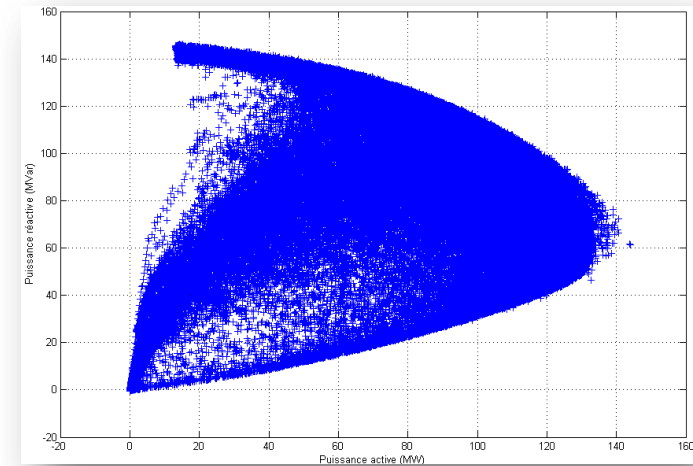
Voltages  
and  
currents  
measurements



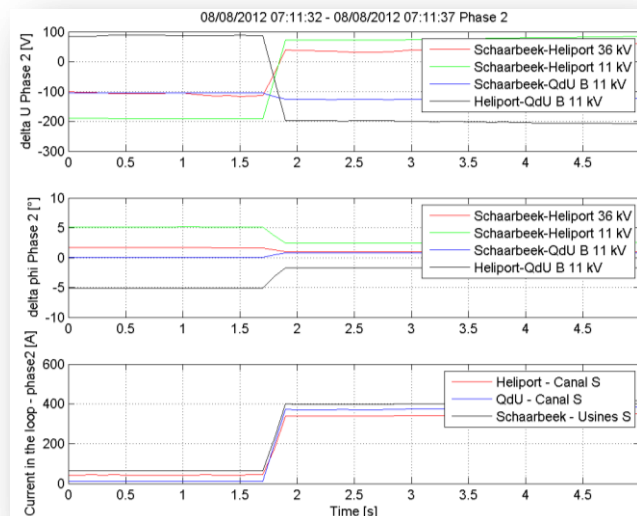
# Enhanced Phasor Measurement Device (EPMD)



Voltage  
spectral  
analysis



PQ diagram



PMU feature

Thanks to excellent time  
synchronization (GPS),  
phase shift measurements  
between busbars are possible

## Customer benefits and current customer cases

- Typical customer cases: DNO's in Europe
- Indeed, classical PMU's are typically used by TSO's at continental level, in fixed locations, communicating in real time with the SCADA (TSO grid is meshed)

whereas **our portable EPMD/PMU:**

- is portable and can be used by technicians of DNO on the road (deployment time: 15min) (DNO grid is a tree)
- is portable and can be deployed by technicians of industrial customers
- gives access to grid data which was not available up to now: (phasor measurements at remote locations)
- In order to facilitate and optimize daily operations, e.g., parallel couplings in MV, in a context of active/dynamic network management,  
→ more and more needed to solve equilibrium issues due to distributed generation
- to track unknown power flows, e.g., due to distributed generation
- to feed network state simulators with well-chosen extra measurements, in order to get reliable simulations



## Three concrete system examples (3/3) Torsion, torsional vibration measurements

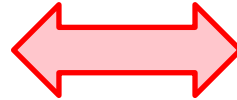


## Some important differences between lateral and torsional vibrations are to be considered

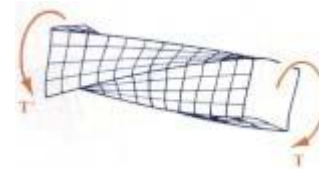
### Lateral vibrations



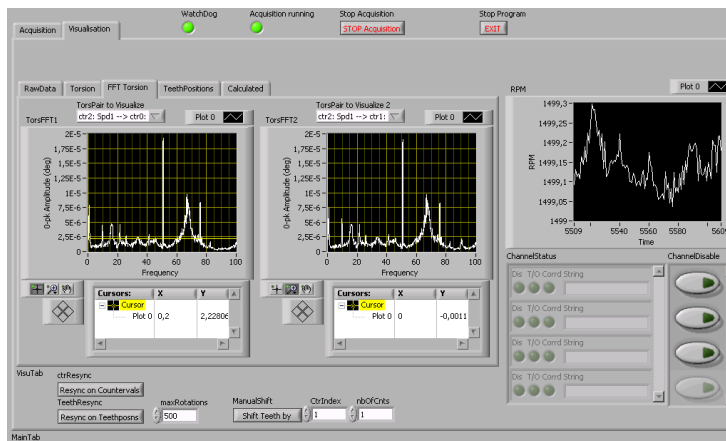
- Horizontal/vertical vibration
- Usually sufficiently damped
- Internal excitation (unbalance, bearing forces)  
→ Excitation implicit in vibration measurement
- Closely monitored
- Criteria/standards advanced
- Vibration is felt on casing



### Torsional vibrations



- Angular vibration
- Very lightly damped
- External excitation (grid)  
→ Extra detailed electrical measurements required
- Not yet closely monitored
- No clear criteria/standards
- 'Hidden' vibration



torsional shaft vibrational measurements (EPMD)



torsional & electrical EPMD  
all-in-one solution (electrical measurements)  
measures both dynamic & static torsion

!!! torsional + electrical measurements !!!  
(you guess the next step...)



## Technical characteristics

- Online assessment of the torsional vibrations of the shaftline
- Single channel mode: “Speed variations”
- Multi channel mode: both static and dynamic torsion
- Alarming and smart storage triggered by alarms
- Based on 80MHz counters
- Automatic correction for missed teeth and/or spikes
- Automatic teeth position profiling

## Customer benefits

- Assess the fatigue of the rotor (components), both static and dynamic, towards the remaining life time assessment
- Understand the root causes (and their impact on fatigue!), to diminish/prevent them and protect your assets



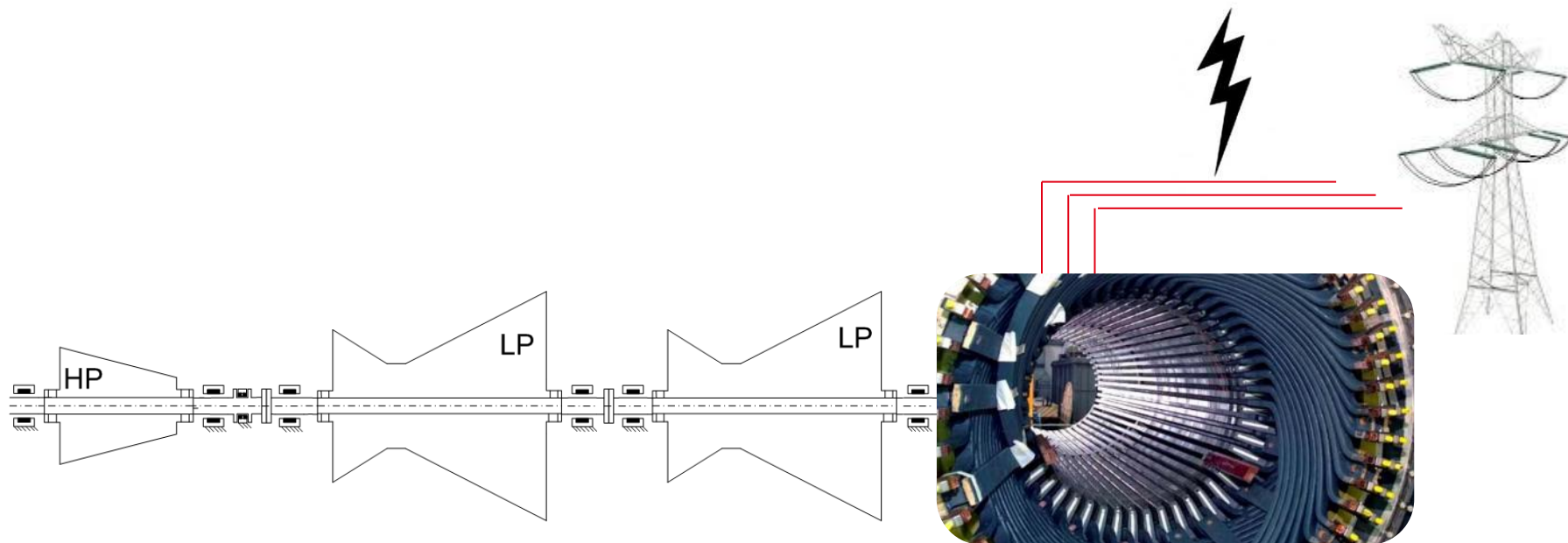
## Case 1 : grid-induced turbo-generator vibrations

Based on a presentation by Frits PETIT, Koen DE BAUW, Kris MATTHYS, Sylvain DOUCEMENT.  
IFTToMM ICORD 2014, Italy.



**Different sources of transients and disturbances on the grid  
... may impact the shaft line of a generator.**





Electro-magnetic field

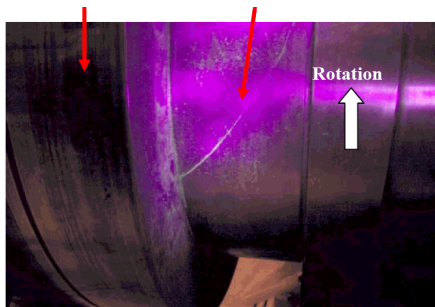
between rotor and stator

couples shaft line and electrical grid

## Different types of damage due to torsional vibrations plead for the interest in this field



- Fatigue cracks at the root of LP turbine blades

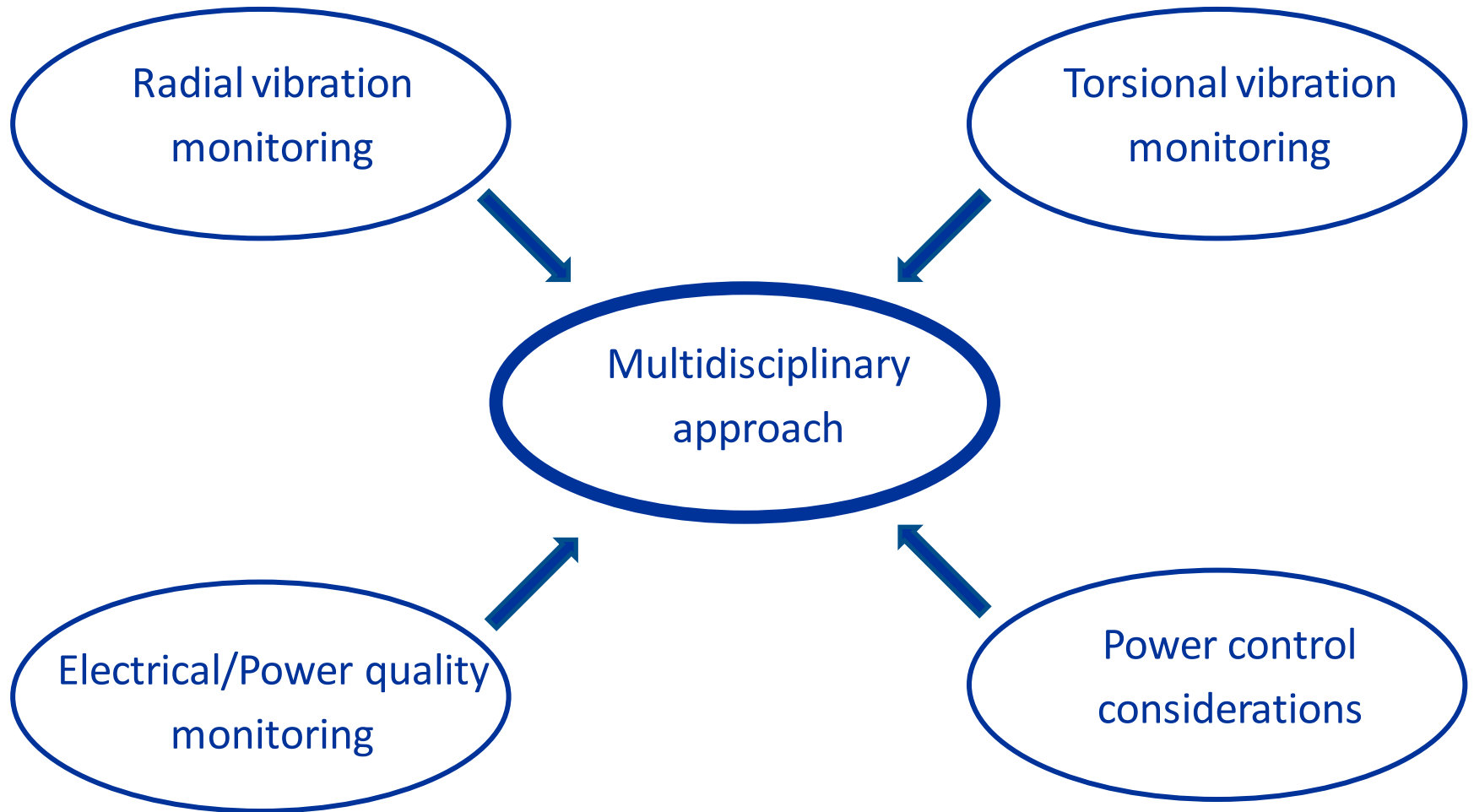


- Fatigue cracks at high stress concentrations on the shaft (e.g. fillets)



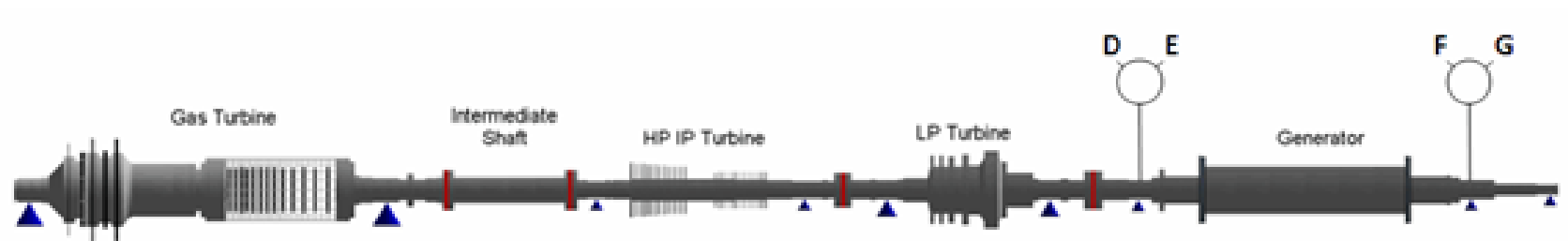
- Fretting fatigue at the shrink fit surface of the retaining rings

## To solve this?



## Context of the case study

- 350 MW combined cycle



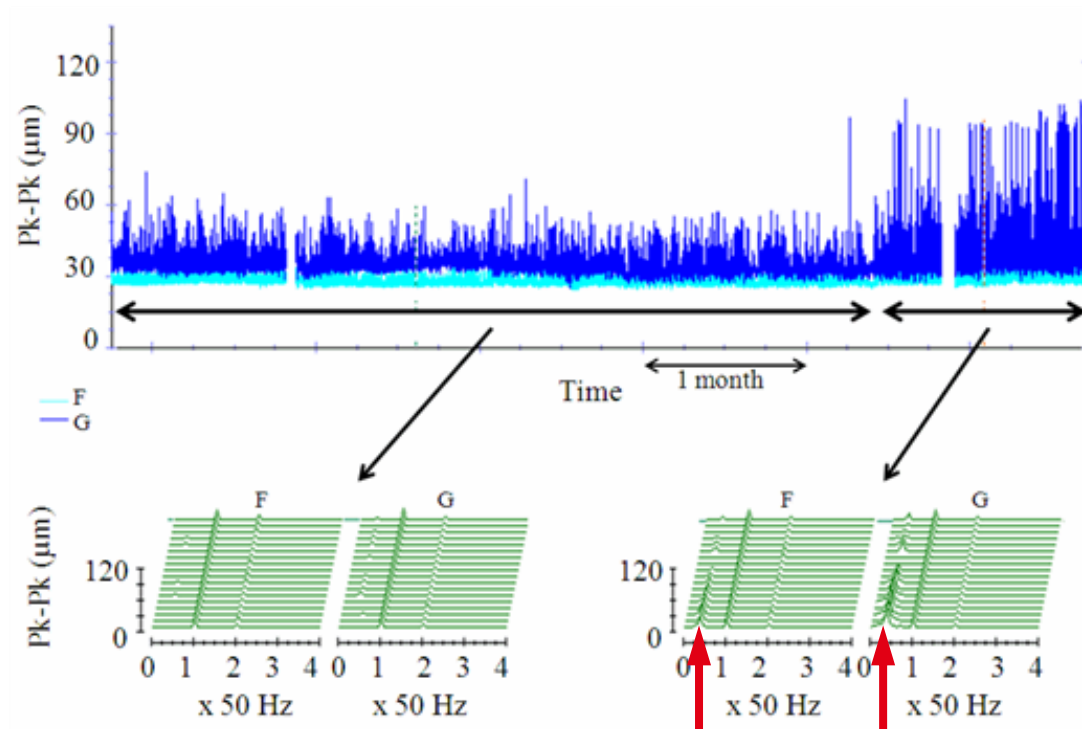
- Three electrical AC arc furnaces nearby

- Sudden power changes, causing flicker
- Rapid changes of the angle between stator and rotor fields excite torsional shaft vibrations
- Disturbances 0-200Hz



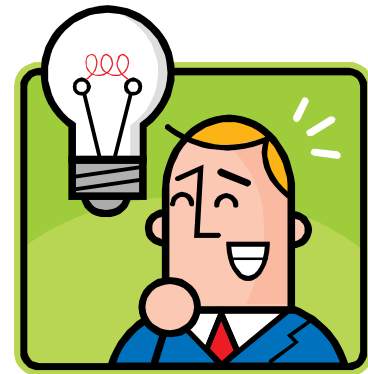
## Context of the case study : Increased shaft vibration behavior

- Unusual vibration behaviour triggered alarms in the vibration monitoring system in 2012
- Global shaft vibration amplitudes  $< 120 \mu\text{m}_{\text{pk-pk}}$
- Appearance of a subsynchronous component at 18 Hz

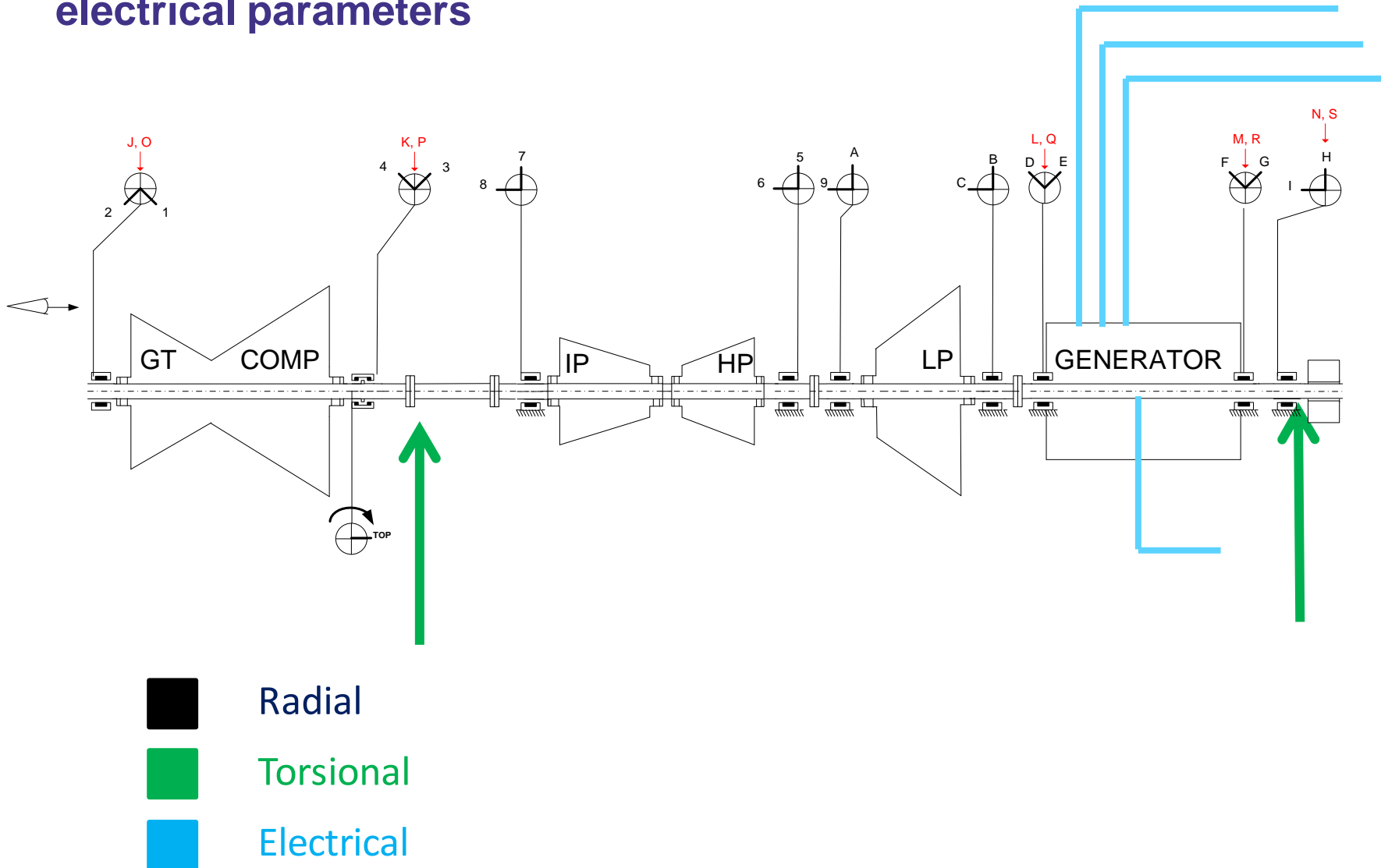


# Root cause analysis

- Measurement error?
- Excitation of subsynchronous vibrations due to intermittent rub? (Mathieu rub)
- Coupled radial/torsional shaft vibrations?
- Forced excitation due to electrical power variations?
  
- A link was identified with the operation mode of the arc furnaces
  
- Decision:  
Measurement campaign to assess the torsion & stress levels in the rotor and to evaluate the impact of different grid configurations



# A synchronous measurement campaign of radial, torsional and electrical parameters



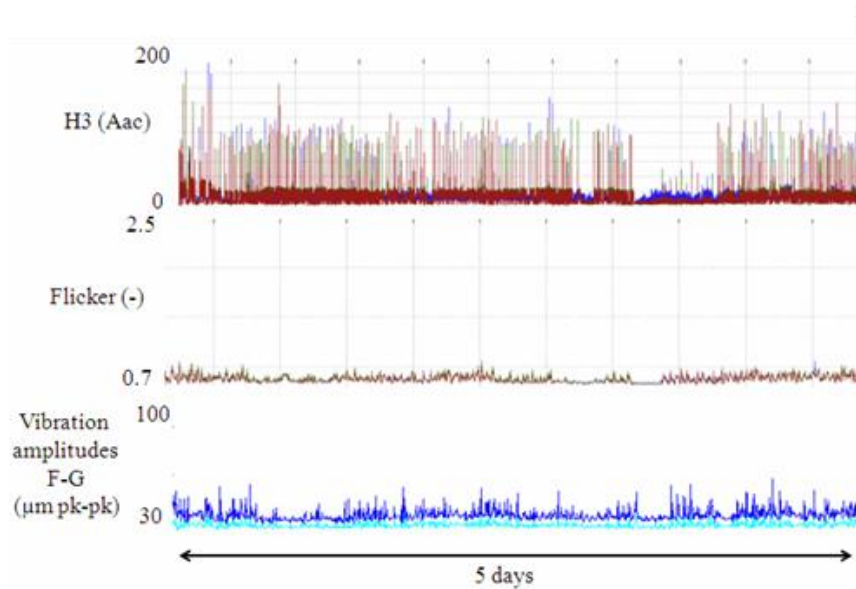
Radial

Torsional

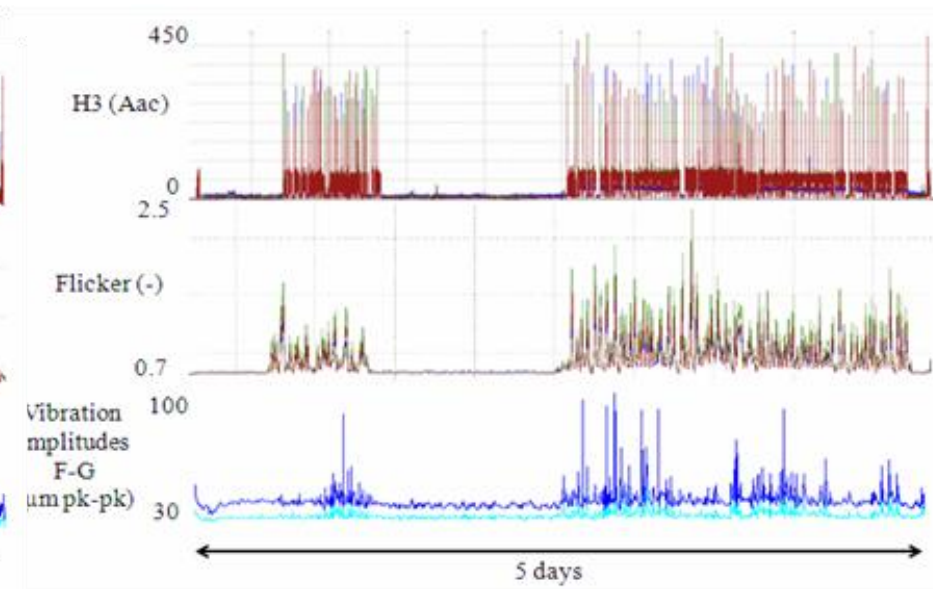
Electrical

# Findings of the measurement campaign

- Influence of the arc furnace operation on flicker components and lateral vibrations



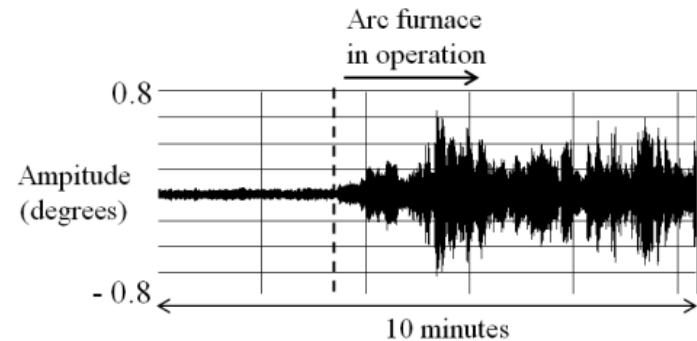
*Without arc furnace operation*



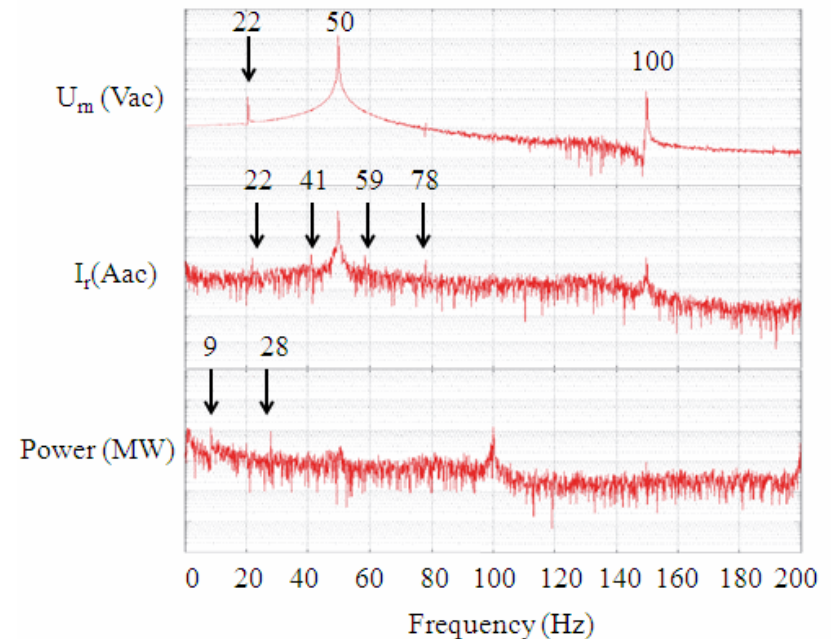
*With arc furnace operation*

# Findings of the measurement campaign

- Influence of the arc furnace operation on torsional shaft vibrations



- The arc furnace operation impacts even the power quality produced by the power plant!





## Conclusion of the measurement campaign

- A multidisciplinary approach was required for identifying the cause of increased generator shaft vibrations
- The sub-synchronous component of 18 Hz in the lateral shaft vibrations
  - does not correspond to a torsional or radial eigenmode
  - was excited by a nonlinear behavior of the UMP.  
(The excitation was reinforced in certain grid conditions, thus causing an increased response)



The 18 Hz component corresponds to a periodic regime of the coupled electrical and mechanical system

- A modification of the grid configuration was sufficient to avoid this 18Hz component



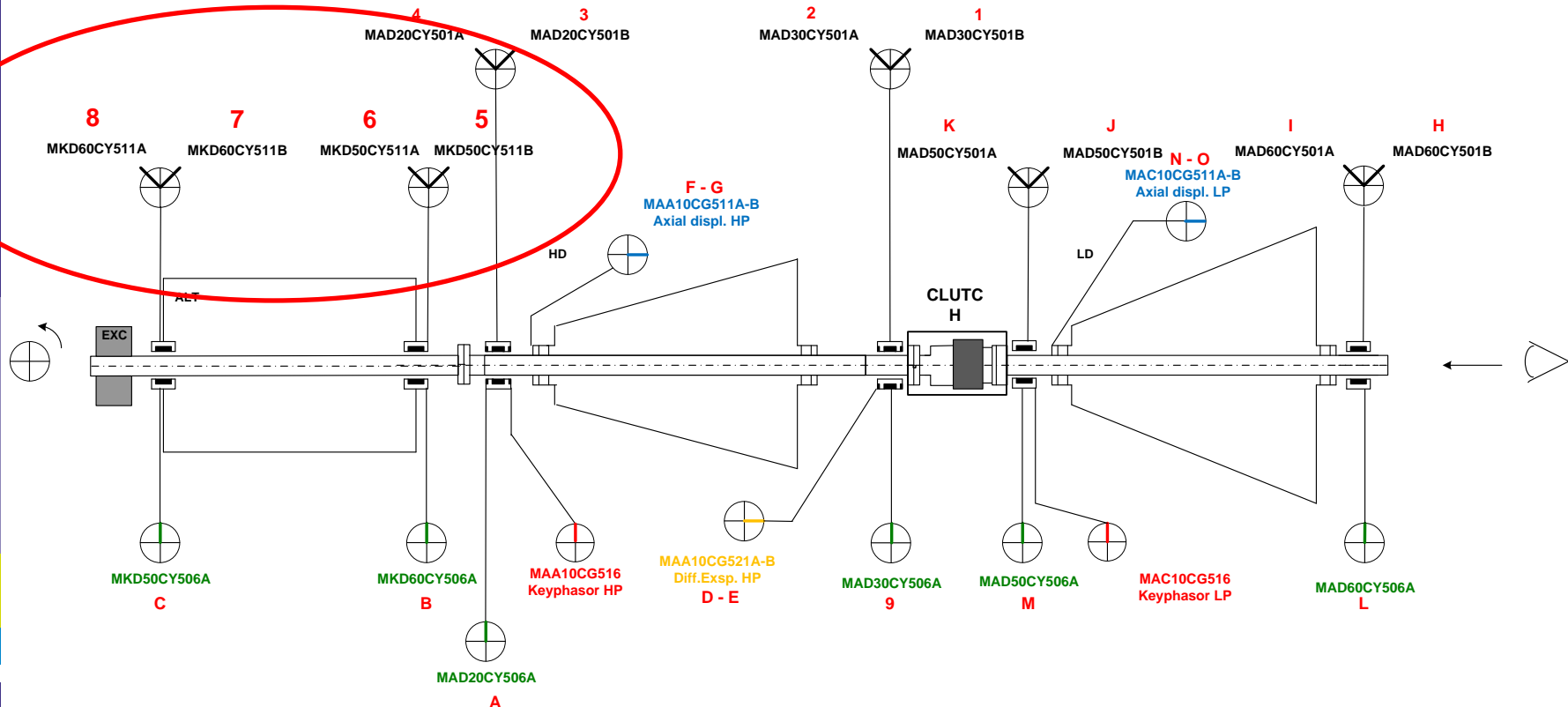
## Case 2 : Oil Whirl Phenomenon (customer in Germany)

Based on a presentation by Clément BRICHART & Koen DE BAUW

# Shaft layout

■ Nominal power : 34.6MW

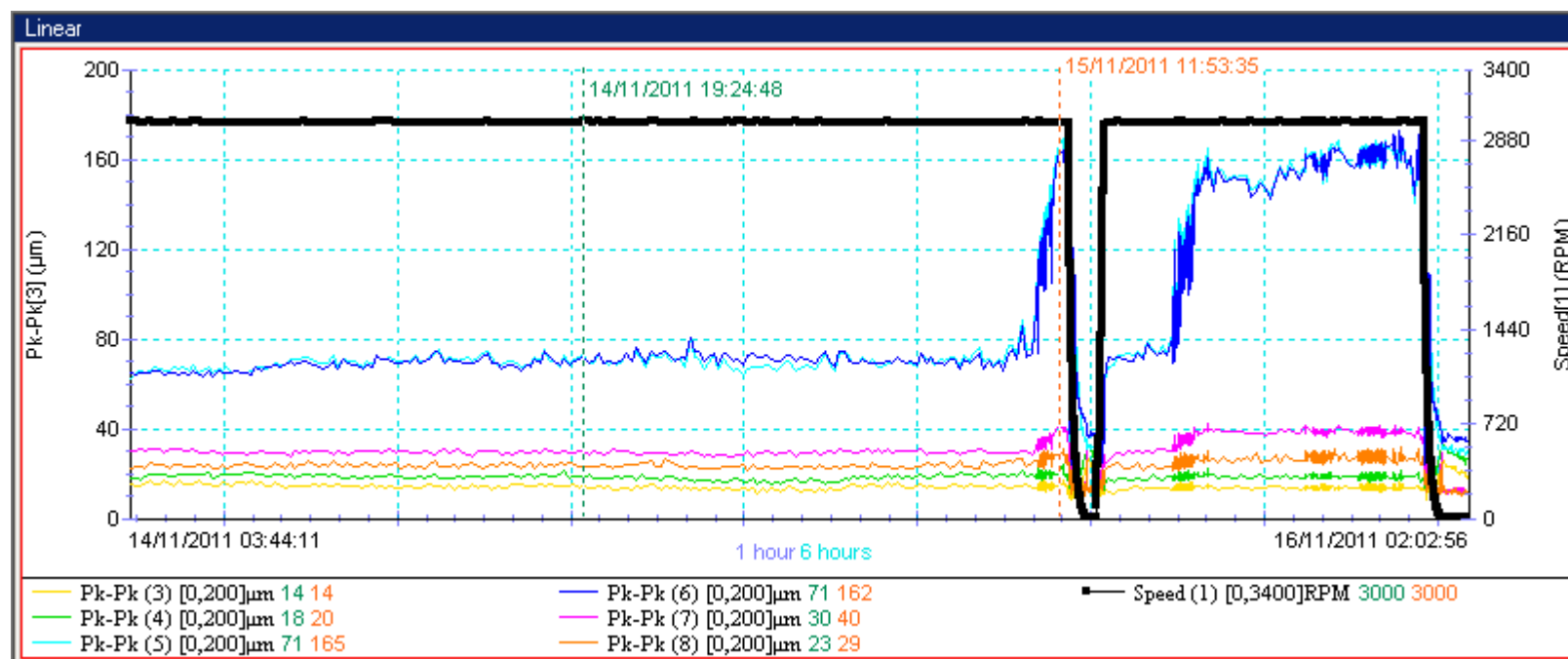
■ Rotating speed : 3000rpm



# Vibrations increase on the generator driven end bearing

## ■ First observation :

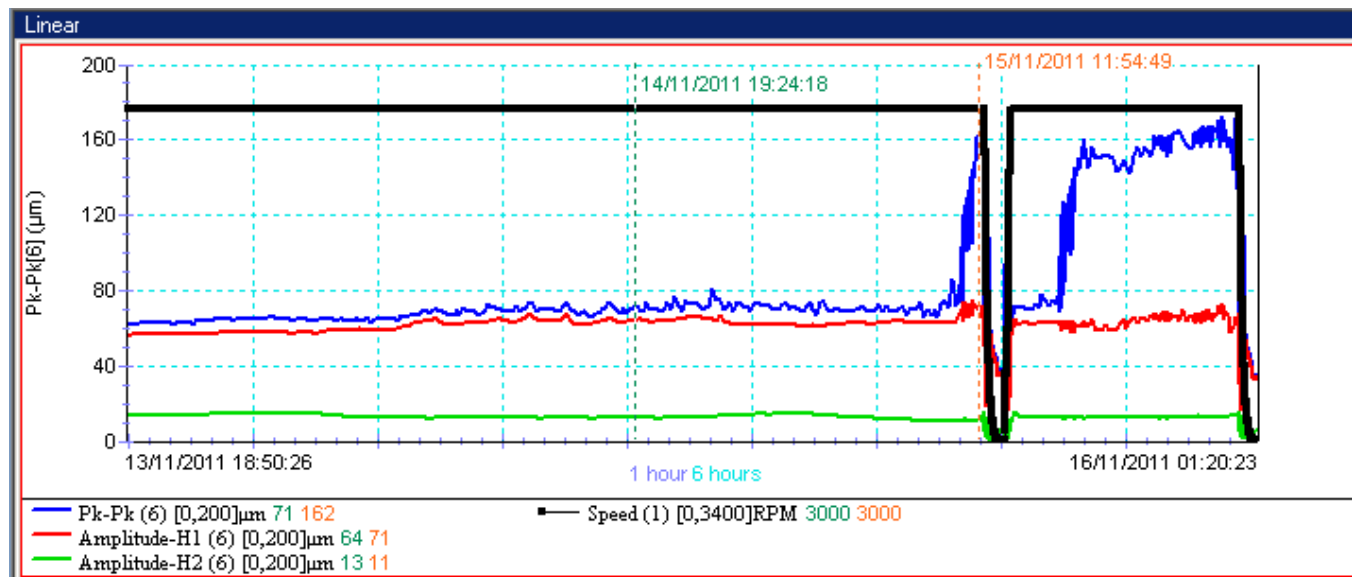
Stopping and restarting the turbine temporarily solves the problem  
but it comes back a few hours later



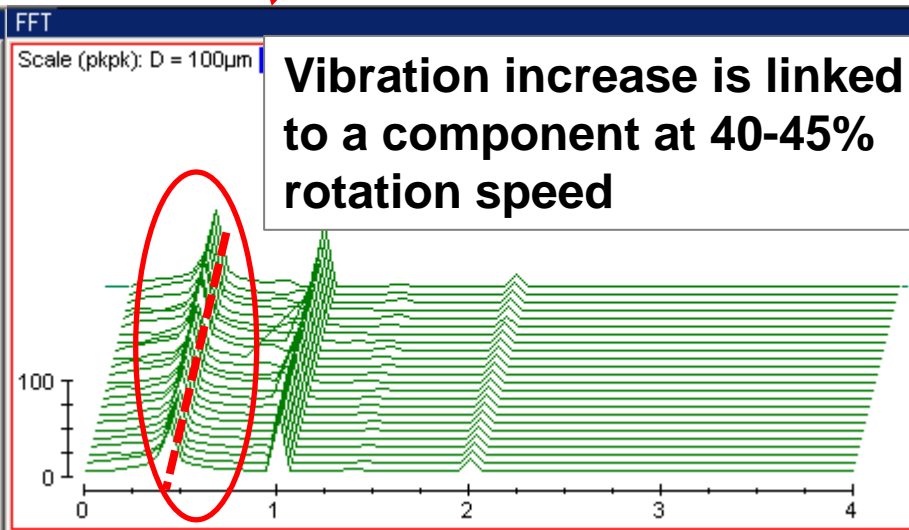
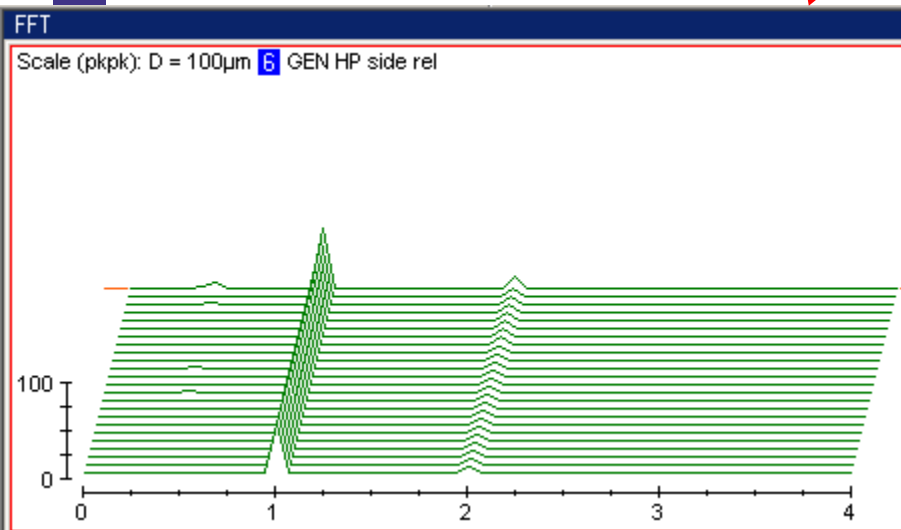
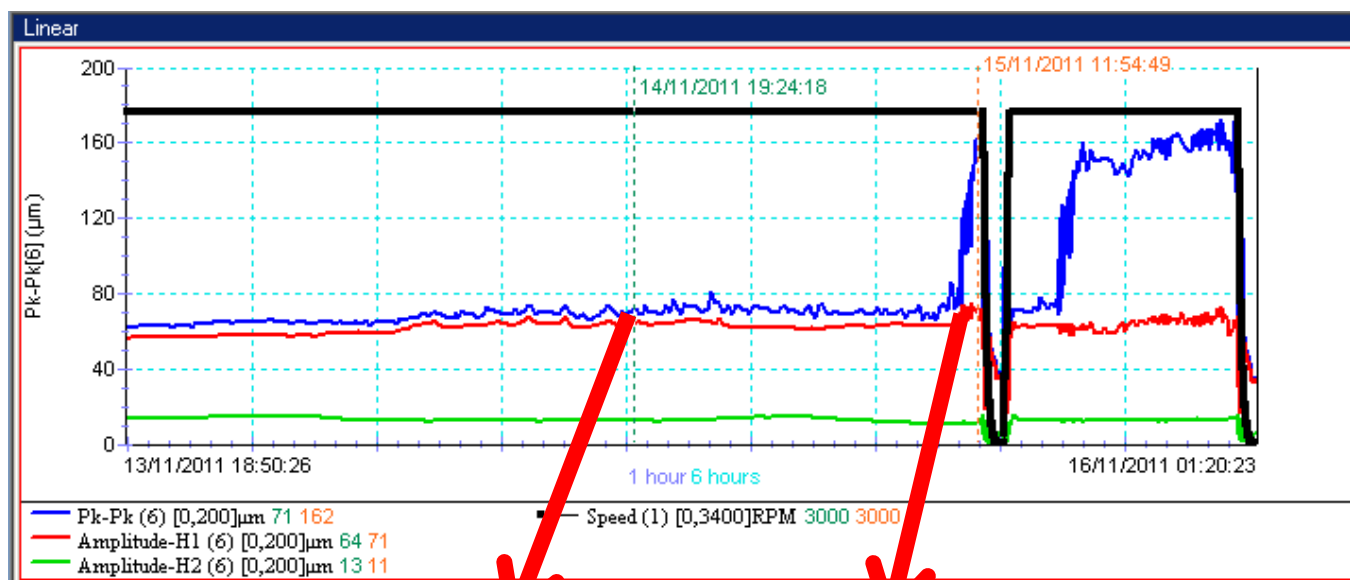
## Further observation

### ■ Further observation :

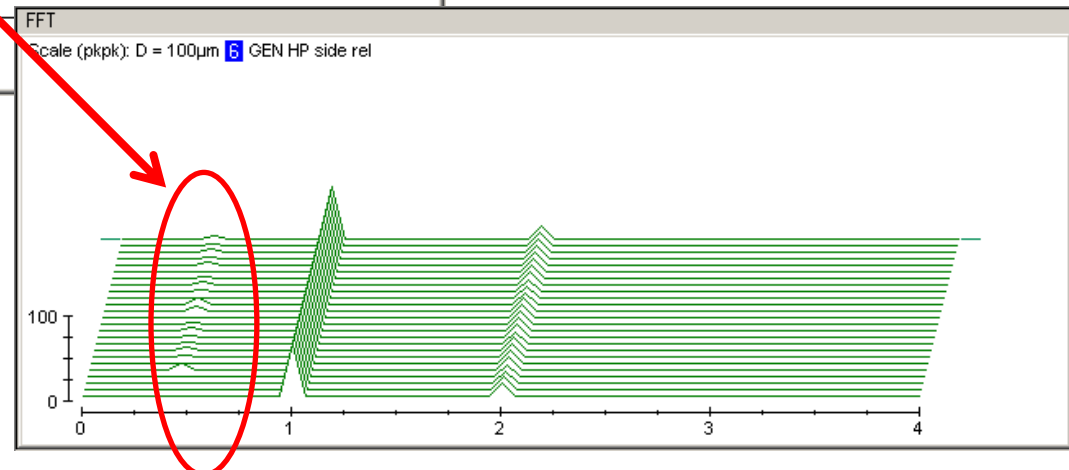
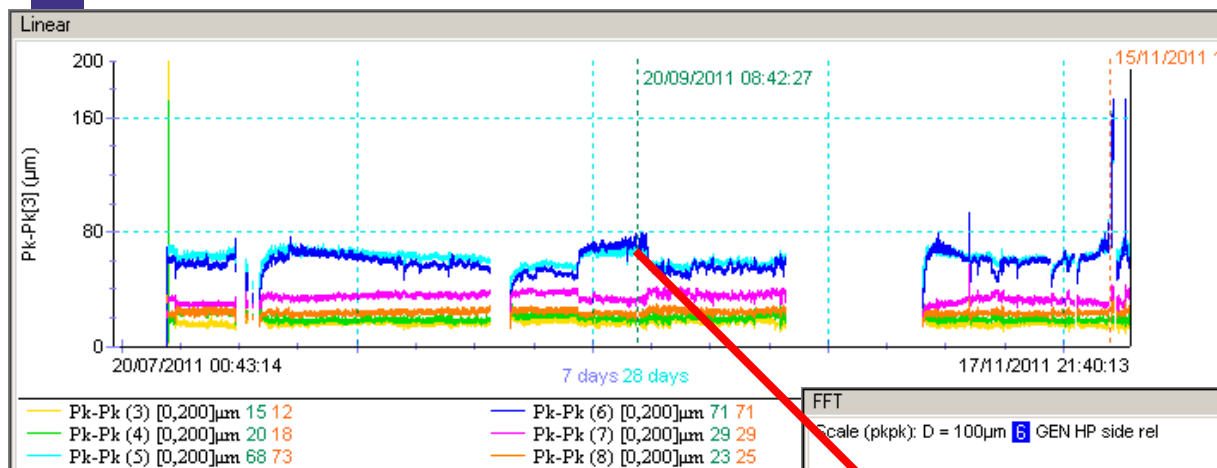
- Occurs at increase to maximum load
- No change of first harmonic (H1) vibration component





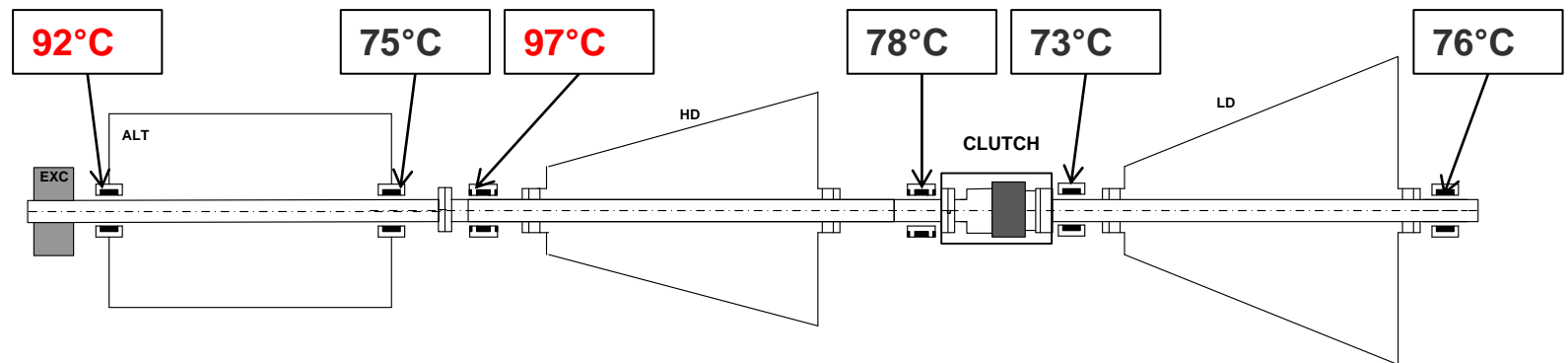


Was already present some months ago  
but less pronounced.

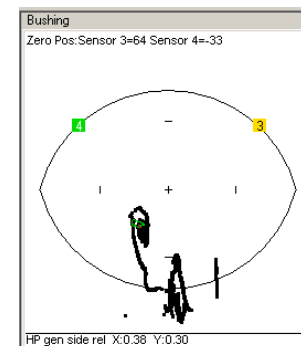
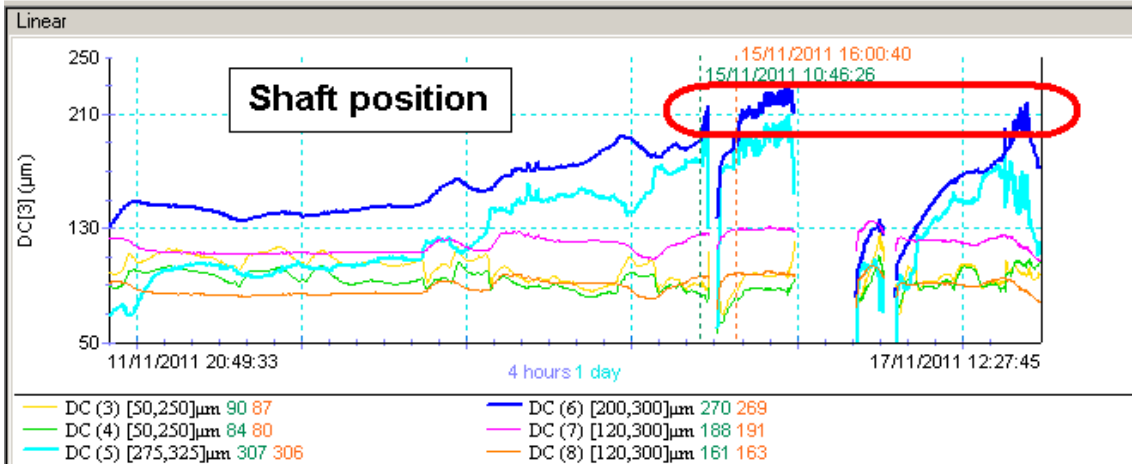
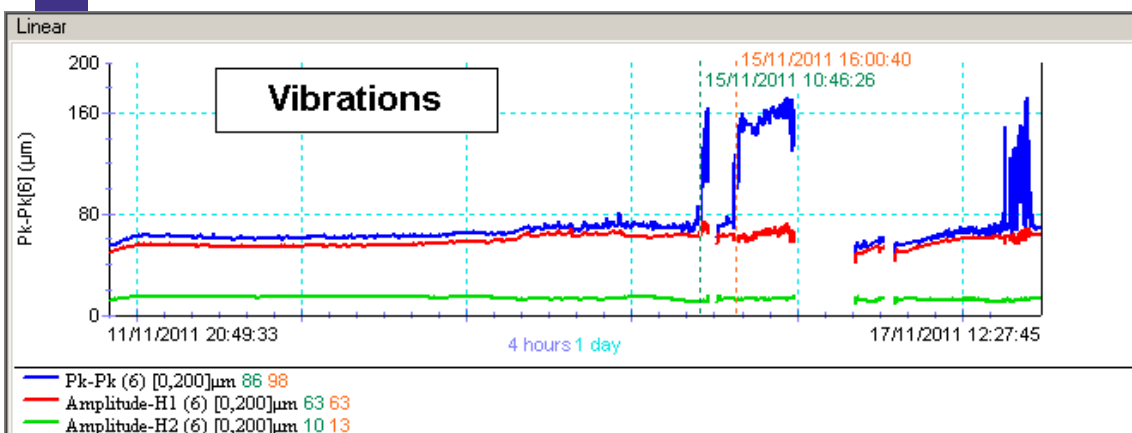


# Hypotheses?

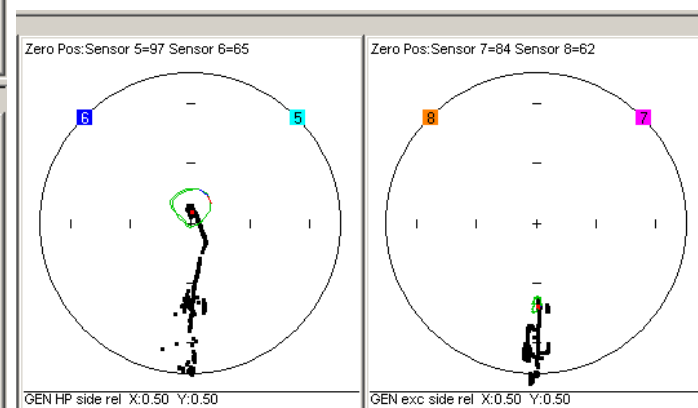
- Misalignment of generator?
- Thermal stress on HP inlet section?
- Oil temperature regulation?
- .....



# Problem is linked with high shaft position in generator DE bearing



HP GEN side: 0.1 – 0.15 mm  
dynamic shaft lift



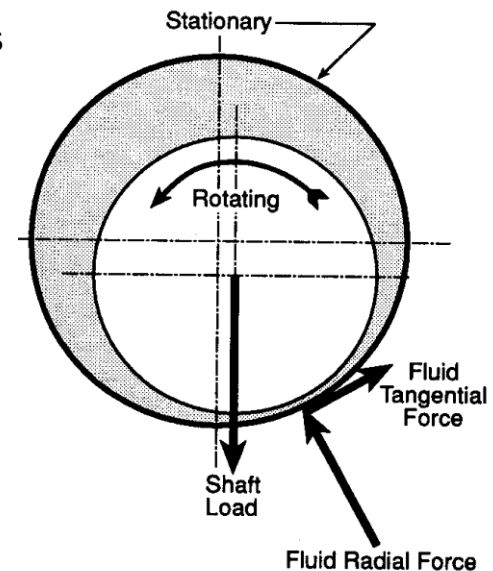
GEN DE side: 0.3 mm dynamic shaft lift

GEN NDE side: 0.15 mm dynamic shaft lift

## Eventually, the Oil Whirl Phenomenon

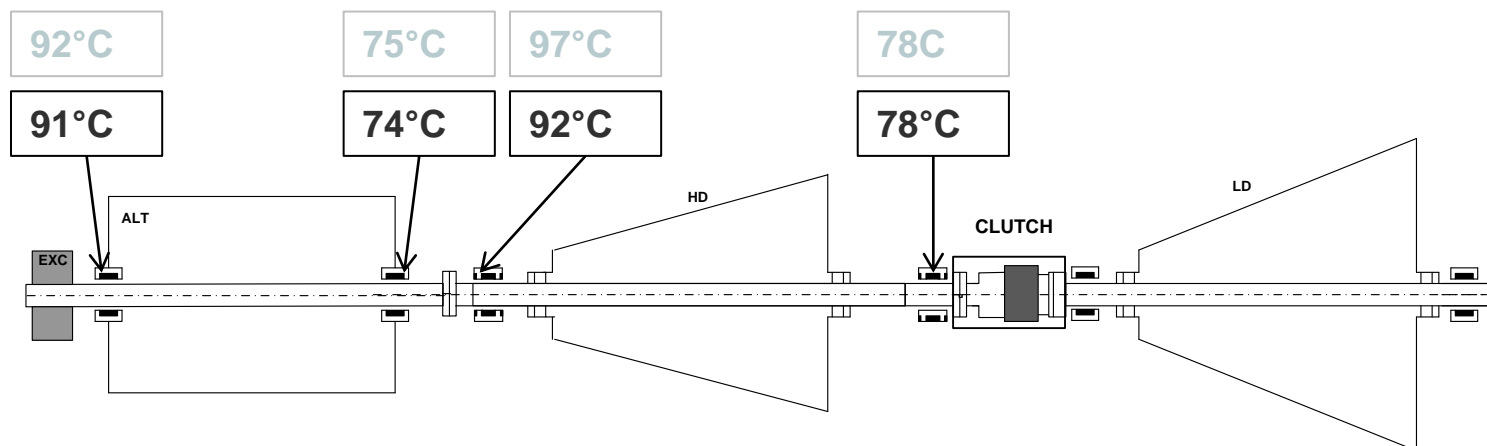
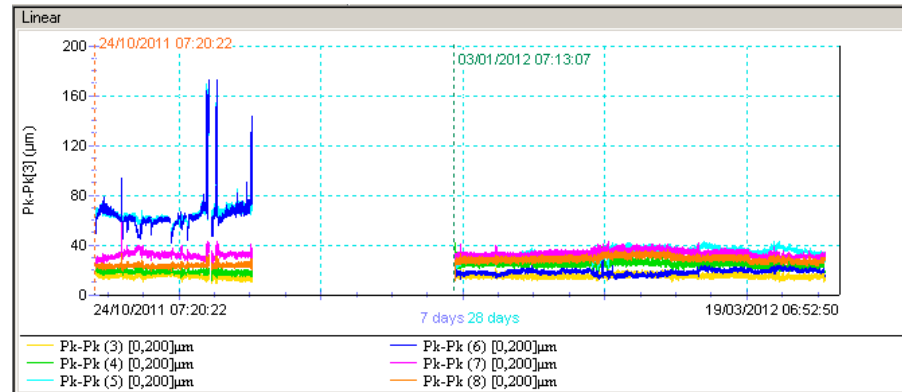
- Vibration behavior seems to indicate an « oil whirl » phenomenon

= self excitation mechanism  
caused by destabilizing forces  
produced by high speed, lightly loaded sleeve bearings



- Corrective action :  
the generator needs to be **0.13mm higher** than the HP turbine rotor,  
including the compensation for the thermal expansion.

# Normal & stable behavior after intervention





## Conclusions

- The vibration **analysis itself can be done very quickly** :  
First conclusions sent after ½ working day in this case.
- **Only possible with the good CM tools** (and experts, of course)
- Relatively small machines (<50MW)  
with 2 sleeve bearings with very different temperatures and close to each other  
are sensitive to the oil whirl phenomenon.



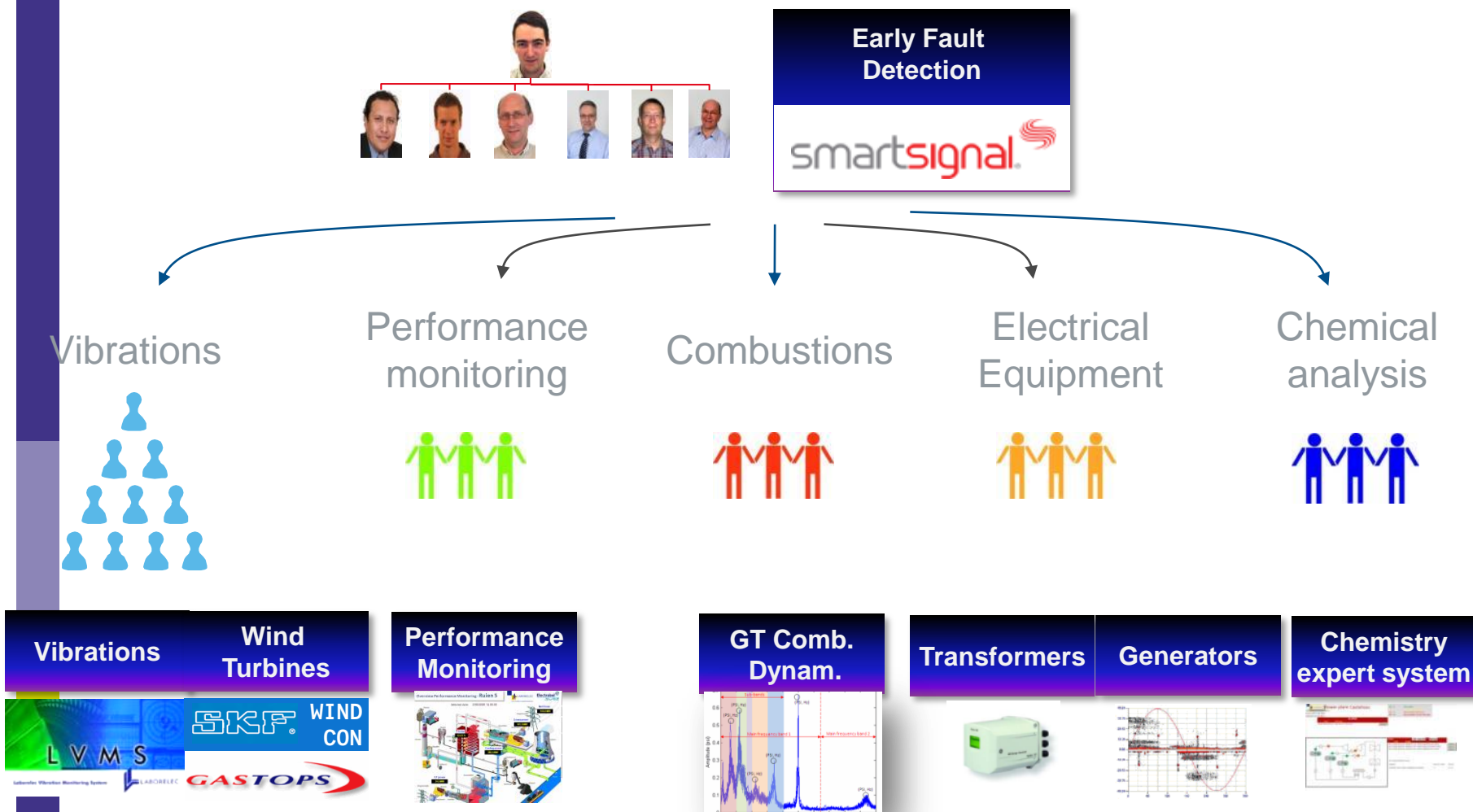
Multidisciplinary approach?

# CM developments at Laborelec (in red → based on NI technologies)

- LVMS, online vibration monitoring of (large) turbogroups
- PM, thermodynamic performance monitoring
- Enhanced Phasor Measurement Device, GPS-synchronized, for advanced power quality measurements and fault recording
- CombustionDynamics, follow-up of the stability of the combustion process of gas turbines
- LPMS, detection of loose parts in the primary circuit of nuclear power plants
- LCES, automated diagnosis of water/steam cycle chemistry related issues
- Dissolved Gas Analysis, online follow-up of the oil quality in transformers
- PMR, performance calculation and monitoring system of wind turbines
- Related condition assessment systems:
  - Torsion, online advanced torsional shaft vibration
  - Continuous LIDAR measurement setup for wind turbines
  - Generic HIL system, powerful and high channel count, many applications
  - Steam turbine Stress Computer for flexibility improvement

■ ....

...to be used in a “Diagnostic Center” approach





## Final messages

# Future condition monitoring (CM) ? → multidisciplinary expertise and systems

## ■ Future condition monitoring will need

- to consider the coupling between assets, between systems, more than ever
- to bring relevant information for different actors
- to monitor in real-time the residual lifetime
- to assess in real-time the risks

## ■ (no... big data won't solve everything...)

## ■ This requires

- multidisciplinary teams, with top expertise → must-have !
- multidisciplinary CM systems → to facilitate multidisciplinary root cause analysis via integration & interoperability of systems, shared knowledge base, data pooling,...
- continuous improvements → implement knowledge acquired in Root Cause Analysis

## ■ And... as always, end-users need to be efficient

→ importance of tools designed by end-users for end-users

## ■ ... Nothing new in these messages/conclusions, except that they become more and more relevant, more and more challenging





## And at Laborelec?

## NI products support this vision !

### ■ Laborelec develops in-house condition monitoring products

when

### InsightCM as a platform

- integration/interoperability with other condition monitoring products → multidisciplinary

- unsatisfying products on the market

- flexibility is needed

- evolving features over time (e.g., extra interoperability with other systems...)

- short time-to-market

- customization for our customers

### CompactRIO

Besides,

- prototyping & research

→ powerful CPU & FPGA

→ possible to process information in real time,  
close to the asset, at high sampling frequency...

### ■ As a by-product, this

→ sending relevant summary information & alarms to central system

→ avoiding the (huge) cost of big data infrastructure & processing...

- improves knowledge (and its retention) in key competencies !

- enables homogeneity among the products + code reuse to increase maintainability

### ■ Laborelec offers a wide range of condition monitoring products & services

- thanks to many top experts in various engineering fields

- designed by end-users for end-users, our experts use these products every day



## LABORELEC BELGIUM

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Belgium

## LABORELEC THE NETHERLANDS

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## LABORELEC GERMANY

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## FROM INNOVATION TO OPERATIONAL ASSISTANCE IN ENERGY

Laborelec is a leading research and services centre in energy processes and energy use, with more than fifty years of experience. We are part of the Research and Technology Division of the GDF SUEZ Group, a world leader in the energy sector.



## FIVE REASONS FOR YOU TO CHOOSE LABORELEC

- Wide range of technical competences in Electricity Generation, Grids, Storage and End-Use
- Increased profitability and sustainability of your energy processes and assets
- Unique combination of contract research and operational assistance
- Independent advice based on certified laboratory and field analyses all over the world
- More than 50 years of experience