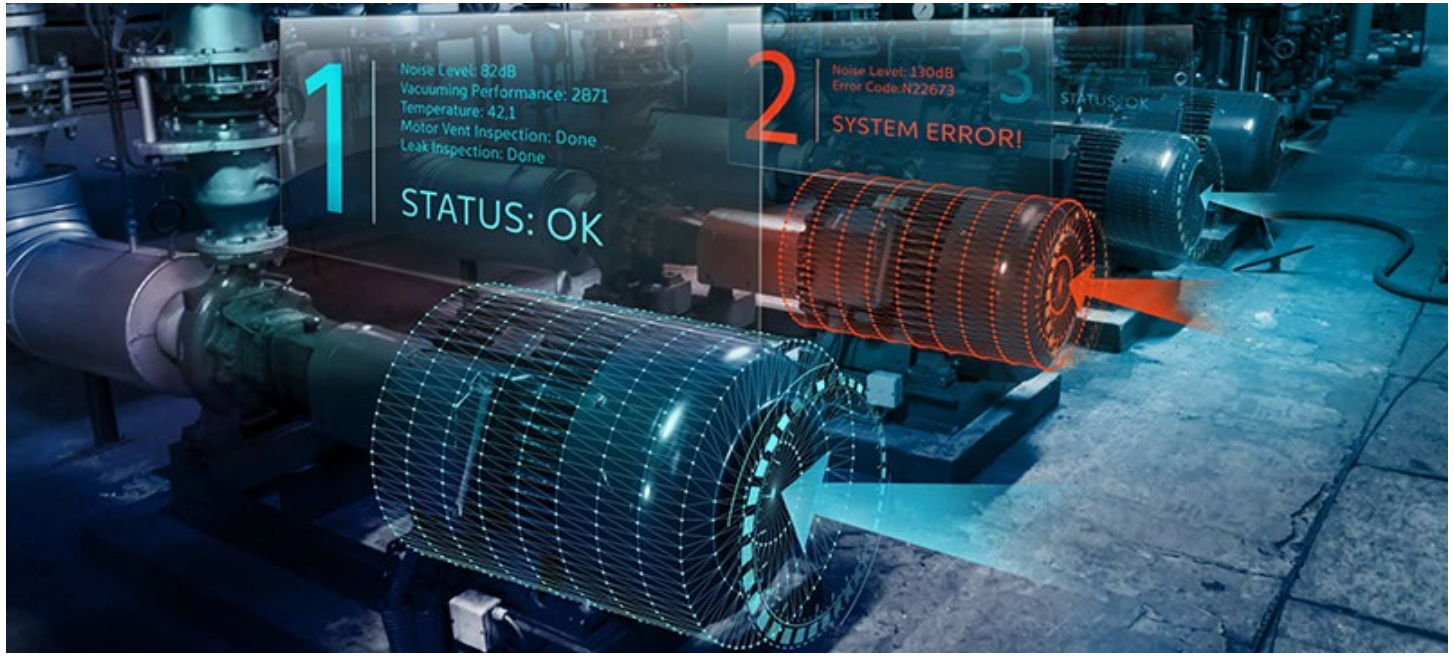
NOVEMBER 16TH, 2022

ENEL Remote Predictive Diagnostic Center and cutting-edge technologies in AI with AVEVA

Presented by: Fiale Mauro and Claudio Macchia

ENEL Remote Predictive Diagnostic Center and cutting-edge technologies in AI with AVEVA



AVEVA world conference, San Francisco

November 14-17th 2022

AVEVA enel Green Power

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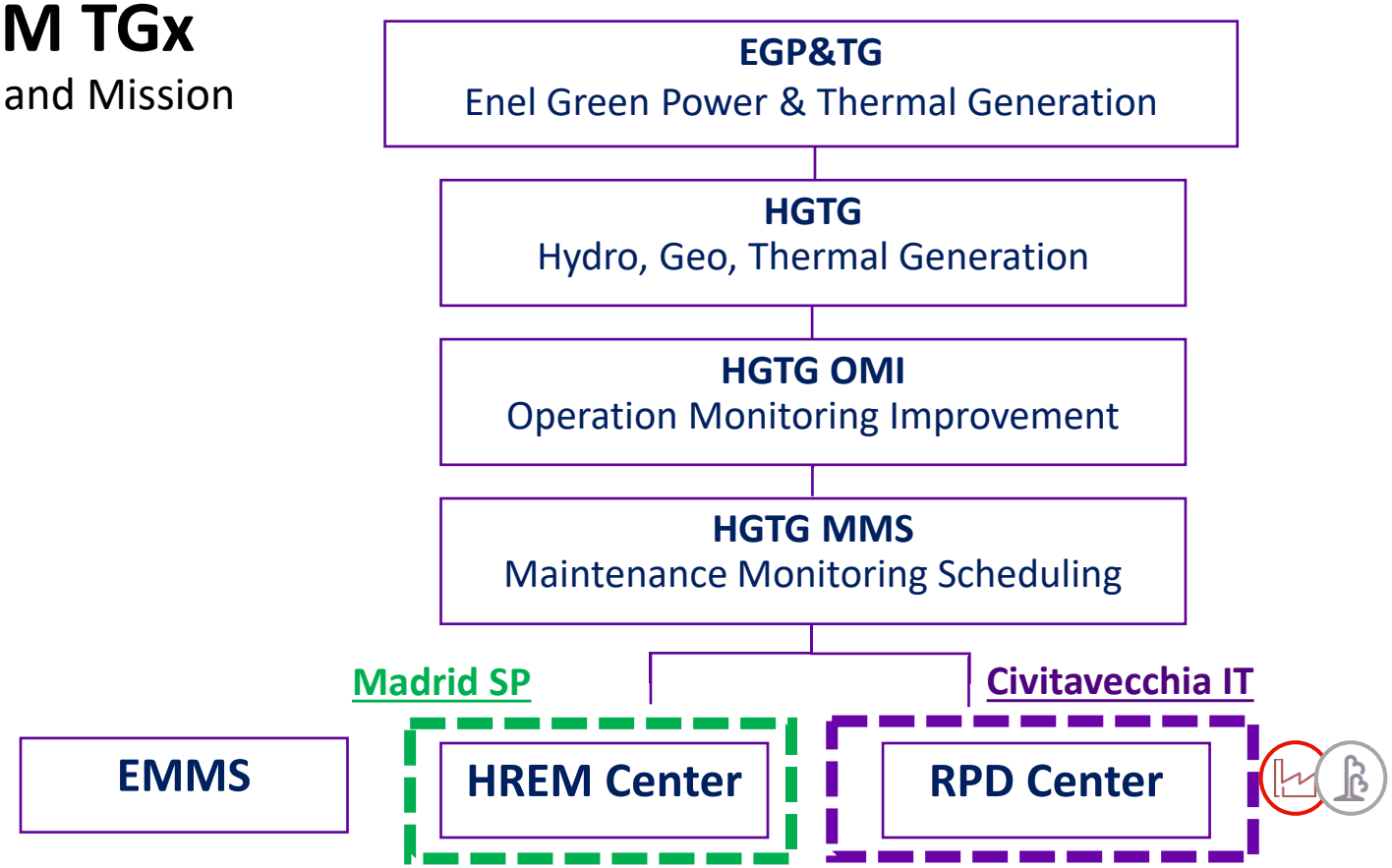
GPG O&M TGx

Organization and Mission



RPD Center MISSION

- To ensure the full **deployment of the diagnostic processes**, involving Engineering and Construction, Innovation and Global Technology Lines;
- To **develop analytics** aiming at supporting the diagnostic process and the performance optimization of the fleet, exploiting features of the Thermal Monitoring and Diagnostic Rooms established at Global and Country level while ensuring their **coordination, leveraging also on digital transformation outcomes**.

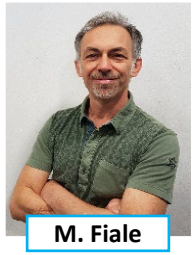
Remote Predictive Diagnostic Center

- RPD Teams

RPD Center

A. Pica

PRODUCT OWNER



M. Fiale

PROCESS OWNER

L. Gianfrancesco

CORE TEAM

S. Sanchez

D. Navarrete

D. Cosentino

A. Iacomelli

M. Leoncini

P. Serpente

C. La Grassa

Technical Support Community

VIBRATION DYNAMICS

F. Randellini

R. Basili

F. Carusi

V. Lissen

I. Navalon

TURBINES

A. Giordanino

BOILER & HRSG

G. Alzetta

CHEMICAL

I. Lecuona

GENERATORS

J. Rodriguez

TRANSFORMERS

A. Susini

I&C

G. Davico

n. 546 Active users in Jira Ticketing Platform

Predictive Analytics and AI

- AVEVA Team

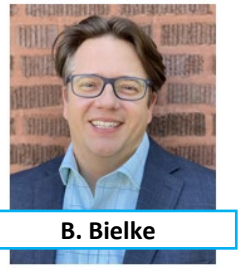
AI CoE

Mike Reed

Product Director

C-M. Pouyez

AI R&D / Development



B. Bielke

Technical Lead

D. Smith

Customer Support

F. Petrone

Project Management

M. Ballarini

Delivery Team

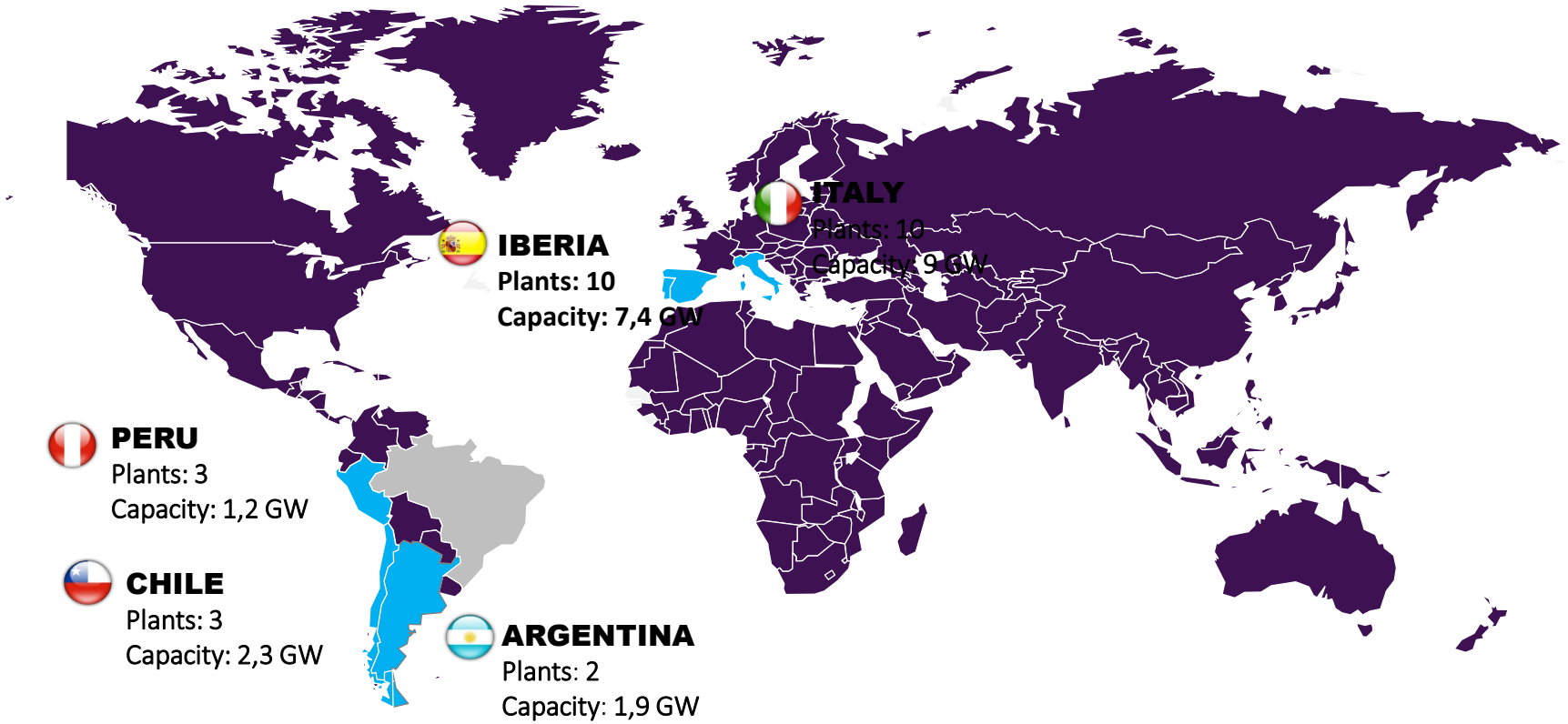
S. Pola

G. John

Remote Predictive Diagnostic Center

Mapping

Remote Predictive Diagnostic monitoring and 1st level diagnostic analysis aims to catch in advance potential failures in power plants, fostering the increase of availability and the reduction of maintenance cost

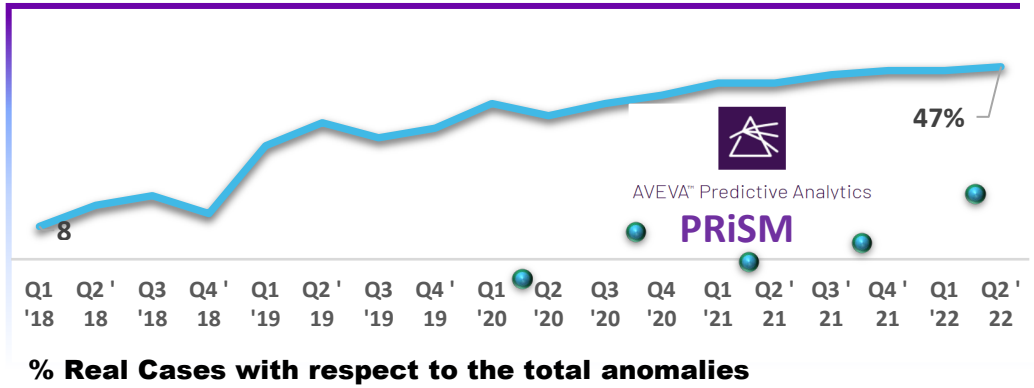


28 Plants 61 Units 21,3 GW 5 Countries 1285 Assets 5035 Analytics

≈70000 OSI PI Tags 9 People in the Team ≈500 involved People in RPD Process

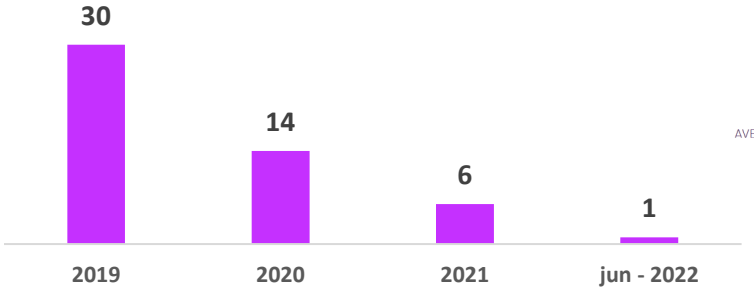
Remote Predictive Diagnostic Center

RPD Process and Main Figures



% Real Cases with respect to the total anomalies

Main KPIs



Mean Time to Action (Days)

461 Total

46,95 M€ Total

PRiSM
AVEVA™ Predictive Analytics

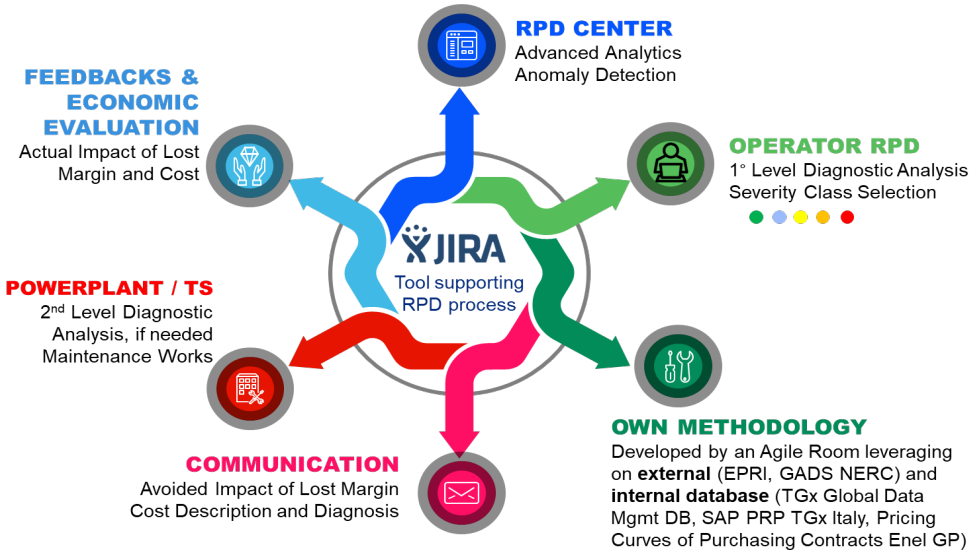
# Catches *	Benefits *
402	40,3 M€
14	1,8 M€

Total Avoided Unavailability

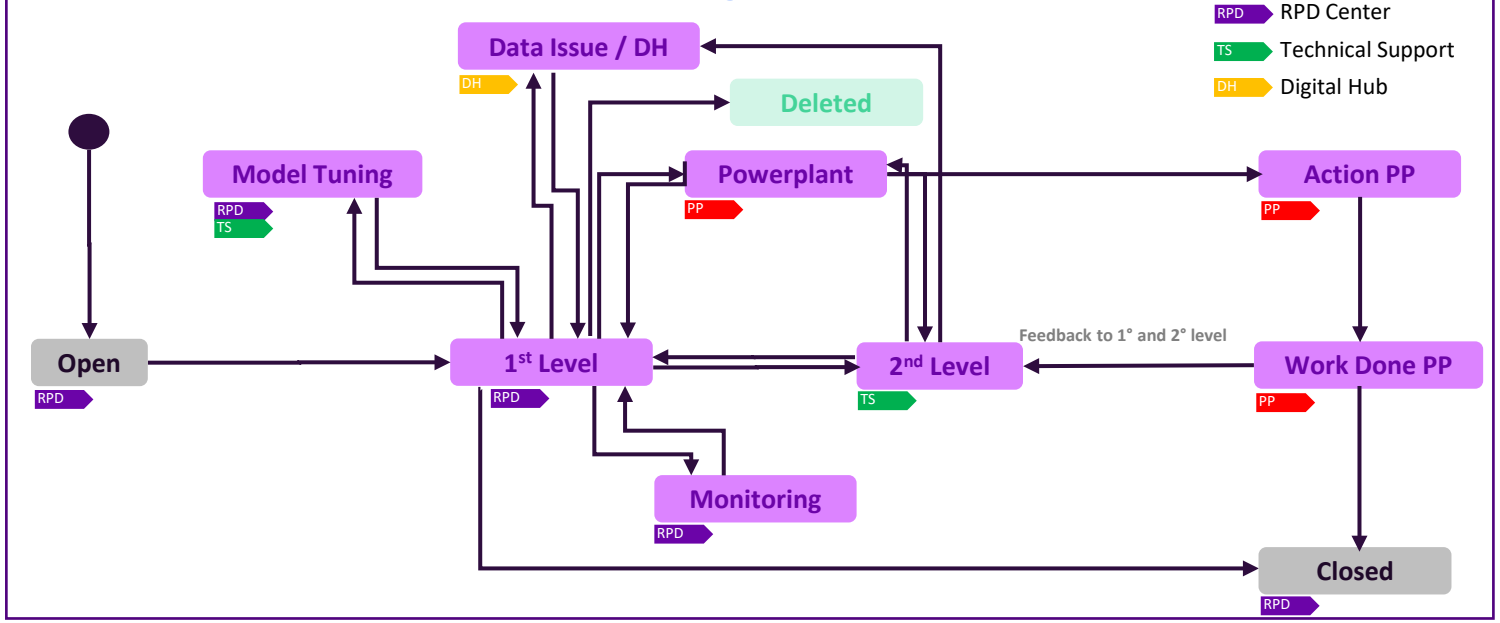
1,48%

(*) 2018 – 2022 ytd

Process and Main Roles
(OP n. 320 Remote Predictive Diagnostic)



Ticketing Workflow



AVEVA

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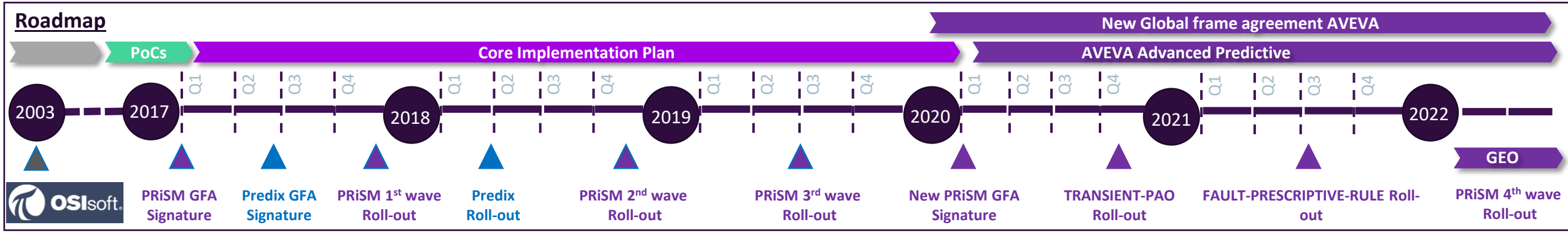
Remote Predictive Diagnostic

Framework development

Remote Predictive Diagnostic monitoring and 1st level diagnostic analysis aims to catch in advance potential failures in thermal power plants, fostering the increase of availability and the reduction of maintenance cost

Roadmap



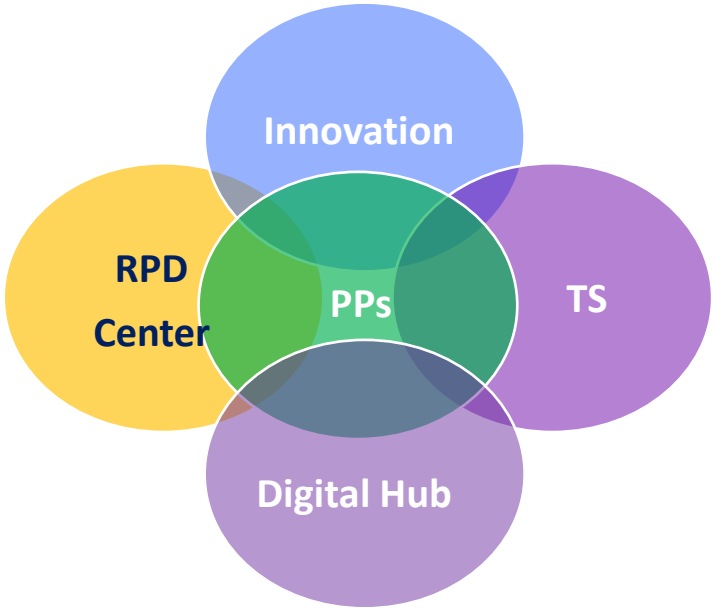
Main Actors involved from the beginning

Innovation
Continuous diagnostic tools scouting, managing pilots' deployment, evaluating benefits and main outcomes, with the aim to select the best ones.

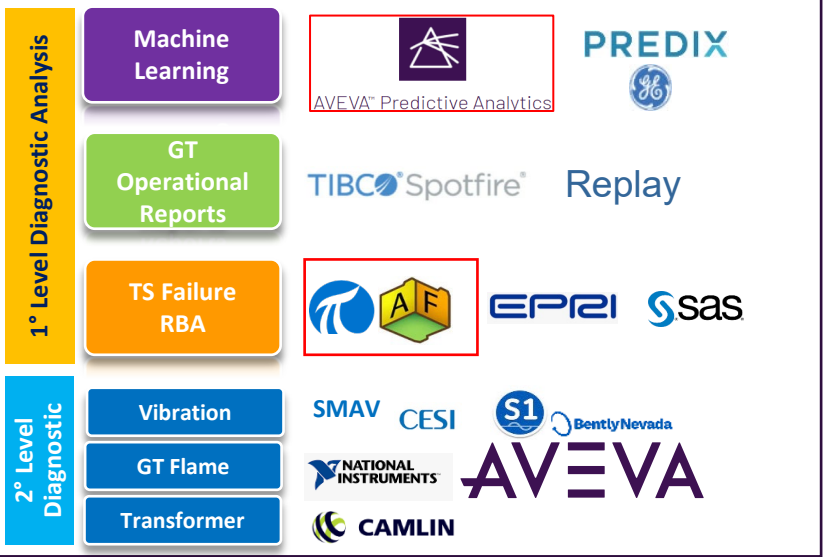
Remote Predictive Diagnostic Center
Support tools selection, use the tools and contribute to validation and benefits evaluation, in order to foster the rolling out activities and to get the highest value once the solution is implemented.

Technical Support and Powerplants
Support in the identification of most critical equipments and problems, and interpretation of specific technical issues in the framework of 2nd level diagnostic analysis.

Digital Hub
Data collection in a proper way from the plant to the Cloud level in order to ensure availability, quality and reliability.



Main tools currently being used



Advanced Predictive maintenance - Aveva

Collaboration Agreement focus

Collaboration Agreement key steps

2021

2022

January 2021:

- Temporal **extension of 2020 Collaboration** Agreement to complete RULE module.

September 2021:

- **New CA** finalization with **extended Scope of Work**
- **Predictive Asset Optimization** and Prism test on **GEO** definition

December 2021:

- Verification of fault diagnostic an prescriptive templates with **ENEL Technical Support community**
- **Global Retrofit** of Fault Diagnostics and Prescriptive to more than **20 thermal plants** and more than **2000 models**

2022 joined develop. milestones:

- **Validation of PAO** on selected use cases
- Kickoff of **Prism Test on GEO**
- **RULE** module presentation a test results

Implementation path

Transient analysis — Done
- *Diagnostic of incipient faults in transitory operation*

PAO — Done
- *Techno economic maintenance activities optimization*
- *Air filter change and compressor washing use cases*

Fault diagnostic and Prescriptive — Done
- *Pattern matching to diagnose and isolate equipment issues and failure mechisms and generate actionable outcomes*

Time to failure - RULE — Done
- *Analysis of the anomaly evolution and time to failure estimation in order to optimize O&M decisions (joined development)*

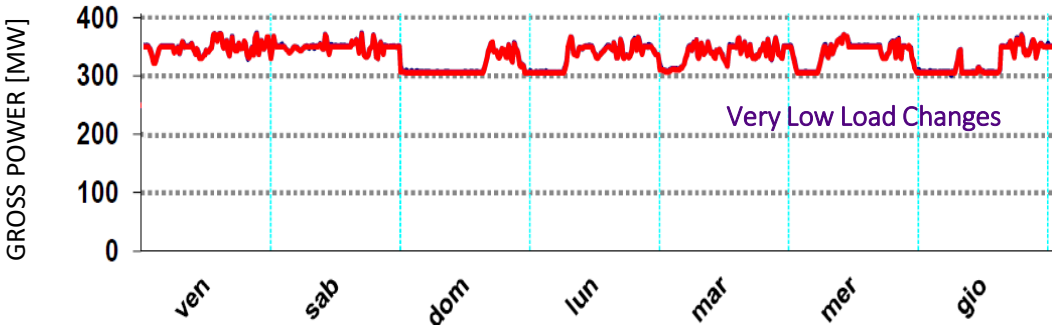
Prism test on GEO — Ongoing
- *Focus on gas extractor*
- *Compressor surge event analysis and operation condition optimization*

Transient Monitoring

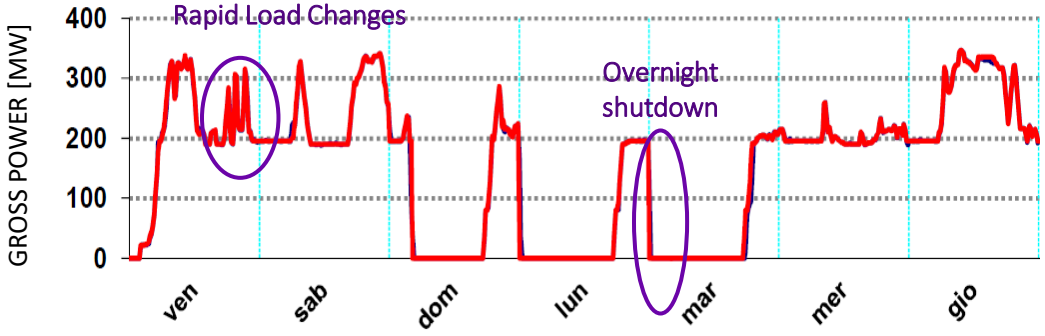
Development methodology

NEW ENERGY CONTEX: TYPICAL WEEKLY TRENDS OF CCGT IN ITALY AND SPAIN

2012



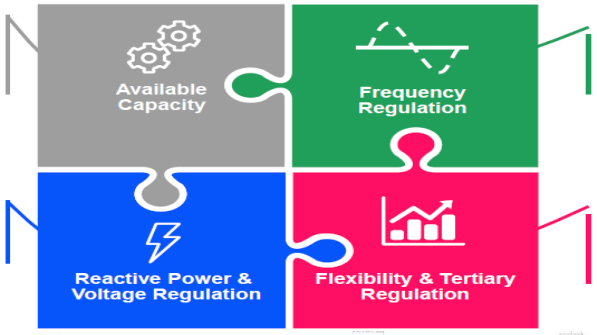
2020



ENEL PROJECTS FOR GT PERFORMANCE ENHANCEMENT

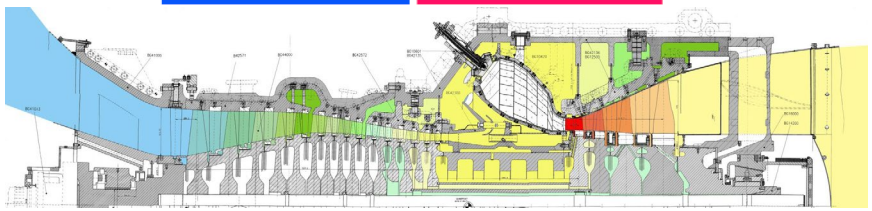
- Maximum Load Increase
- Dual Fuel
- Efficiency Increase

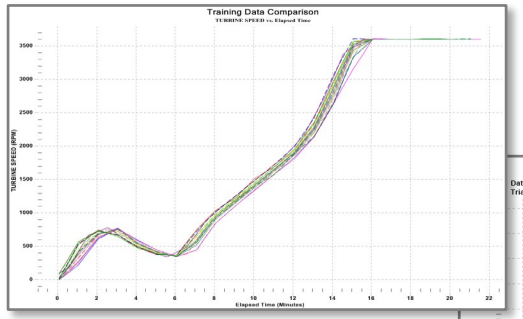
- Primary and Secondary Voltage Regulation
- Running as Synchronous compensator

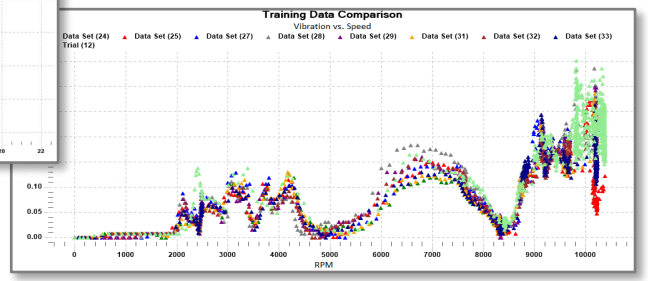


- Primary Frequency Regulation (PFR)
- Secondary Frequency Regulation (SFR)

- Minimum Load Decrease
- Fast Start
- Ramp Rate Increase







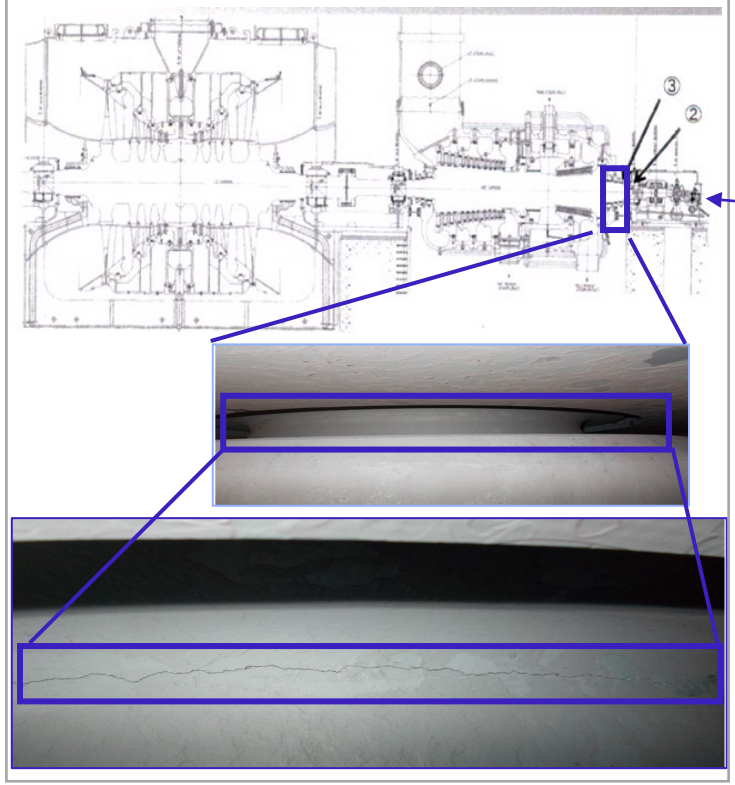
It’s crucial to support PP also during transient phases

Transient Monitoring

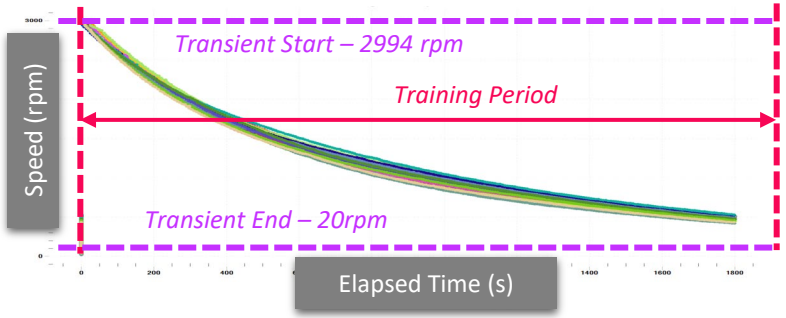
Use case Steam turbine transient model

Case Background

- **May 2019:** a circumferential crack was discovered in the HP rotor of this steam turbine

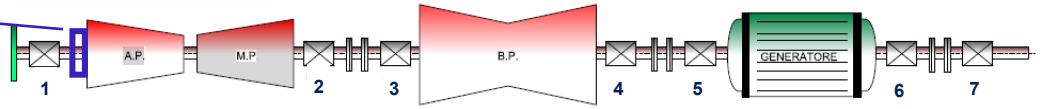


Model Training data

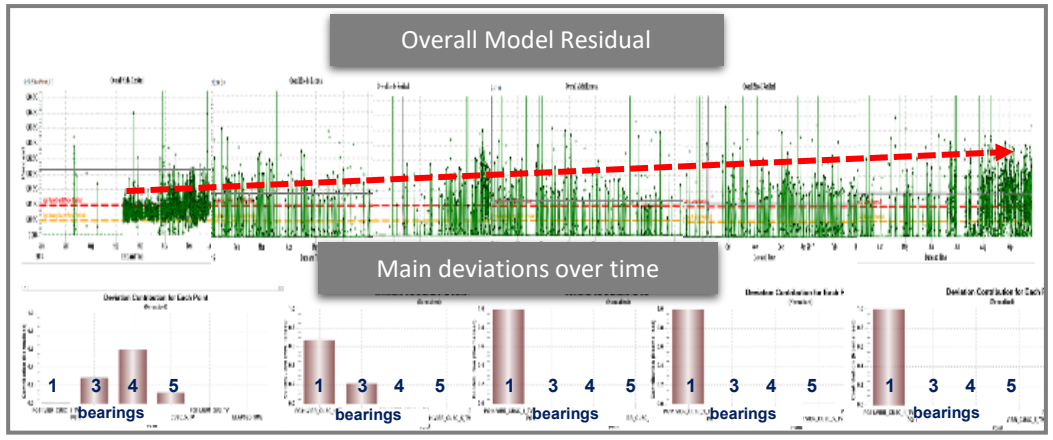


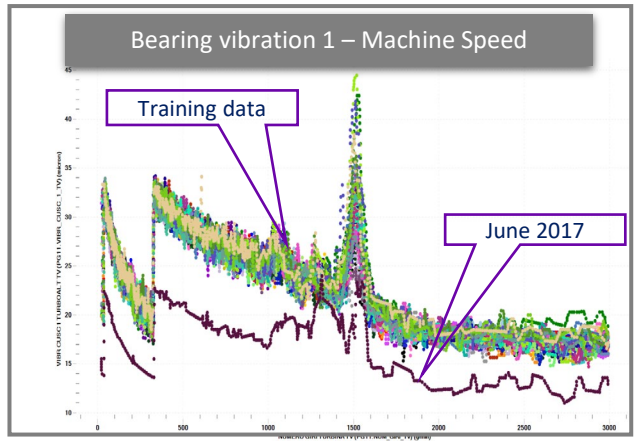
- Jan 2014 - May 2019 (turbine speed and bearings vibration)
- Model training data => Q1 2014
- Machine run-downs:
  - Transient start at 2994 rpm
  - Transient end at 20 rpm

37 machine run-downs as training data



Results



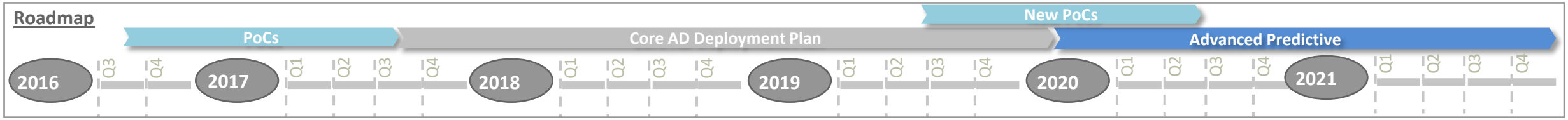


As early as July 2014 a change in shaft vibration characteristic is clearly detected. The greatest contribution is Bearing 1, that closest to the crack.
Analysis of one run-down in June 2017 more clearly shows the changes in vibration characteristics

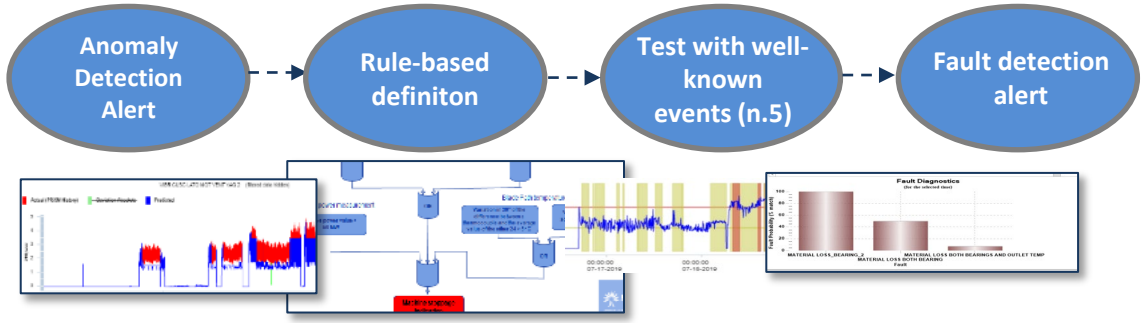
Fault Detection and Prescriptive

Development methodology

Roadmap



Methology for testing



5 uses-cases identified

Powerplant - unit	Asset involved	Issue
La Casella – 2	Steam Turbine	Water entrance
Brindisi – 2	Feed water pump	Seal failure
Besos - 5	IP Feed Water Pump	Bearing Failure
La Casella 3	V94 Steam Turbine	c.c tile detachment
Dock Sud - 9	GT26 Gas Turbine	Compressor Failure

Anomaly detection

- Rapidity in deployment
- Experiencing new tools
- Definition of a new process
- Focusing on data,
- Best choice whit varied failures

- Number of false positive
- High effort for Root cause analysis
- The definition of the “normal” behavior couldn’t be easy

VS

Fault Diagnostic Detection

- Provide simultaneously Predictive and Prescriptive info
- Low effort for Root Cause Analysis
- Low false positives

- Requires a large number of failure records
- Very high effort for deployment

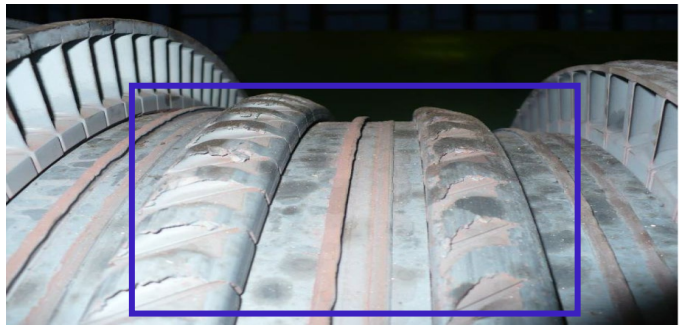
Increase in the ability to detect failure signals

Fault Detection and Prescriptive

Use case Steam Turbine fault detection and prescriptive

Case Background

- 10thApril 2008 a significant amount of condensate has entered the machine through the steam turbine intake valves during a startup causing serious damage. No particular indication in subsequent start-ups.
- August 2008: a performance reduction was reported by the plant
- November 2009 plant shutdown for major outage and discovered serious damage. Damage comprised missing 2nd / 3rd stage rotating blades (found in the bottom of the casing), damaged seals and evidence of ovality of the casing amongst others.



Results

ST Mechanical Model

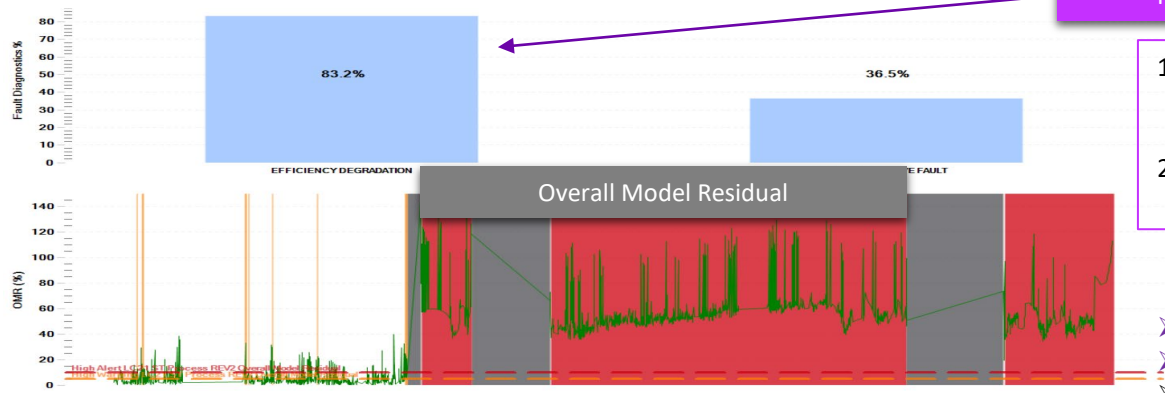
Fault Diagnostic

1. Shaft balance issue has the highest match (means we have some change in the dynamics of the rotor.

List of defined rules

- Bearing hot (n.1 for each brg)
- **Bearing failure (n. 1 for each brg)**
- **Shaft Balance Change**
- Lube oil Cooler
- Cooling Water Temp High

ST Process Model



Fault Diagnostic

1. Strong fault match – higher steam flow, higher exhaust temperature (lower isentropic efficiency)
2. Weaker match because of increased steam flow only

List of defined rules

- **Control Valve Fault**
- **Efficiency Degradation**
- Inlet Strainer Blockage

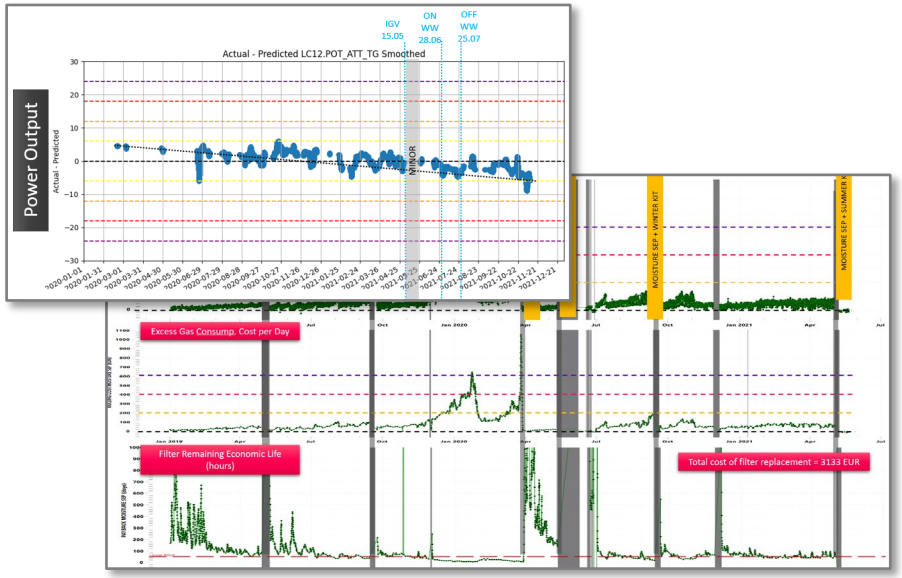
Both models suggested damage to the machine 5 months before the outage
Damage to the steam path, possible loss of blading on rotating or fixed elements and possible damage to seals

Predictive Asset Optimization (PAO)

Development methodology

Approach and Benefits

1. Link Predictive Analytics and First principle Performance to Isolate and measure **Gas Turbine Filter Fouling** and **Compressor Degradation**
2. Determine impact on **fuel consumption** and **monetarize** via gas cost
3. Evaluate **remaining economic life** by comparing future fuel savings impact with direct / indirect costs of maintenance
4. Directly link performance monitoring to monetarized **maintenance benefit**
5. **Optimize** gas turbine routine maintenance expenditure

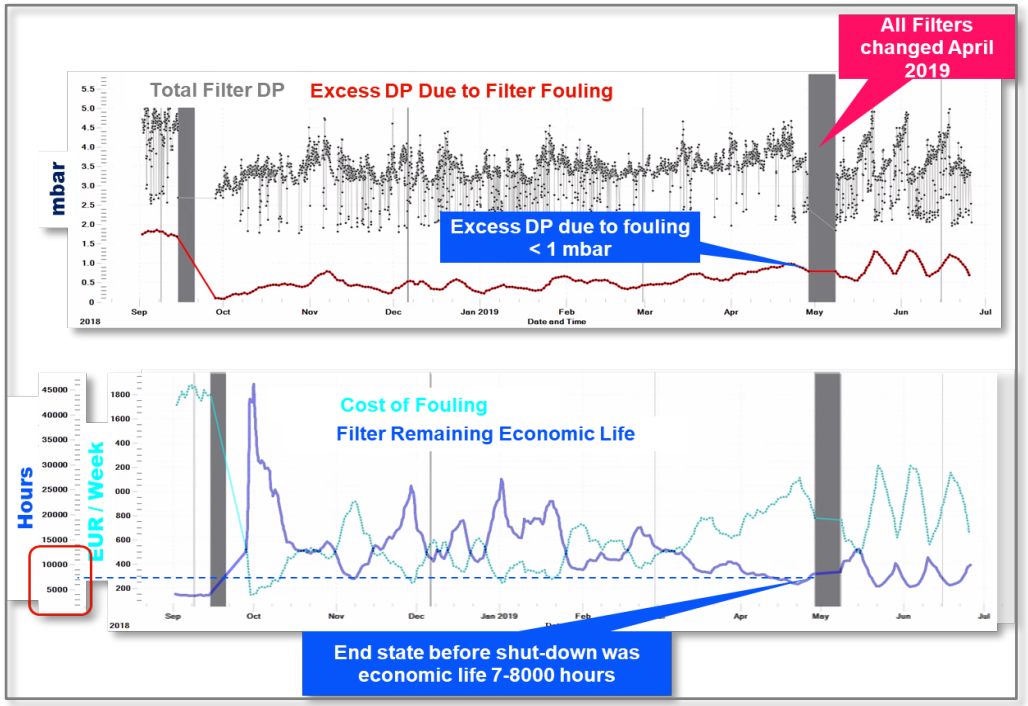


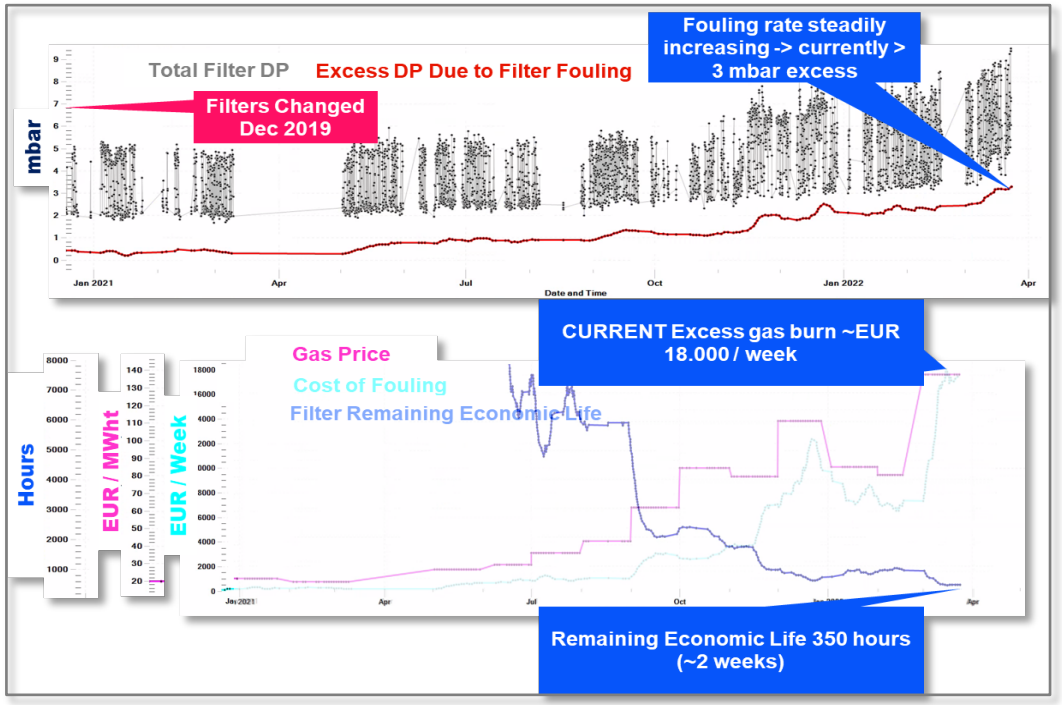
- First Principles to define **machine condition**
- Predictive Analytics to **measure degradation** with hig resolution
- Monetarize incremental **operating cost** of degradatic
- Real-time view of **return on maintenance investmen**
- O&M advice when and where to **prioritize action**

Natural Gas Price

Predictive Asset Optimization (PAO)

- Use case PAO





Case 1 : Over Maintenance

Filters previously changed in September 2018, but the entire filter was changed again in April 2019 at a cost of ~ 40kEUR. At the time of the second change the excess pressure drop due to fouling was only between 0.5 and 1.0 mbar. Consequently the remaining economic life of the filter was still more than 7.500 hours -> the filter change was premature.

Case 2 : Maintenance Due

The filter was previously changed in December 2019. By Q1 ’22 the filter is in degraded condition in combination with the significant increase in gas price means that the additional gas burn is about EUR 18.000 per week and the current economic life of the filter is only 2 weeks -> filter should be changed as soon as is convenient

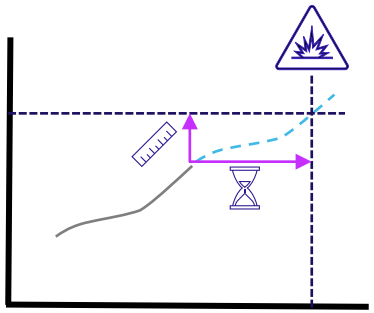
Time to failure - RULE

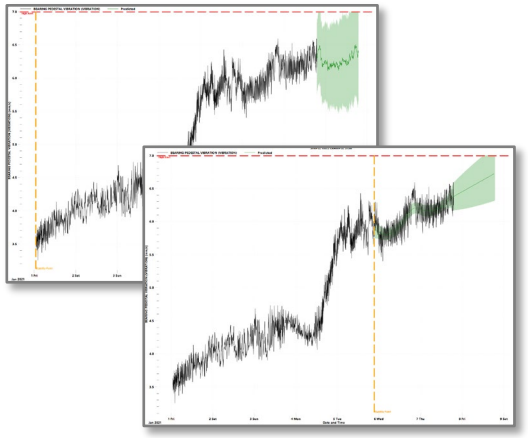
- Development methodology

last but not least !!

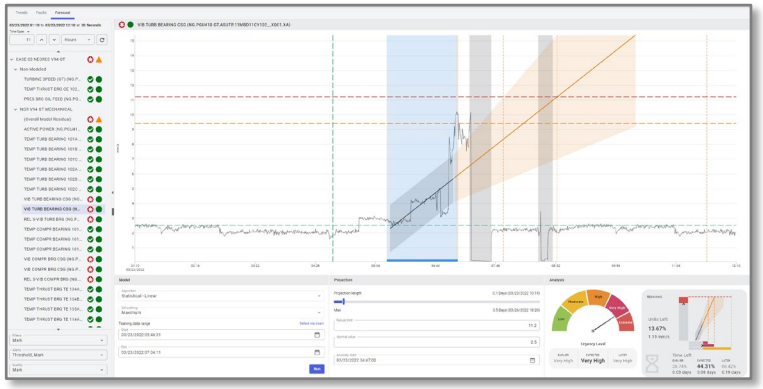
Approach and Benefits

1. When Predictive Analytics detects abnormal behavior track the propagation of the fault to forecast the remaining **distance** and **time** to reach **machine integrity limit.**
2. Determine the **risk and urgency** associated with equipment degradation with a systematic approach to track remaining useful life.
3. **Guide decision making** on maintenance intervention and thereby reduce occurrence of trips and significant equipment damage.





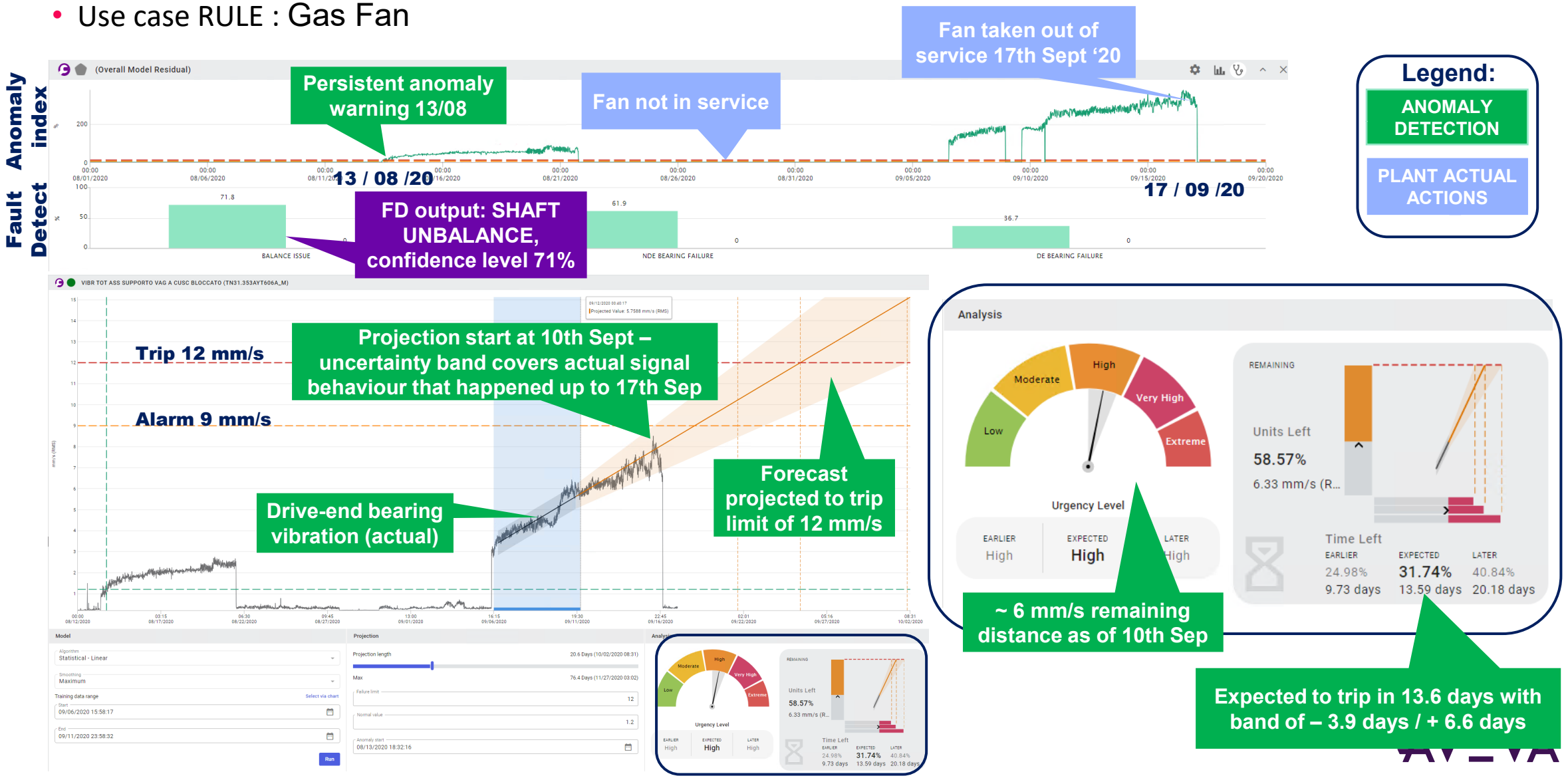
Plant/equipment	Problem	Fault Detection outcome	RULE Benefit (end state)	Impact estimation
V94 Gas Turbine	Compressor blade failure	OK (SHAFT UNBALANCE)	Very high urgency shutdown required: Trip < 2 days	3,9 M€
Feedwater Pump	Bearing failure	OK (BEARING FAILURE)	High urgency shutdown: Alarm < 4 days	50 k€
ID Fan Vibration	Bearing failure and fly ash deposition	OK (SHAFT UNBALANCE AND BEARING FAILURE)	Very high urgency: Trip < 12 days	360 k€



Algorithm development / testing → **Back Testing Use Cases** → **On-line monitoring implementation**

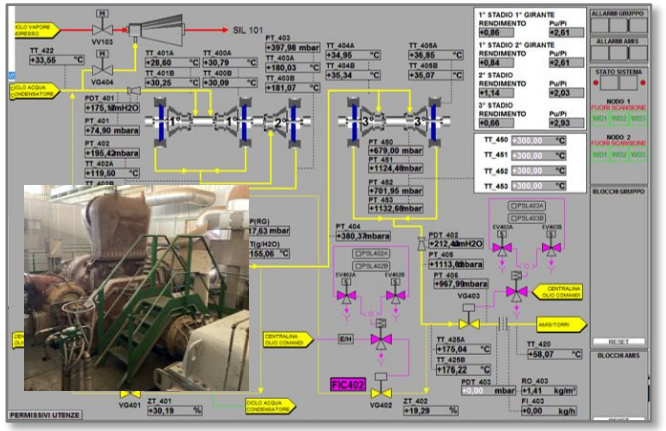
Time to failure - RULE

- Use case RULE : Gas Fan



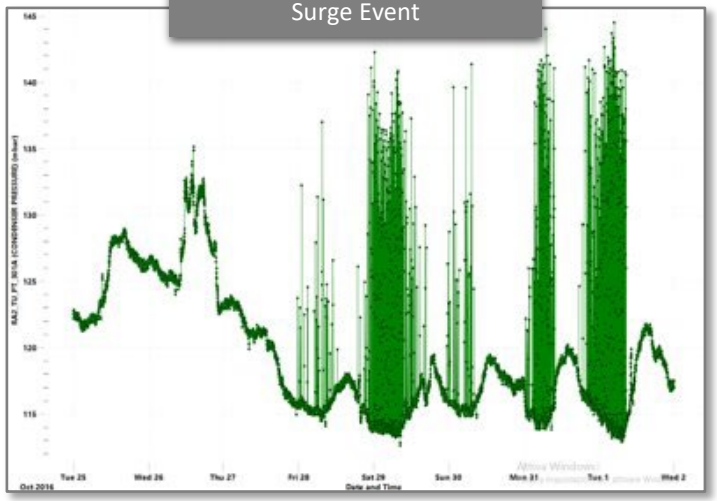
GEOTHERMAL PLANT

- WORK IN PROGRES…..



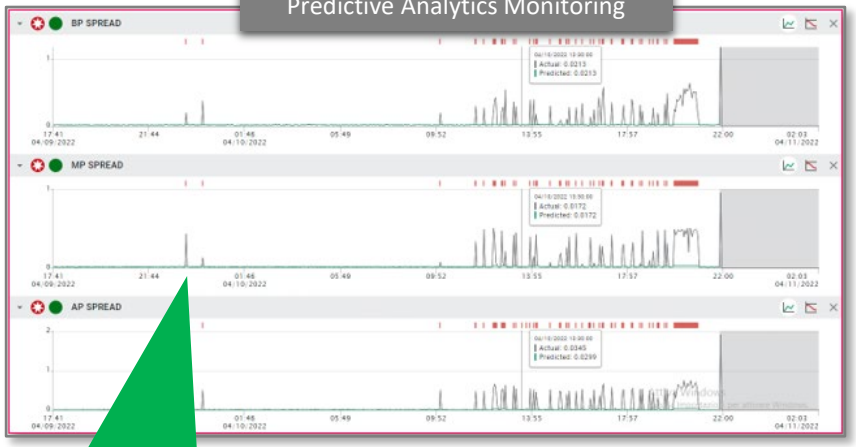
1. Predictive Analytics Focus on integrally geared compressor which removes **non-condensable gasses** at the condenser
2. Compressor surge events can cause rapid fluctuations in condenser pressure which, if not caught by the operator, can **cause the plant to trip in a short space of time** after which a restart can take several hours of lost production
3. Dirt in gas and instrumentation issues mean that **normal anti-surge control is not reliable**
4. **Predictive Analytics is** being introduced to give **advance warning** when entering surge and allow the operator time to adjust compressor operating point to avoid plant crash

Surge Event



- Rapid fluctuations in condenser pressure directly affecting steam turbine performance and electrical generation
- Mechanical stresses on compressor, fluctuation in shaft position causes plant to trip if unabated
- Onset can be difficult for an operator to forsee

Predictive Analytics Monitoring



Early indication that compressor is entering mild surge

- Predictive analytics used to deduce from mechanical and process behaviour of the compressor when it is first entering mild surge behaviour and before the onset of deeper surge
- Early indication of surge allows operator to take preventative action by adjusting anti-surge valves to move operating point before deep surge initiates

CONTENTS

Detected catch with transient PRiSM model

Ticket 1105 CCGT – GT GE6 – Compressor surge during start-up phase

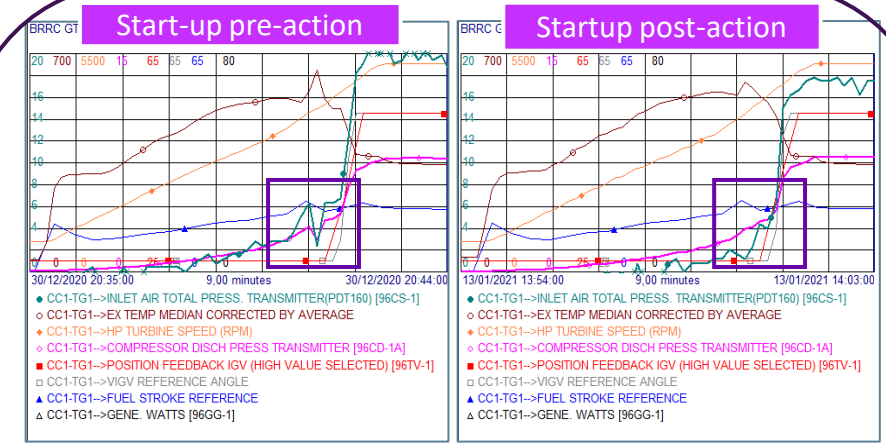
AVEVA™ Predictive Analytics

RPD - Diagnostic analysis

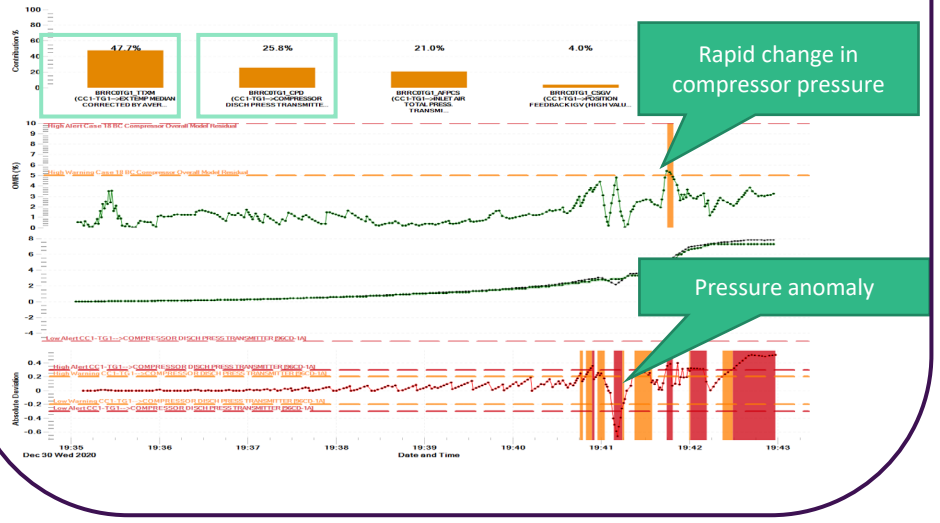
December 31th – RPD: At the end of December, RPD identified a temperature and pressure anomaly in a gas turbine installed in the power plant, during a start-up phase.
This detection was possible thanks to specific models developed for transients monitoring with the Prism tool (used for the Thermal fleet since 2018) and in accordance to a failure already happened on the same turbine model in a similar power plant on June 2020.
At that time, a phenomenon of compressor surge had deeply damaged the turbine blades and the restoration required 78 days of plant unavailability (about 0,9 M€ in terms of avoided cost for margin) and about 3.1 M € of repair cost.

PP - Action

January 27th – PPs Early detection allows alerting in time Powerplant and O&M Gas teams. The anomaly has been promptly checked by the PP colleagues, which had shutdown the machine as a precautionary measure.
Subsequently the manufacturer (General Electric) has been engaged and it suggested modifying the setup of the machine, in particular of Static Frequency Converter. The improvement were immediate and setting changes were extended to all similar gas turbines in the Spanish and Italian fleet.

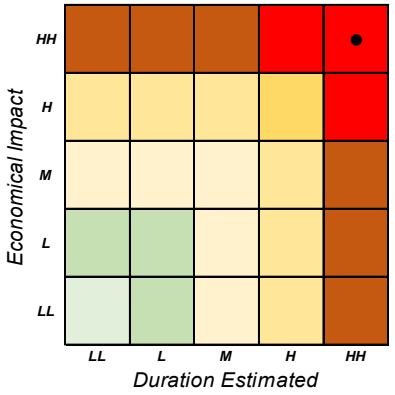


During a start-up before the action, a pressure reduction can be noticed (pink curve) due to compressor surge.



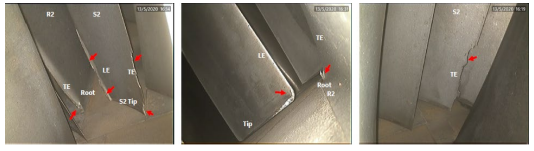
Estimated Impact

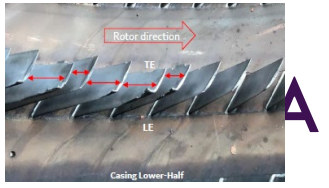
Predictive Module	Gas Turbine
Equipment	Turbo & Compressor



Global Unit Code	BRRC-GT11-CC-2x1
Net Maximum Capacity	68,7MW
Equivalent Duration	75,6 Hrs Eq
Total Economical Estimation	3.980,00 K€
Lost Production Opportunity	880,00 K€
Restoring Cost	3.100,000 K€
Estimated EUOF Impact	7,51%

Potential avoided damage (GRAN GT4)





Thanks

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State your name and company.

Please remember to…

Navigate to this session in the mobile app to complete the survey.

Thank you!

AVEVA

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