AN INNOVATIVE FLEET CONDITION MONITORING CONCEPT FOR A 2MW GAS TURBINE

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Introduction

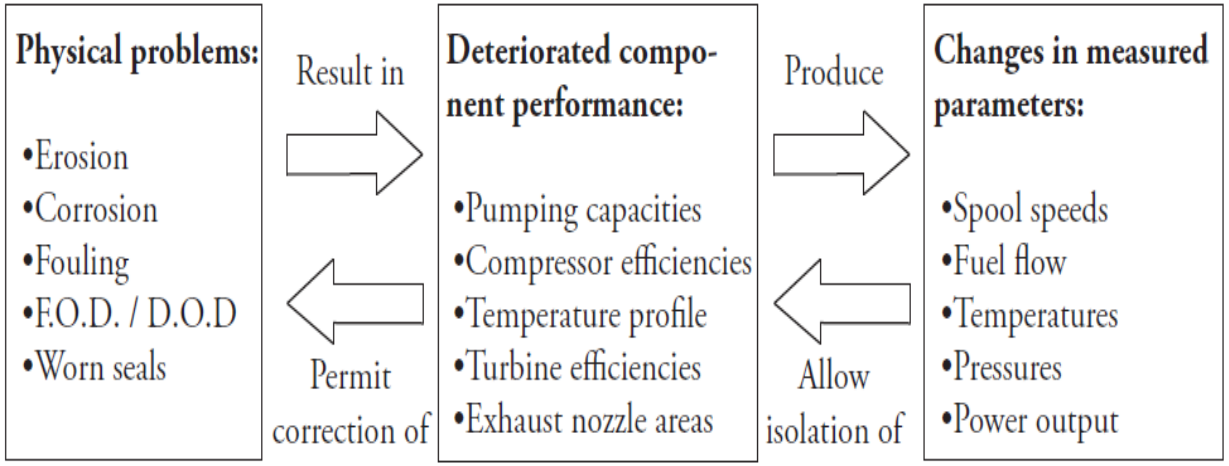
- Development of *GTPtracker©* innovative gas turbine condition monitoring technology
  - Advanced modelling and simulation methods
  - Benefit from latest available ICT technology

- Innovative & cost effective OP16 2 MW class gas turbine
  - Compact, simple and robust design for high reliability
  - Advanced technology for high fuel flexibility, efficiency and low emissions

Collaborative effort to demonstrate GTPtracker on OPRA OP16 engine fleet

Gas turbine condition monitoring overview

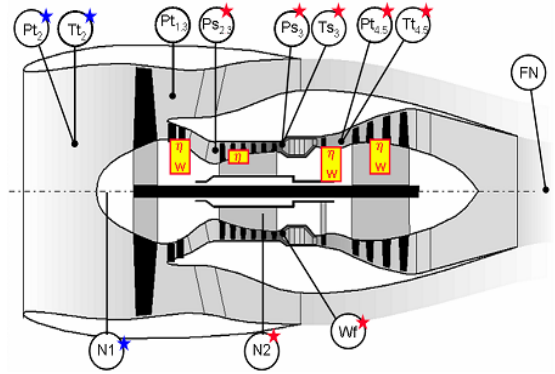
- Gas turbine condition monitoring
  - Performance analysis (gas path)
  - Vibration analysis
  - Lubrication system
  - ....
- Physical degradation ↔ Measurements
- System condition ↔ Component condition
- Diagnostics & Prognostics
  - Maintenance decision support
  - Optimize RAM (Reliability Availability, Maintenance)
  - Minimize LCC (Life Cycle Costs)

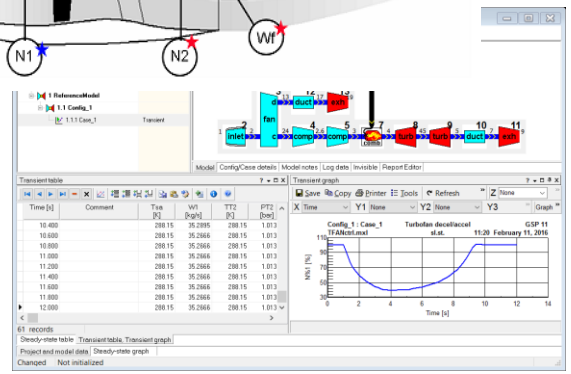


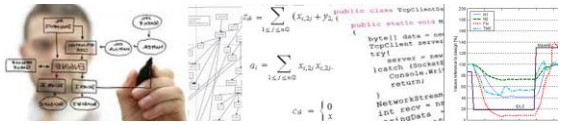
(from Urban, 1972)

Condition monitoring challenges

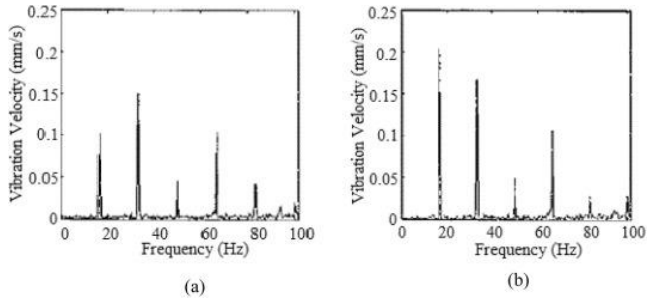
- Modelling effects of faults & deterioration
  - Translating measurements into component condition information
  - Physical models
    - No need for operation history
    - Only cover known mechanisms
  - Empirical approach
    - Need history including faults and deterioration, or models
    - Genetic algorithms, Neural Networks, 'Machine learning' etc.
    - Valuable to identify unknown correlations among effects







- On-line condition monitoring
  - Requires ***real-time*** running of analysis models
  - Limits on model complexity
  - Find ways to simplify models
    - Minimize reduction of fidelity essential for fault & deterioration analysis



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GTPtracker© key elements

- Models relating measurements with condition
  - Off-line comprehensive detailed models (GSP cycle model)
  - ***On-line*** surrogate models (derived using off-line model)
- Condition indices
  - Indicating % deviation from base line
- Rulesets
  - Relating specific faults and deterioration to condition index patterns
- Diagnostics
  - Evaluating rulesets on performance snap shots (real-time)
- Prognostics
  - Predicting ruleset matches
- Relating rulesets to maintenance actions

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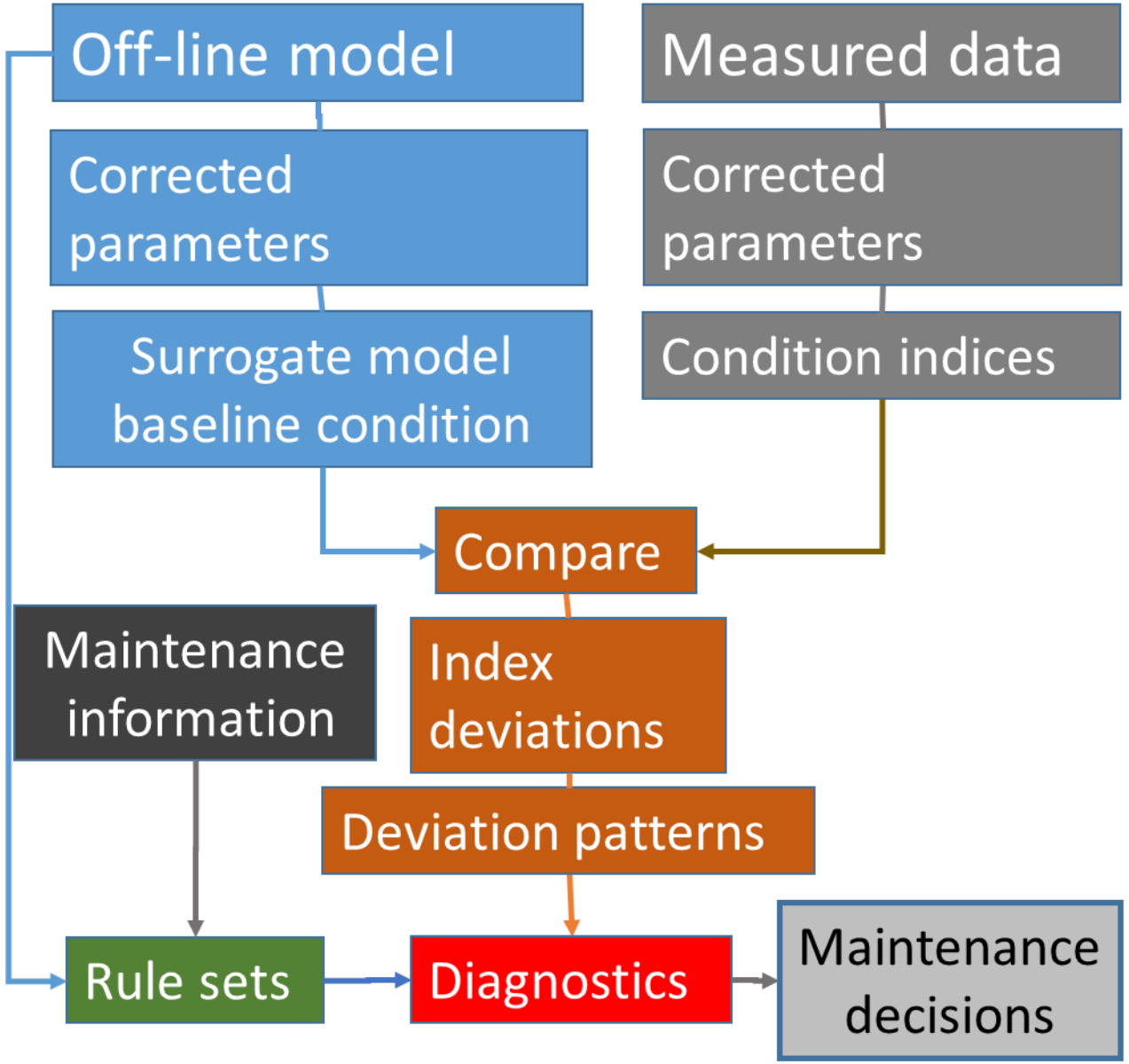
GTPtracker methodology – work flow



Surrogate Model derivation

Example: Base line Power – EGT (T45) relation

- Reduced Power

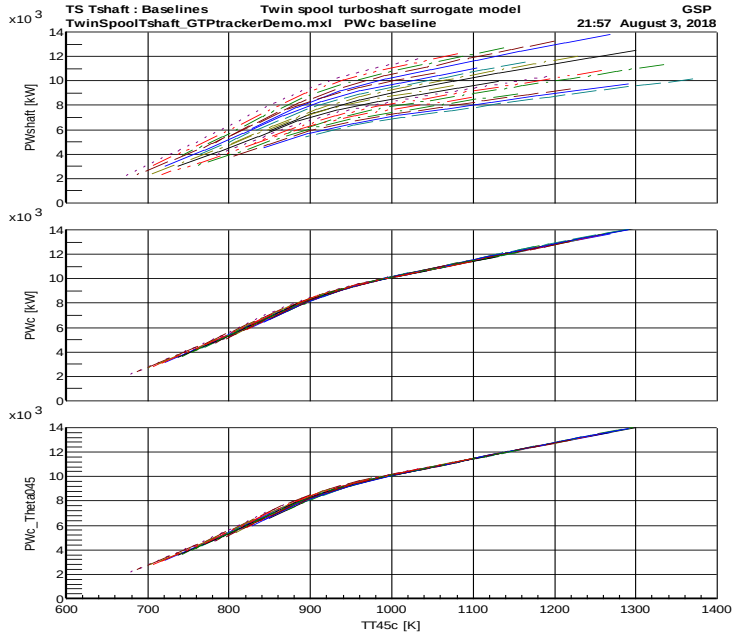
$$PWc = \frac{PW}{\partial^a \ \theta^b} + c.\delta + d.\theta + e$$

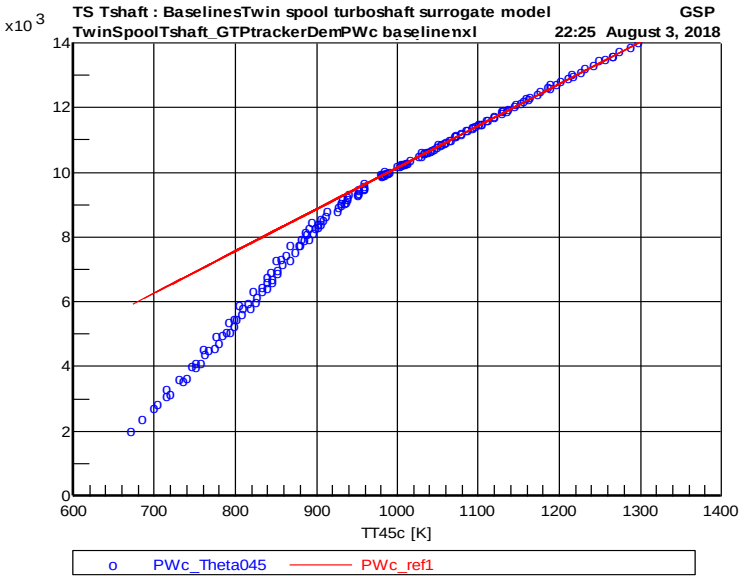
$$TT_{45c} = \frac{TT45}{\theta}$$

- Use model to find coefficients a..e

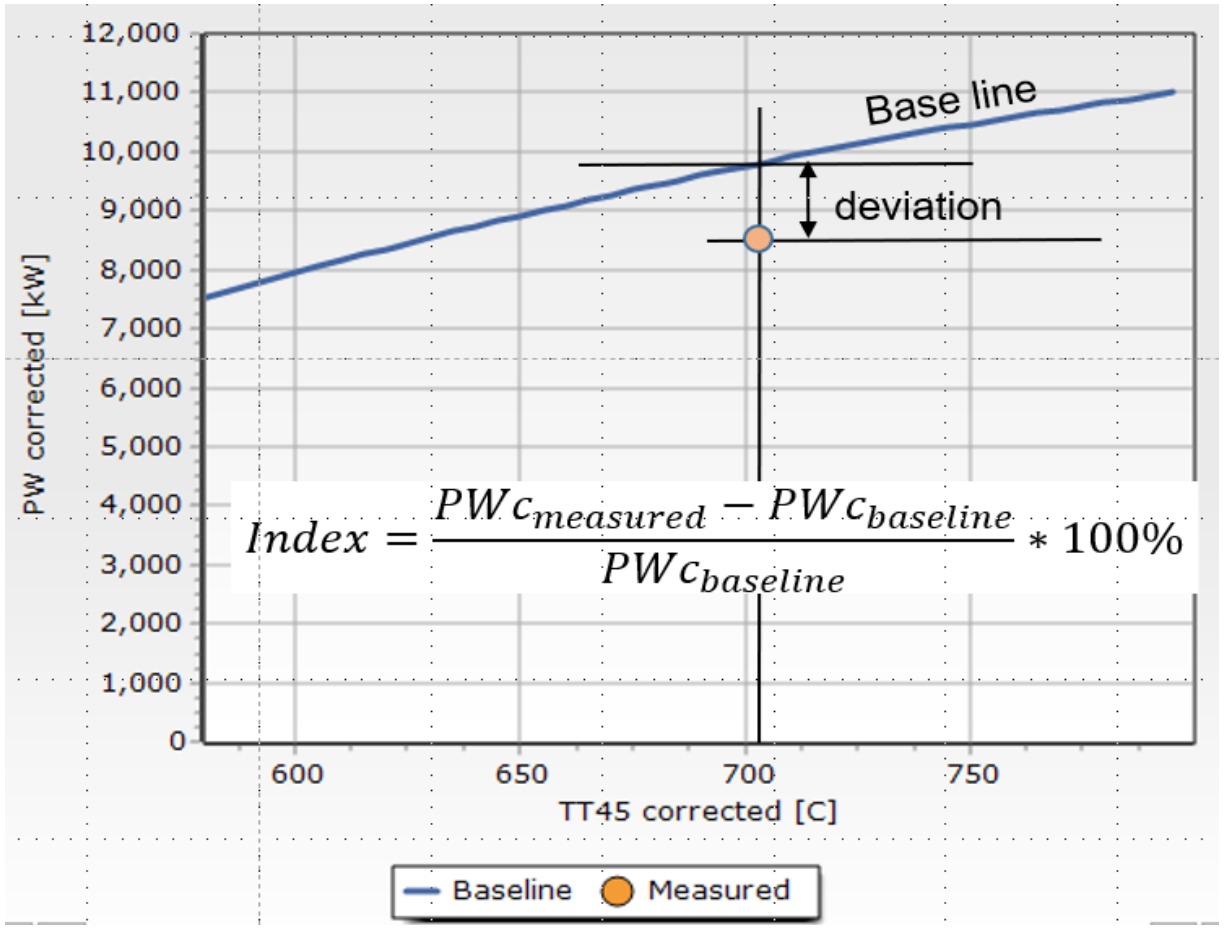
- Regression

$$PWc_{ref} = 9900 + (\mathrm{TT45c} - 980) \cdot 12.9$$





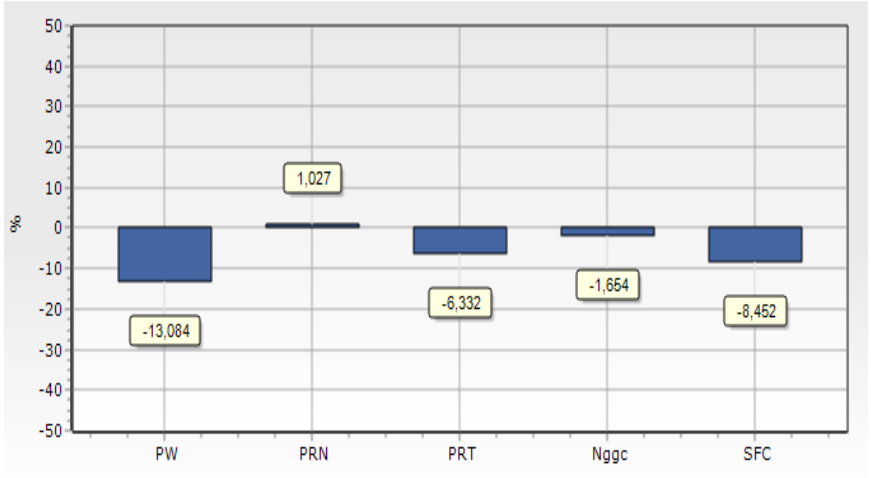
Condition Indices



$$Index = \frac{PWc_{measured} - PWc_{baseline}}{PWc_{baseline}} * 100\%$$

Rulesets for diagnostics

- Patterns of deviations from baseline model
  - Characteristic for specific faults and engine health problems
  - Combinations of ‘above-below’ rules
  - A match of a ruleset with an operating point indicates a specific problem
  - Optimally isolate single root cause of problem
  - Prefer parameters independent of inlet conditions (indices)
  - Link to specific maintenance actions
- Generate rulesets using detailed off-line model
  - Simulation of faults and deterioration modes
  - Include uncertainly (Monte Carlo simulations)
- Unknown problems & deterioration modes
  - Develop rulesets based on experience
  - Apply AI (GA, ANN, machine learning etc.)



Rulesets for configuration: OP16 Config 2

Name	Description	Component	Maintenance ty
Compressor	Compr.Gen.Dete	Compressor	water wash

Fieldname	Display label	Unit	Below	Above
PW index [%]	PW index	[%]	-2.00	
PR index [%]	PR index	[%]		-3.00
TT3_2 [°C]	TT3_2	[°C]		280

Turbine det		Turbine	Inspection 1

Fieldname	Display label	Unit	Below	Above
PW index [%]	PW index	[%]	-3.00	
PR index [%]	PR index	[%]	-3.00	
TT3_2 [°C]	TT3_2	[°C]	280	

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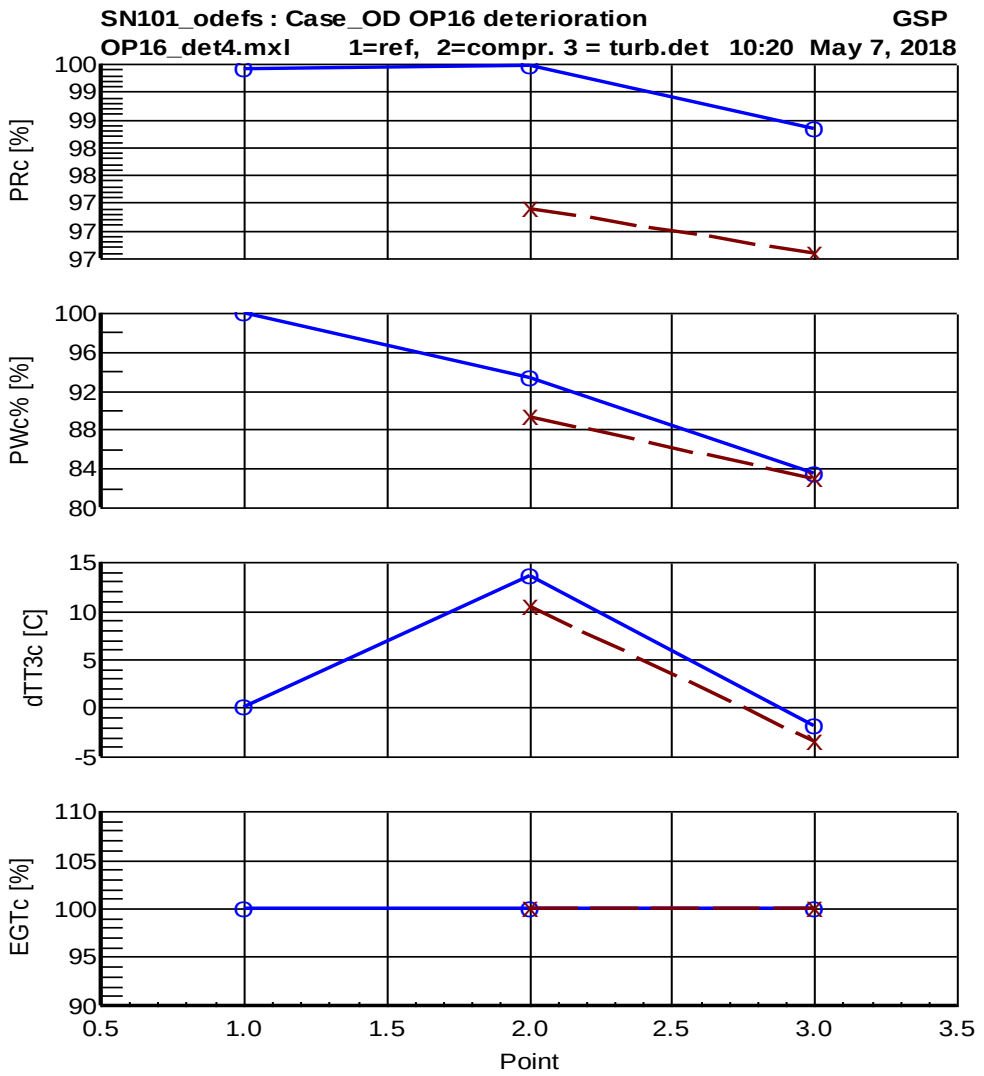
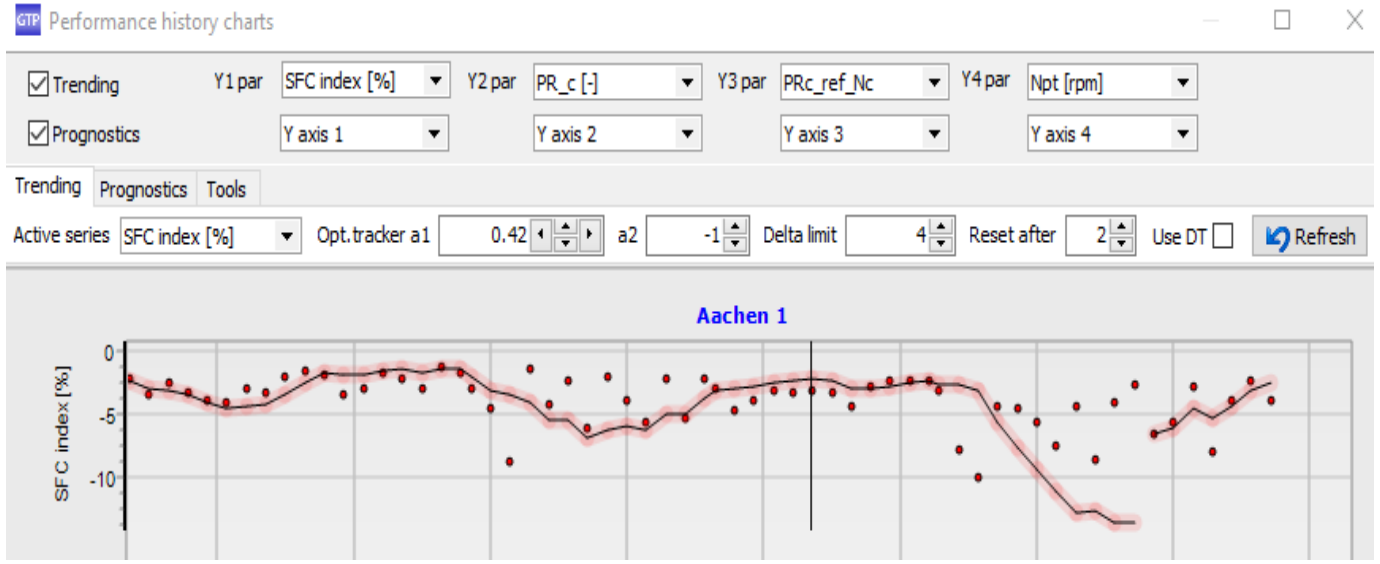
Simple ruleset generation example

- Isolation of compressor vs. turbine deterioration



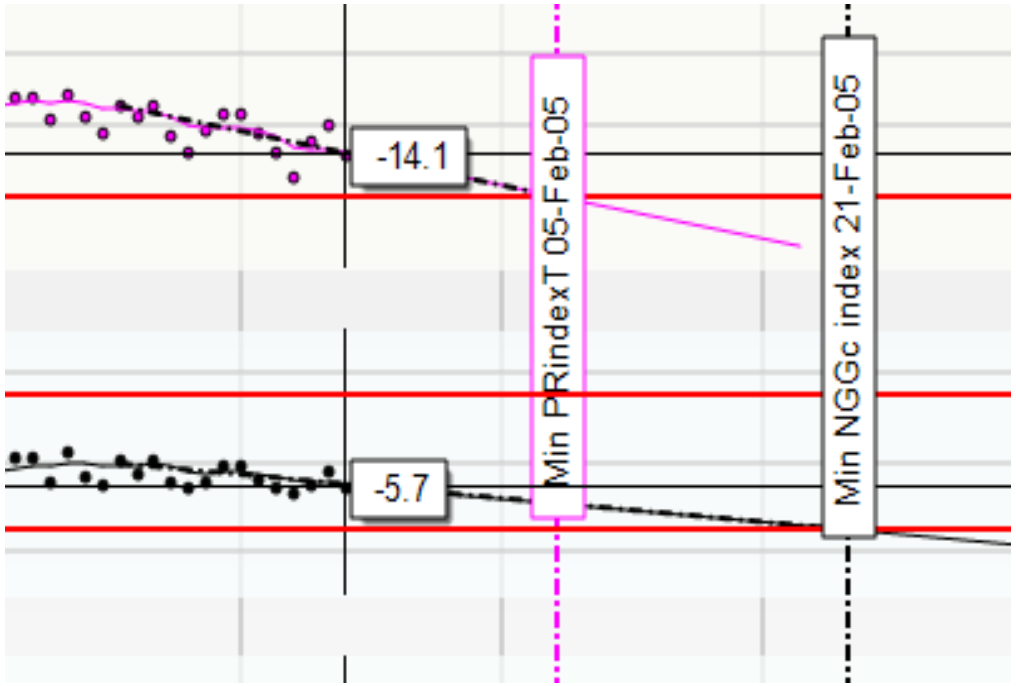
Trending

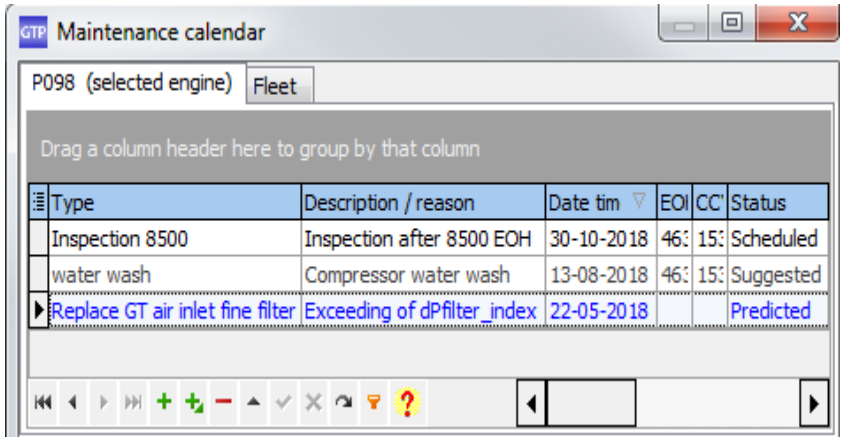
- Time series analysis methods
- Optimal tracker Kalman filter
  - *see 'Everything Works Wonderfully' by Mike Provost*
  - User configured (factors per parameter)
  - Automatic elimination of outliers
  - Automatic reset at discontinuities and known maintenance actions



Prognostics

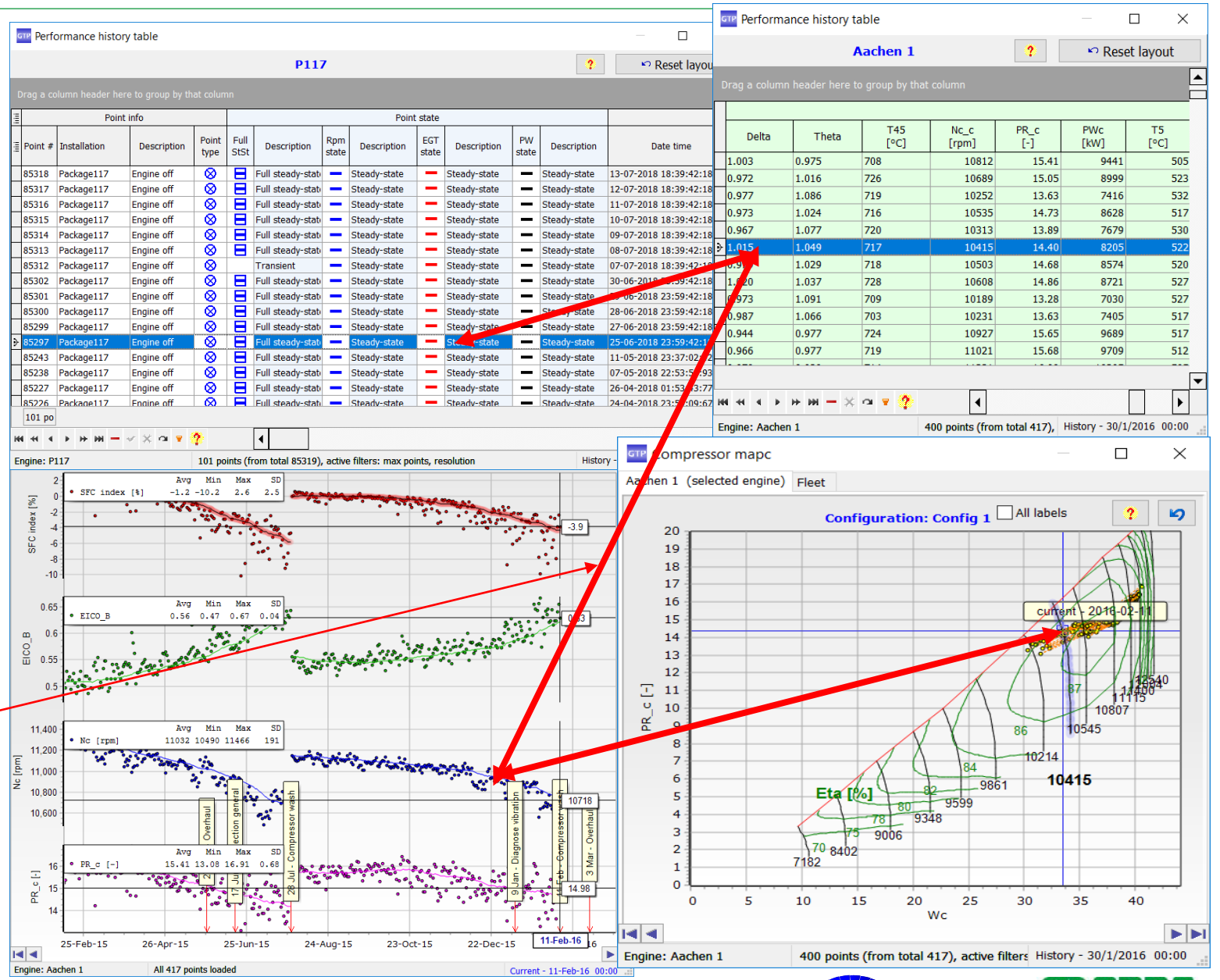
- Extrapolation of recent trends
  - If correlation coefficient > minimum
  - Perform ruleset diagnosis at intersection with parameter limit
  - Automatic suggestion of maintenance action (maintenance calendar)
  - Continuous real time analysis





Analysis tools

- Performance history tables
  - Point type & state
- Filtering data on point type, state, date and more
- End user configurable sets of analysis graphs
  - Time series, X-Y
  - Baselines, component performance maps
- Cursor synchronized in all tables and graphs on the selected operating point
- On-line / real time refresh adding new points



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Data processing

Asset data

- Measured data
  - DA system
  - Historian
  - Manual import source
- Selection of parameters
  - application specific
  - Performance
  - Vibration
  - oil system
  - status flags
- Required for
  - trending
  - diagnostics
  - prognostics

GTPtracker Import Service

- Continuous import
  - On-line
  - Real-time
- Filtering data
  - Only useful time series data
  - User specified filter
- Data reduction ratio
  - Operation type
- Assignment of
  - Point type
  - Point states

GTPtracker client

- Analyze subsets of data
  - Diagnose
  - Predict
- Select subsets
  - Query Filter
- Filter on
  - Time, EOH, cycles
  - Point type
  - Point state
  - Resolution

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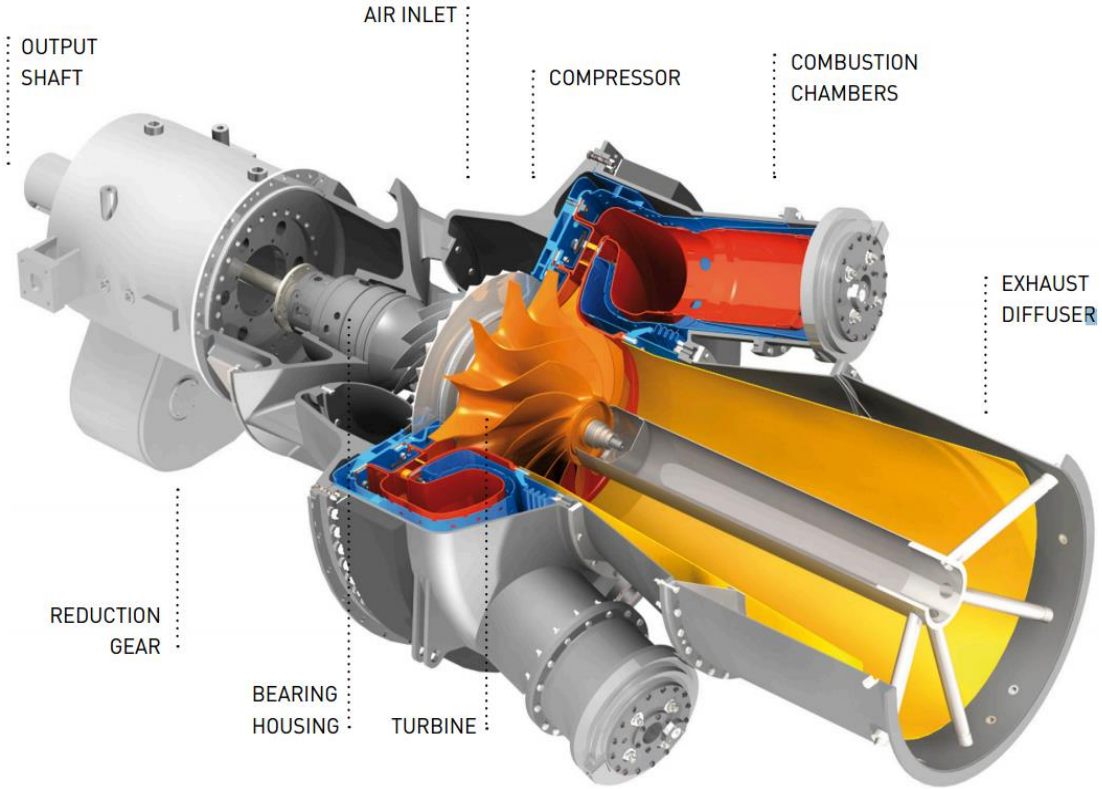
The OP16 gas turbine

- Power generation gas turbine, 1.85 MW
- Compact, single-shaft, all-radial rotor
- Single stage centrifugal compressor, 6.7:1
- Four combustor cans mounted in reverse-flow direction



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Application of GTPtracker to OP16 gas turbine fleet

- Corrected parameters are calculated in real-time by the surrogate OP16 performance model embedded in GTPtracker.
  - EGT, Power, PR, Thermal efficiency
- Performance indices, derived from the corrected parameters, are continuously trended, along with other measured/calculated parameters.
- Based on detailed off-line OP16 performance model and OPRA's experience, rule sets are developed relating deviation patterns to faults.
- Usually, the base load data is filtered out to accurately trend and analyze the measured and calculated parameters.

- Case studies on available field performance history

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Case study 1: Detecting faulty fuel flow measurement

- Constant power and EGT index trends and a deviation in thermal efficiency index characterize a faulty fuel flow measurement.

- Specify corresponding pattern in a ruleset ：

Configuration of engine type: OP16

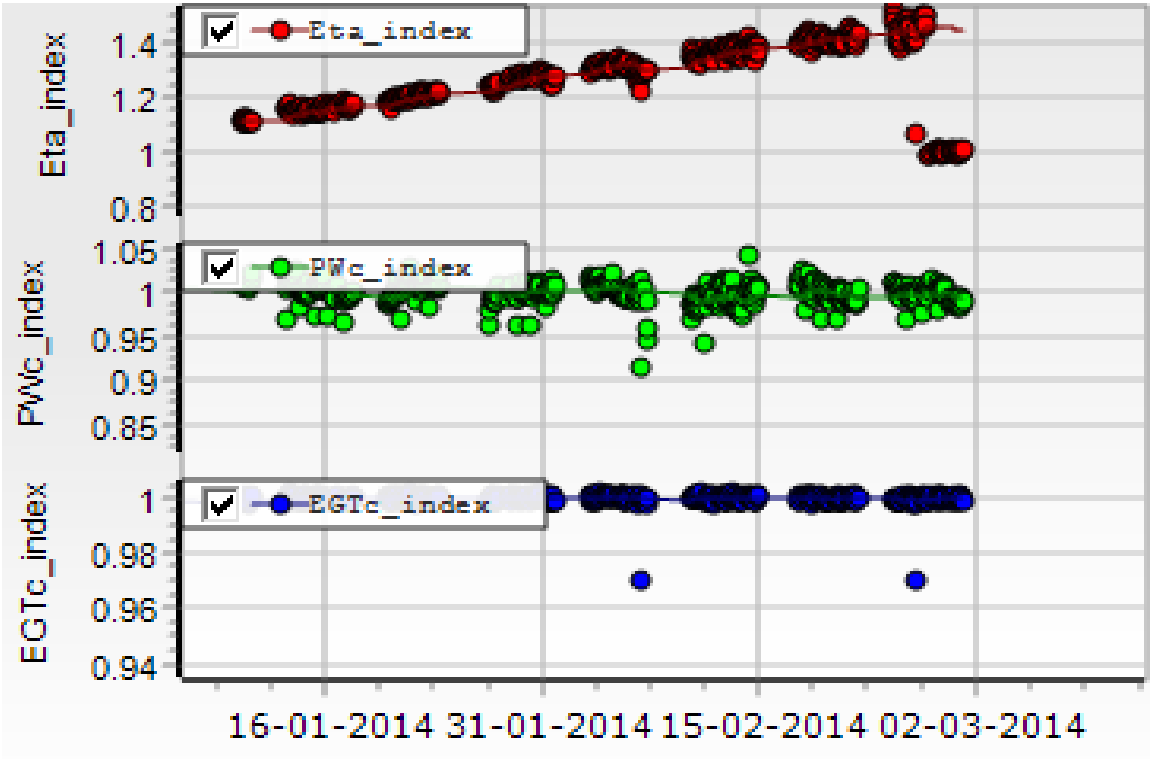
Constants | Baselines / maps | Rulesets

Name	Description	Component	Maintenance type
Fuel flow sensor	Fuel flow sensor drift		Fuel flow sensor reset

Fieldname	Display label	Unit	Below	Above
PWc_index [-]	PWc_index	[-]	1.050	0.950
EGTc_index [-]	EGTc_index	[-]	1.005	0.995
Eta_index [-]	Eta_index	[-]	0.800	1.200

Case study 1: Detecting faulty fuel flow measurement

- Trend of performance indices: Thermal efficiency, Power, Exhaust gas temperature

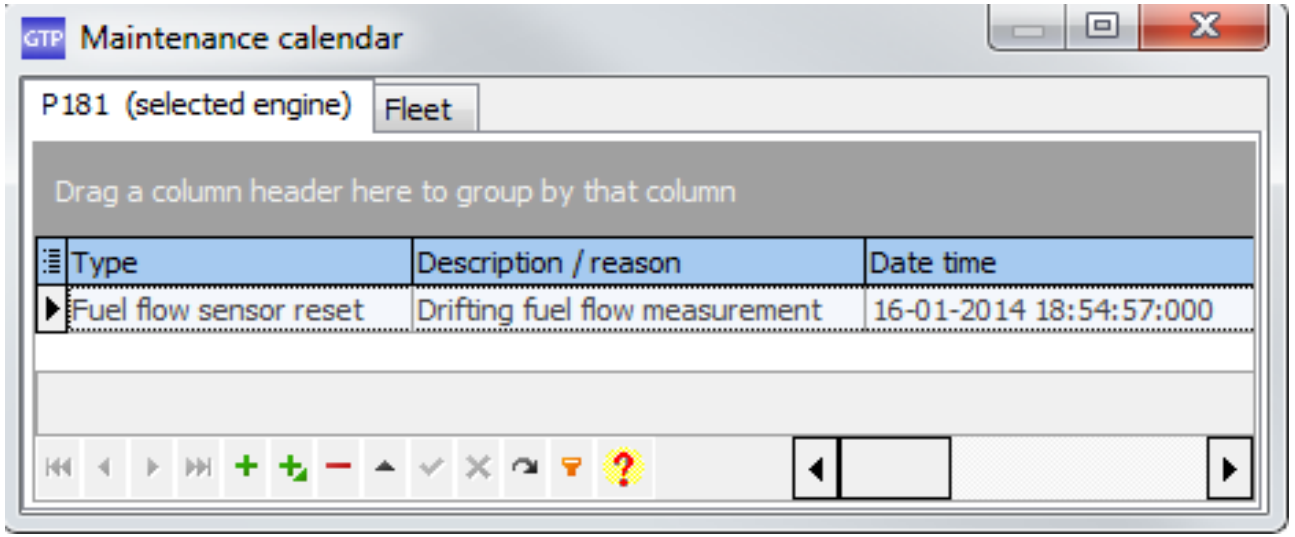


- Ruleset match detected at 16-1-2014
- Repaired 1-3-2014

Case study 1: Detecting faulty fuel flow measurement

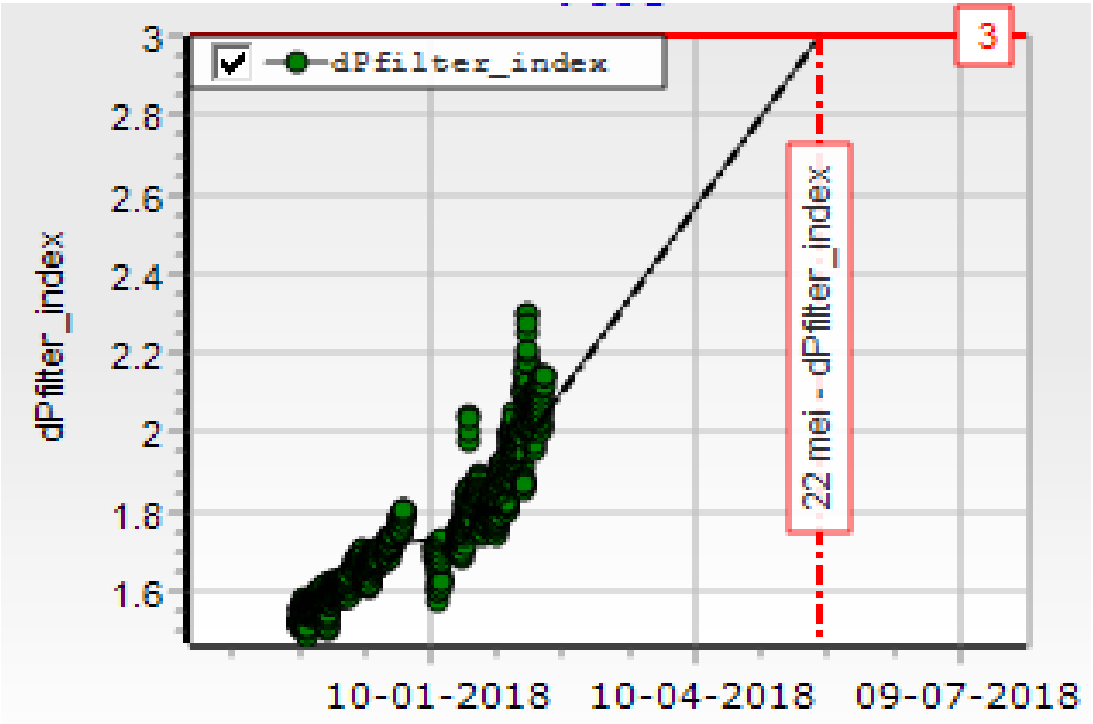
- Upon detection, the maintenance calendar is automatically updated, adding the maintenance action of sensor replacement.

- Maintenance decision
  - Automatic initial status
  - ↓
  - To be confirmed/changed by operator
  - ↓
  - Scheduled maintenance



Case study 2: Predicting filter clogging

- Rate of increase of differential pressure across a filter determines the rate of clogging.



- Simple 1 parameter limit on level and/or rate of change

Conclusions

- An innovative online condition monitoring system has been developed for the OPRA OP16 gas turbine using the GTPtracker monitoring and tracking tool.
- The connection of the condition monitoring process with accurate cycle models capable of simulating deterioration via a surrogate models and rulesets for diagnostics offers an optimal compromise between complexity and functionality.
- The GTPtracker environment and configuration user interface provides a powerful tool for diagnostics engineers to optimize maintenance (minimize costs), reliability, availability and safety for a gas turbine fleet.
- A customized version of the GTPtracker tool has recently been deployed for the OP16 engine.
- GTPtracker can rapidly be deployed and coupled to gas turbine data acquisition systems

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Questions

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