INDUSTRIAL GAS TURBINE HEALTH and PERFROMANCE ASSESSMENT with FIELD DATA

I. Roumeliotis - N. Aretakis - A. Alexiou

LABORATORY of THERMAL TURBOMACHINES
National Technical University of Athens

Contents

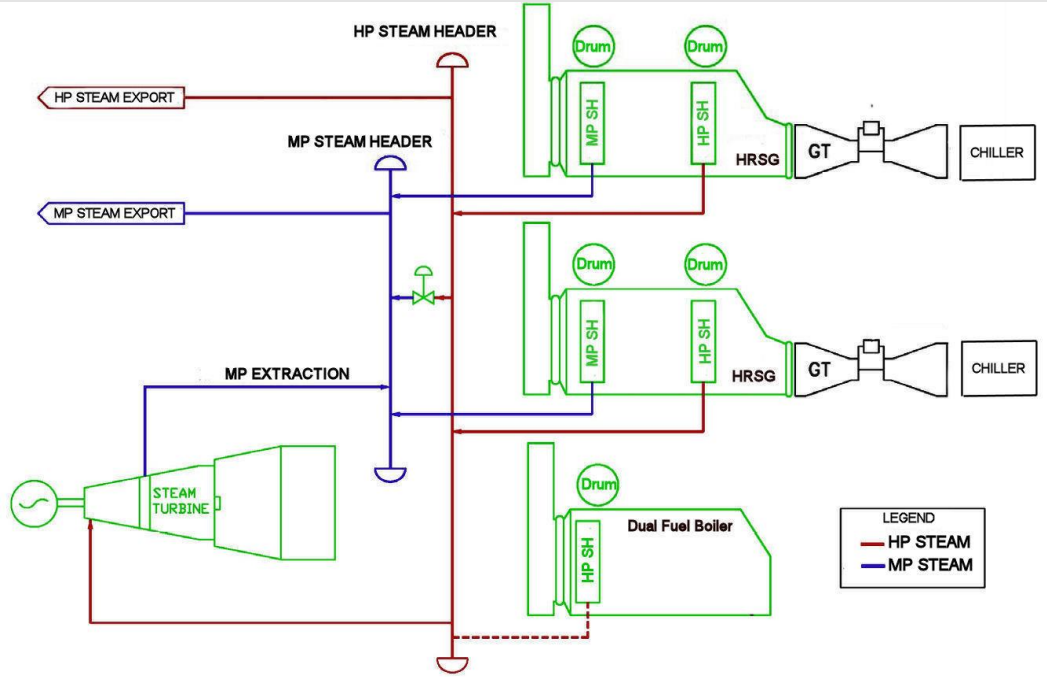
- **Introduction**
  - Scope of the paper
  - Test Case description
- **Performance Models**
  - The PROOSIS Platform
  - GT Model Adaptation Process
  - Integrated Models
- **GTs Health Assessment**
  - Performance Shift
  - Performance Deterioration
- **Economic Assessment**
  - Washing Routine Assessment
  - Washing Routine Optimization
- **Summary-Conclusions**

Contents

Scope of the paper

- Advanced Diagnostic Methods application in Combined Cycle Gas Turbine Power Plants (CCGT) is sparse
- CCGT operating mode was predominantly base load. Now days it shifts to load following operation, thus making methods capable for part load health assessment necessary
- Health and Performance Monitoring can help in controlling Recoverable Deterioration such as Fouling, benefiting plant profitability
- This work presents elements of an on-line integrated system developed for health and performance assessment of a Gas Turbine CHP power plant
- For demonstrating the information that can be obtained, results derived by a procedure where a GPA (adaptive modeling) method is coupled with a water/steam cycle model and an economic module are presented
- The results are used for the health/performance of the plant GTs and for the power plant performance and economic assessment by the operator

Test Case Description

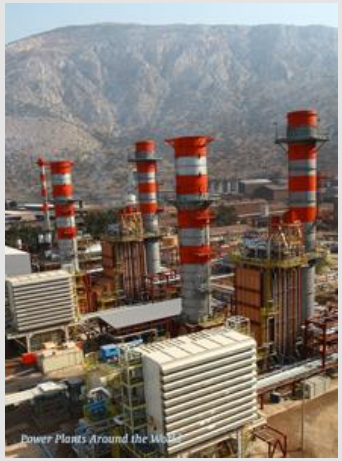


General Information	
Type of Plant	Combined Heat and Power (CHP)
Main Fuel	Natural Gas
Back up Fuel (Dual Fuel Boiler only)	LFO

Performance Data (net, @ 29 to 15 °C with chillers, sea water cooled)	
Configuration	2X2X1
GT Type	2 x Heavy Duty, DLN
HRSG Type	2x Horizontal Natural Recirculation
ST Type	1xExtraction Condensing type
Frequency	50Hz

Guaranteed Cases	No.1	No.2
Output (MW_{el})	321,2	320,8
Thermal Output*, (MW_{th})	216,17	258,28
Cogeneration Efficiency* (%)	69,96	73,31
HP steam (t/h)	200	200
MP steam (t/h)	74,4	128,4
NOx Emissions, vppmd (corrected @ 15% O2)	<25	<25

(*) according to CHP Directive 2004/8/EC



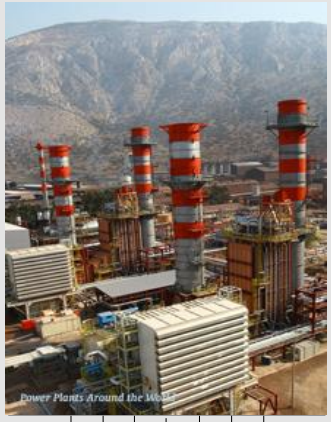
Usually operates in 1x1x1 configuration

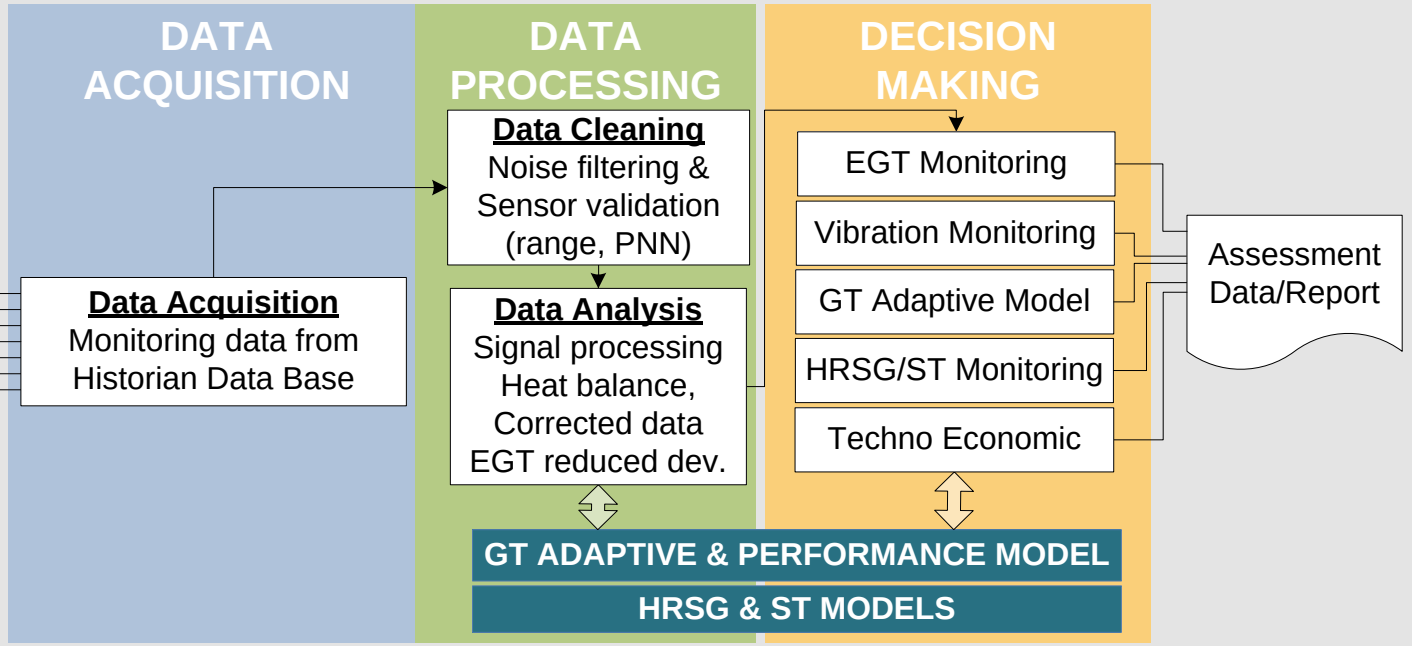
Process Steam Prioritized

GTs: IHB for DLN combustor

GTs: Chillers operation

Health and Performance Assessment

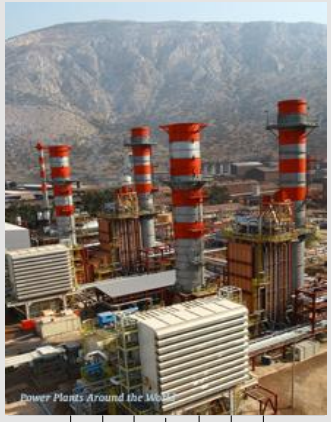


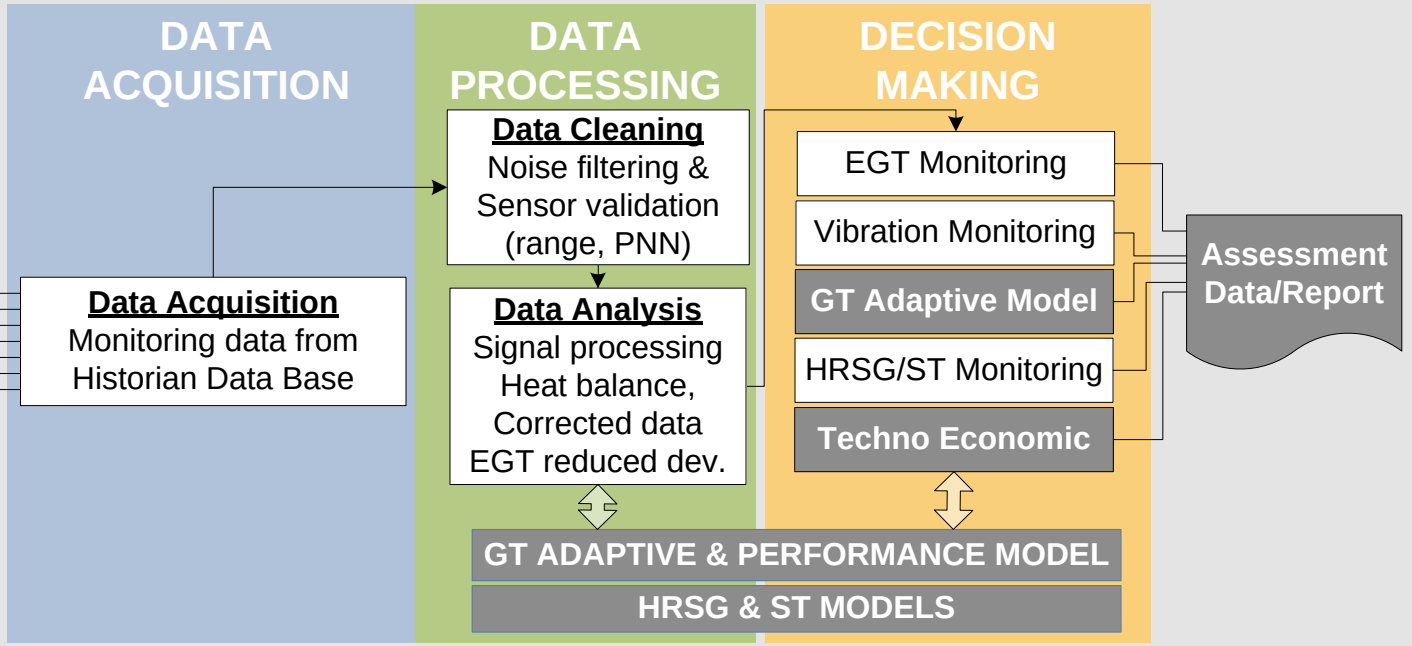


A s/w system developed by LTT/NTUA has been installed on-site for the on-line power plant performance and GTs health assessment

Several methods developed and validated by LTT/NTUA are integrated to the system as modules

Health and Performance Assessment





A s/w system developed by LTT/NTUA has been installed on-site for the on-line power plant performance and GTs health assessment

Several methods developed and validated by LTT/NTUA are integrated to the system as modules

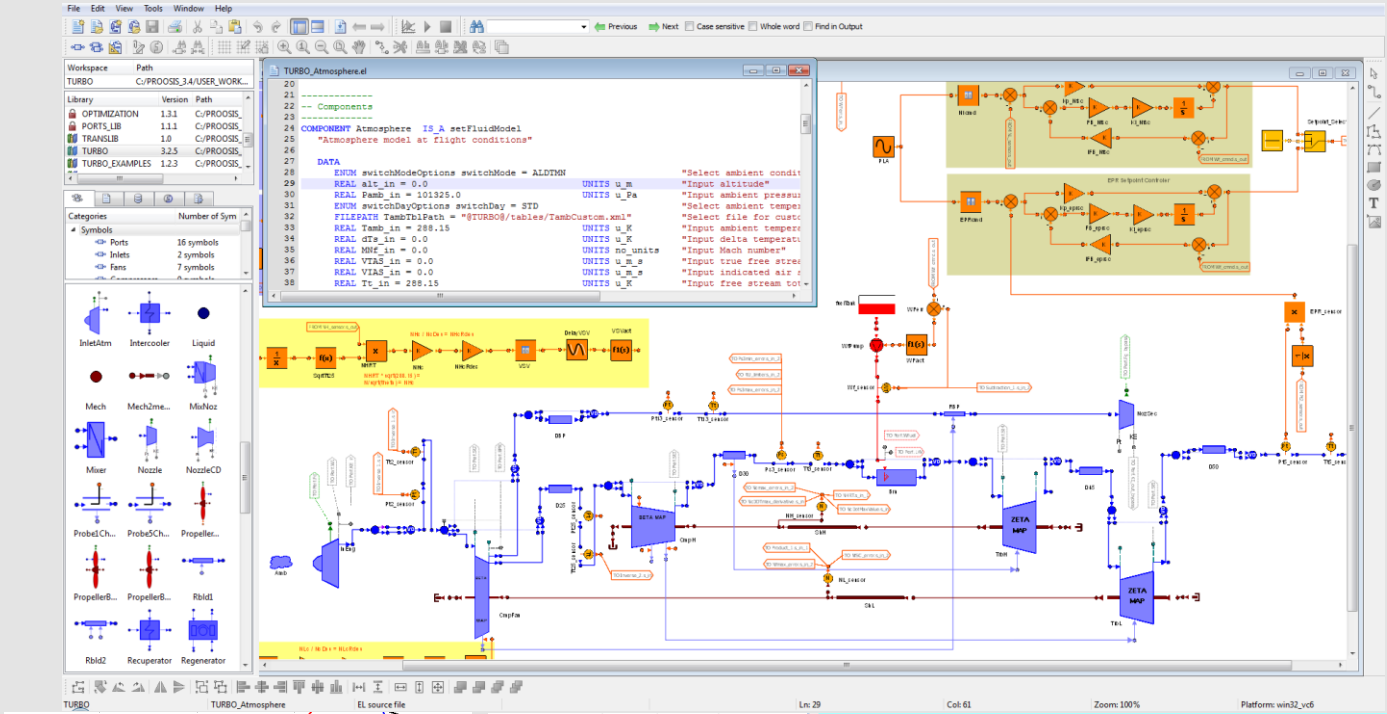
Contents

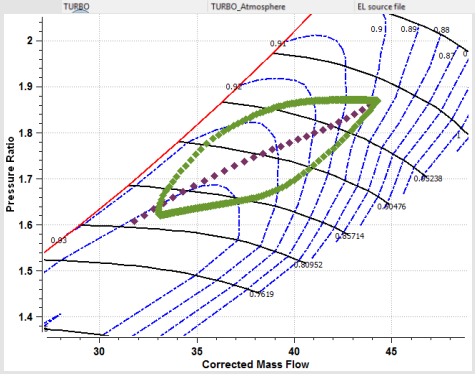
- ❑ **Introduction**
  - Scope of the paper
  - Test case description
- ➢ **Performance Models**
  - The PROOSIS platform
  - GT Model adaptation process
  - Integrated Models
- ❑ **GTs Health Assessment**
  - Performance Shift
  - Performance Deterioration
- ❑ **Economic Assessment**
  - Washing Routine Assessment
  - Washing Routine Optimization
- ❑ **Summary-Conclusions**

Engine Adaptive Model

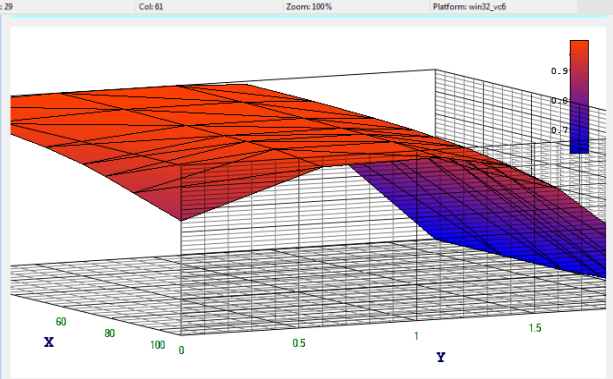
The PROOSIS platform

- Object-Oriented
- Steady State
- Transient
- Mixed-Fidelity
- Multi-Disciplinary
- Distributed
- Multi-point Design
- Off-Design
- Test Analysis
- Diagnostics
- Sensitivity
- Optimisation
- Deck Generation
- Connection with Excel & Matlab
- Integration of FORTRAN, C, C++



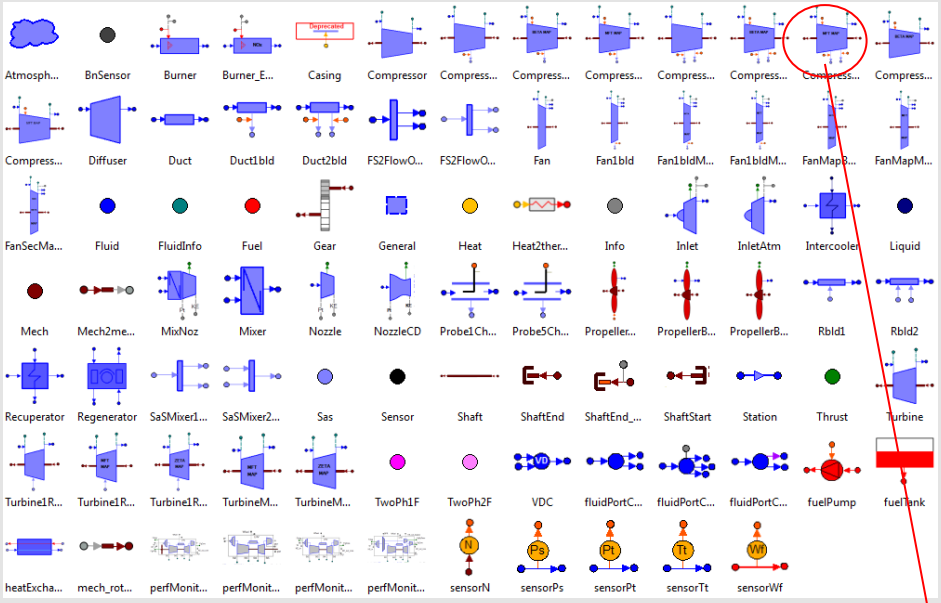


Name	Alias	Station	1
#Calculation id	--	--	steady-1
#Status	--	--	STEADY_OK
#ESI	--	--	0
FN (N)	--	--	63008.679
WF (kg/s)	--	--	1.70123433
Amb.alt (m)	alt	--	11000
Amb.dTamb (K)	dTamb	--	0
CmpH.BETA (-)	--	--	0.5
NH (rpm)	--	--	9607.23139
TURBO.MNf (-)	XM	--	0.8
TrbH.ZETA (-)	--	--	0.516350527
W1 (kg/s)	--	--	100
SFC (g/(kN·s))	--	--	27
Tt41 (K)	--	--	1301.13095



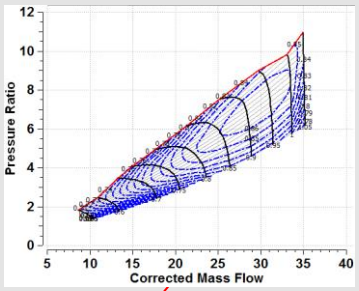
The PROOSIS platform

TURBO library of gas turbine components

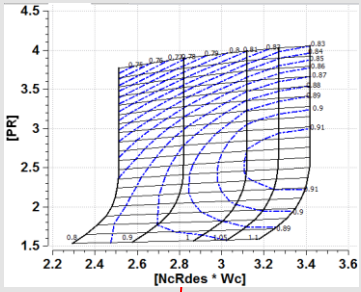


- **Industry-accepted** performance modelling techniques
- Respects **international standards** in nomenclature, interface & Object Oriented programming

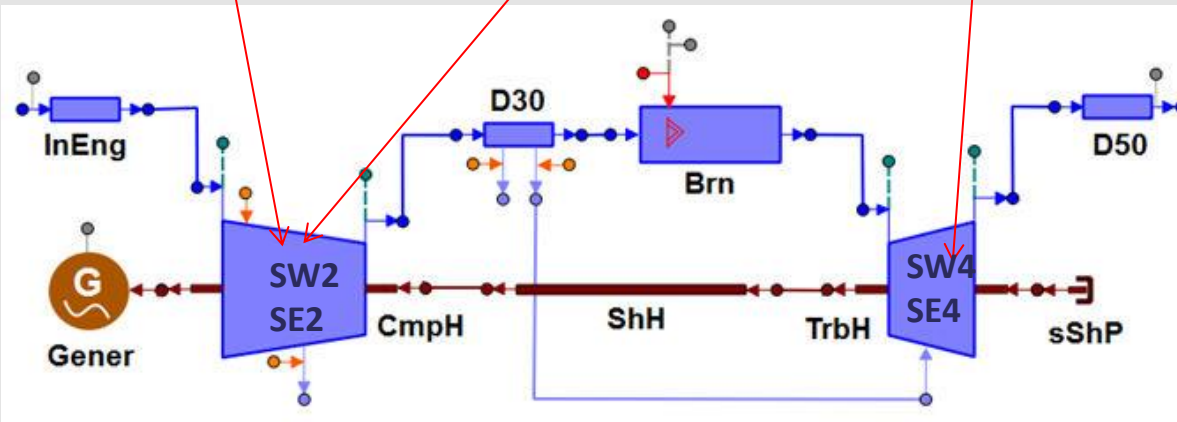
Compressor map



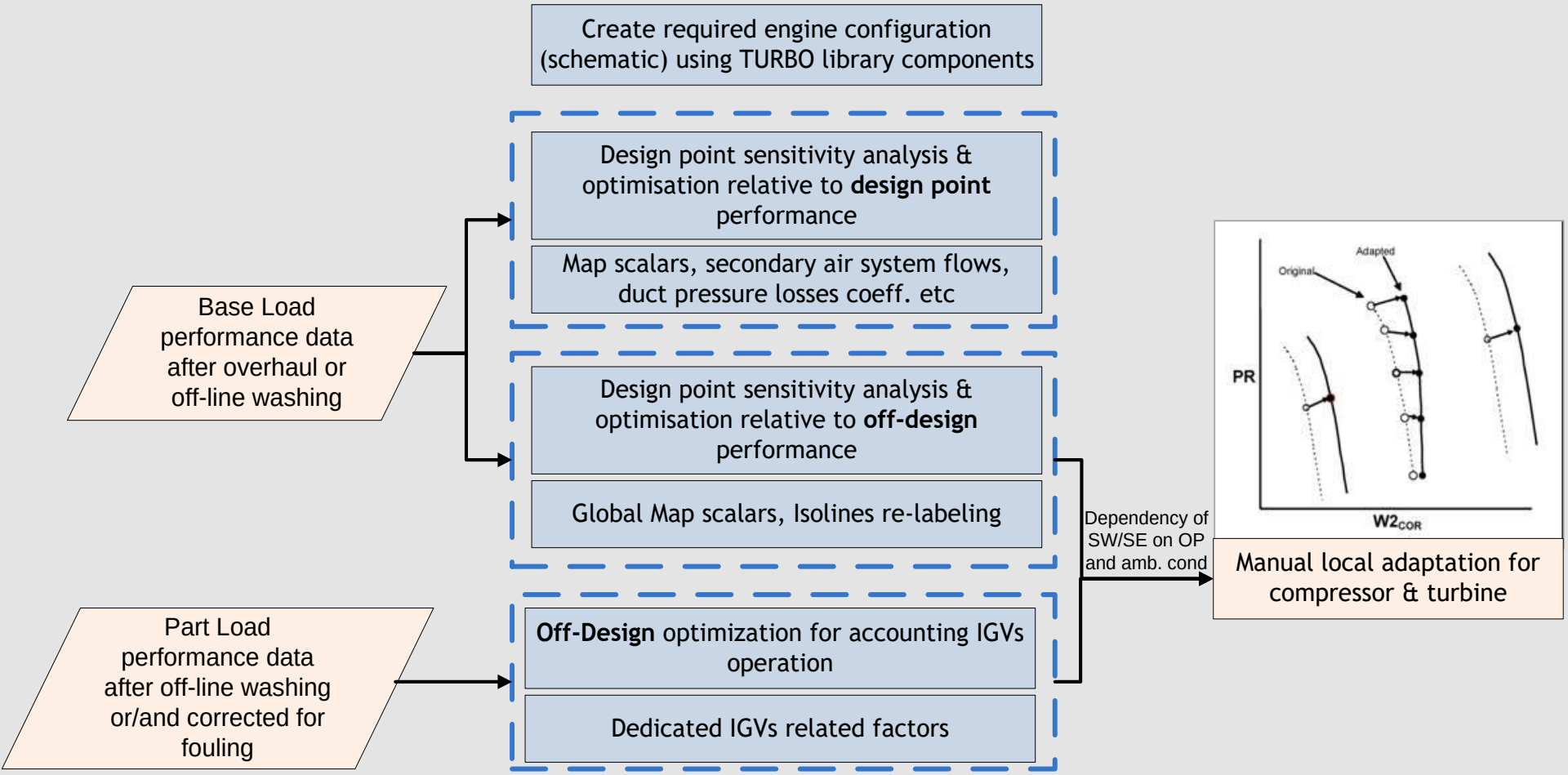
Turbine map



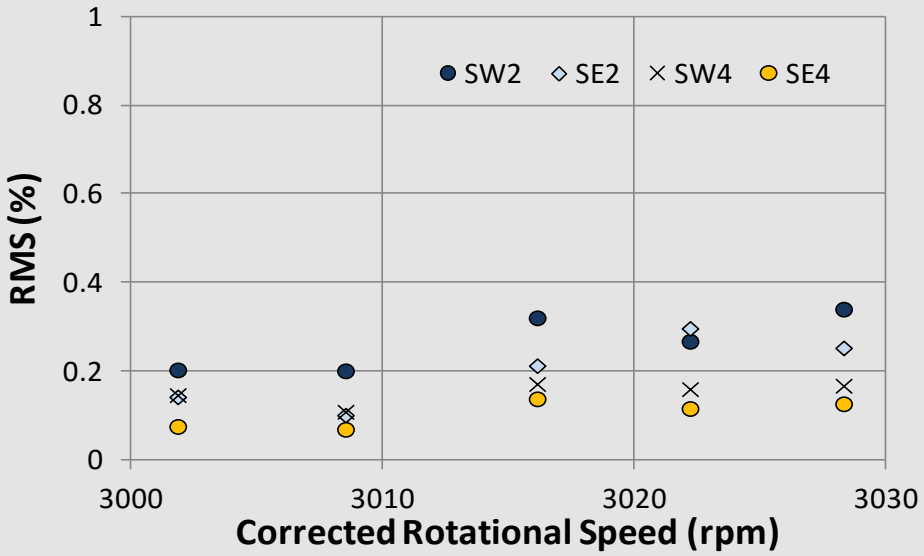
Component	Health Parameter	Symbol
Compressor	Flow	SW2
	Efficiency	SE2
Turbine	Flow	SW4
	Efficiency	SE4

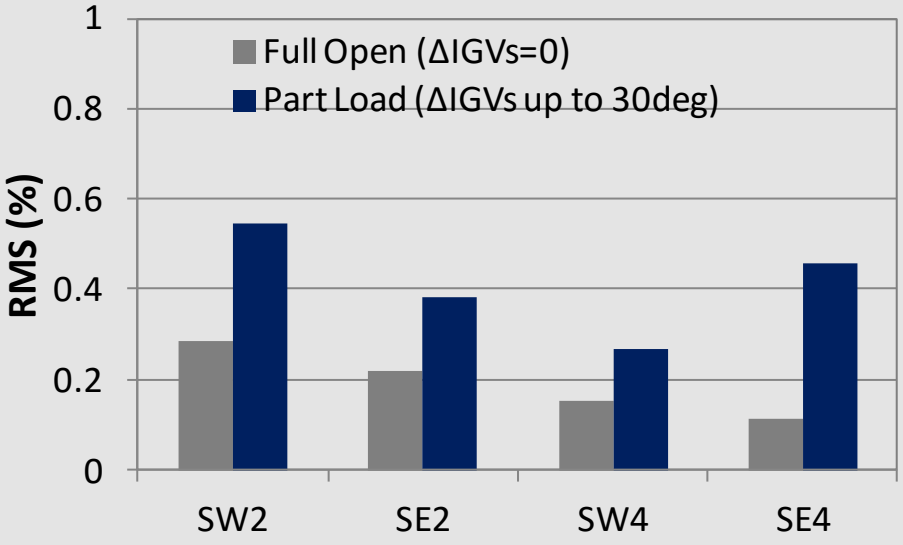


Engine Adaptive Model



Engine Adaptive Model





✓Predictions lie within **±0.5%** for both Base and Part Load

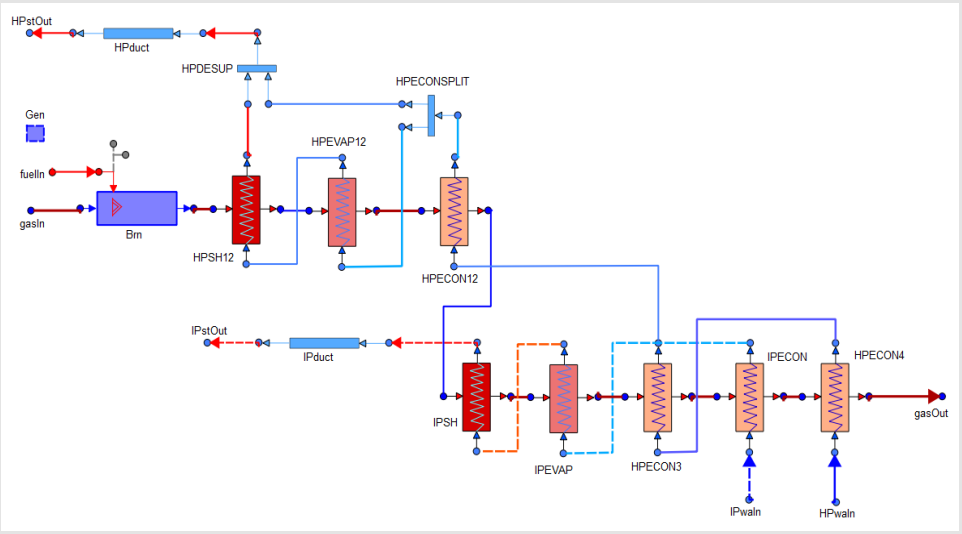
✓**No dependency** on operating point and ambient conditions

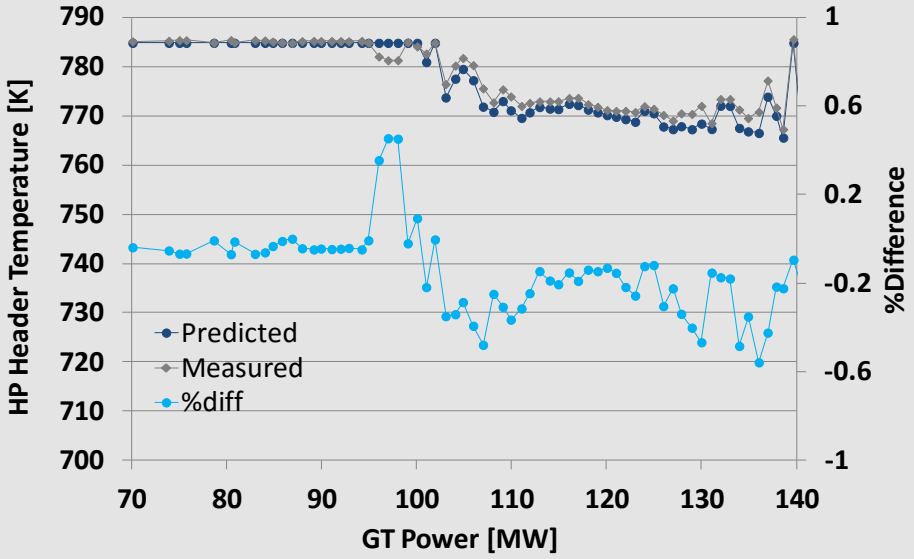
Interesting Notes

➢NG Fuel properties (LHV, RD) should be measured especially for the case of multiple NG entries to the national system

➢Threshold selected at historian (minimum deviation for changing the stored value) should be evaluated and refined if needed

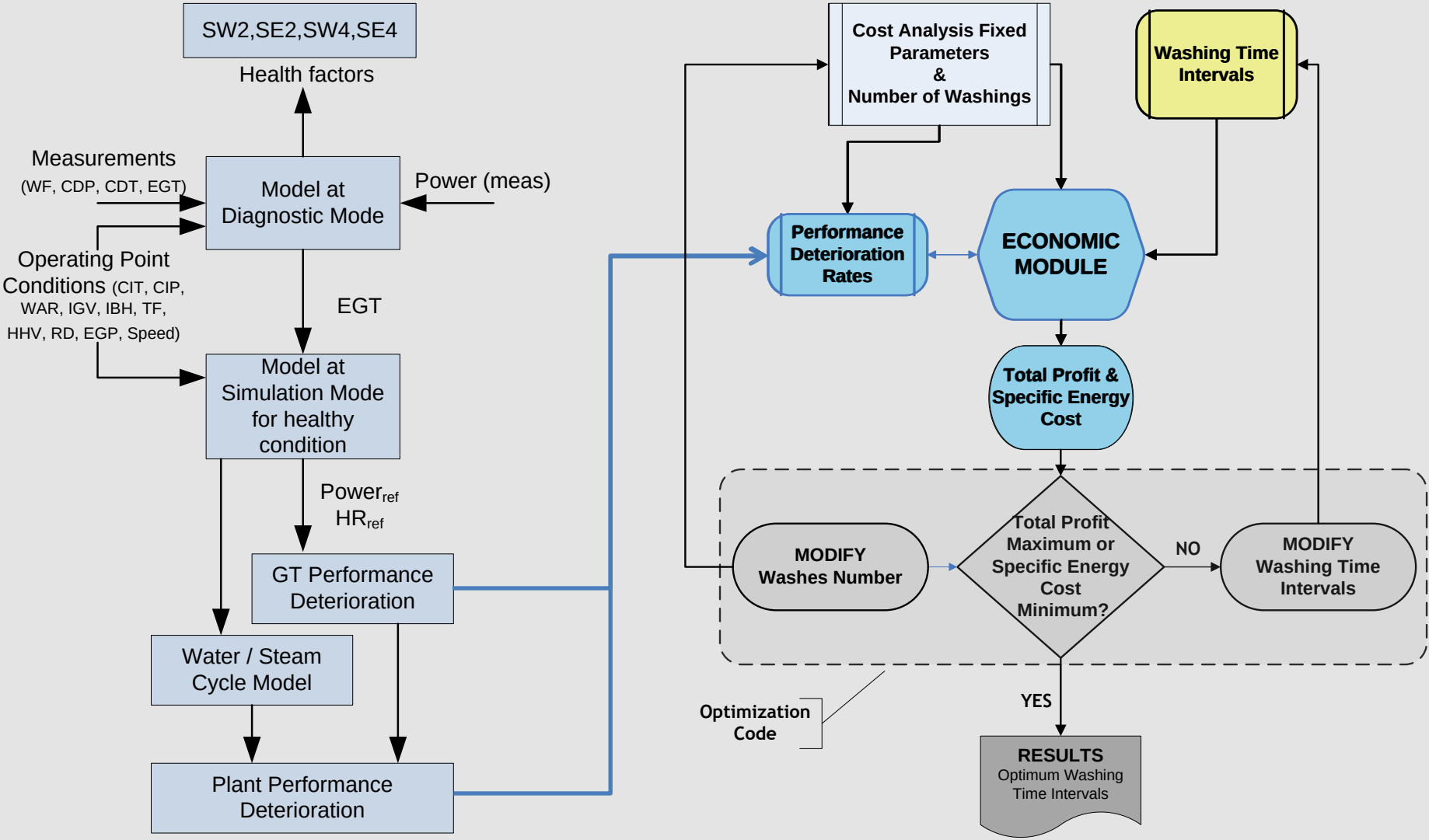
Water/Steam Cycle Model





- The HRSG modeling is based on NTU-effectiveness method
- The steam turbine is modeled utilizing Stodola law and efficiency correction for part load
- HRSG and steam turbine models were calibrated versus operation data
- ✓Predictions lie within **±1%** for both base and part load and for all available pressure & temperature measurements

Integrated Procedure

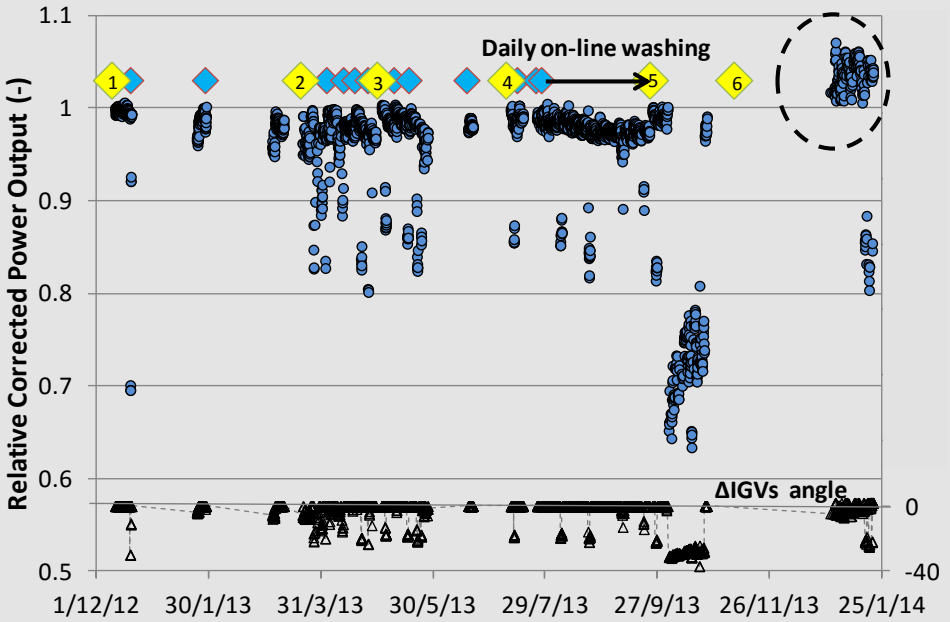


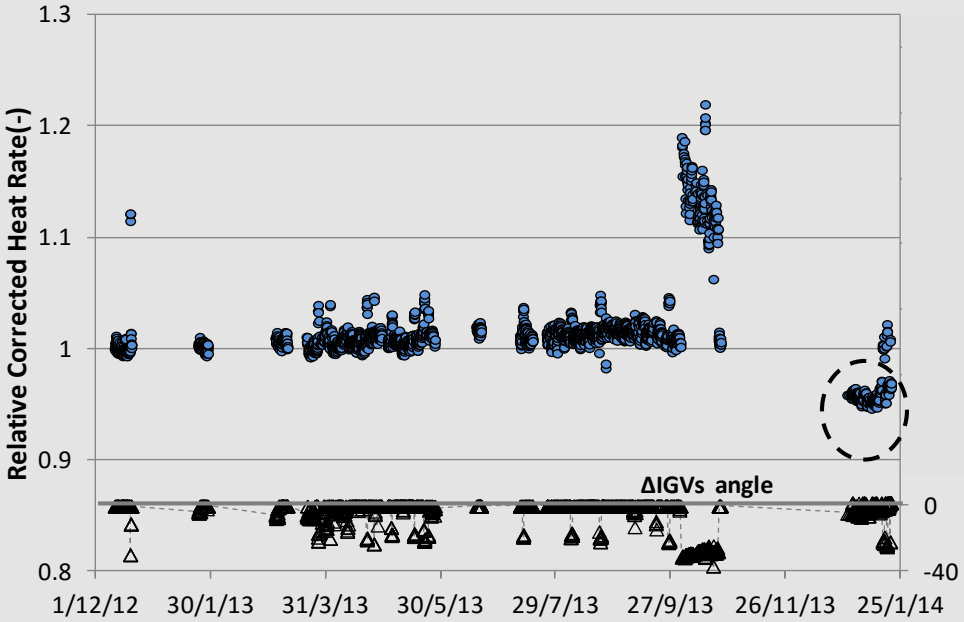
Contents

- ❑ **Introduction**
  - Scope of the paper
  - Test case description
- ❑ **Performance Models**
  - The PROOSIS platform
  - GT Model adaptation process
  - Integrated Models
- ➢ **GTs Health Assessment**
  - Performance Shift
  - Performance Deterioration
- ❑ **Economic Assessment**
  - Washing Routine Assessment
  - Washing Routine Optimization
- ❑ **Summary-Conclusions**

GTs Health Assessment

Relative Corrected Performance (~ 14 months)

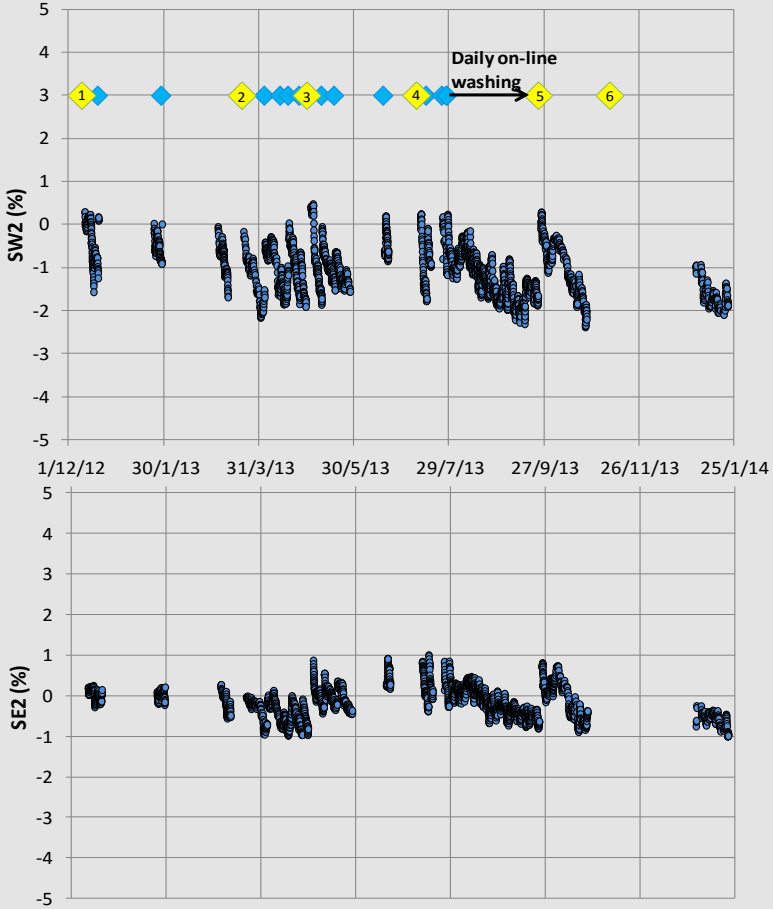


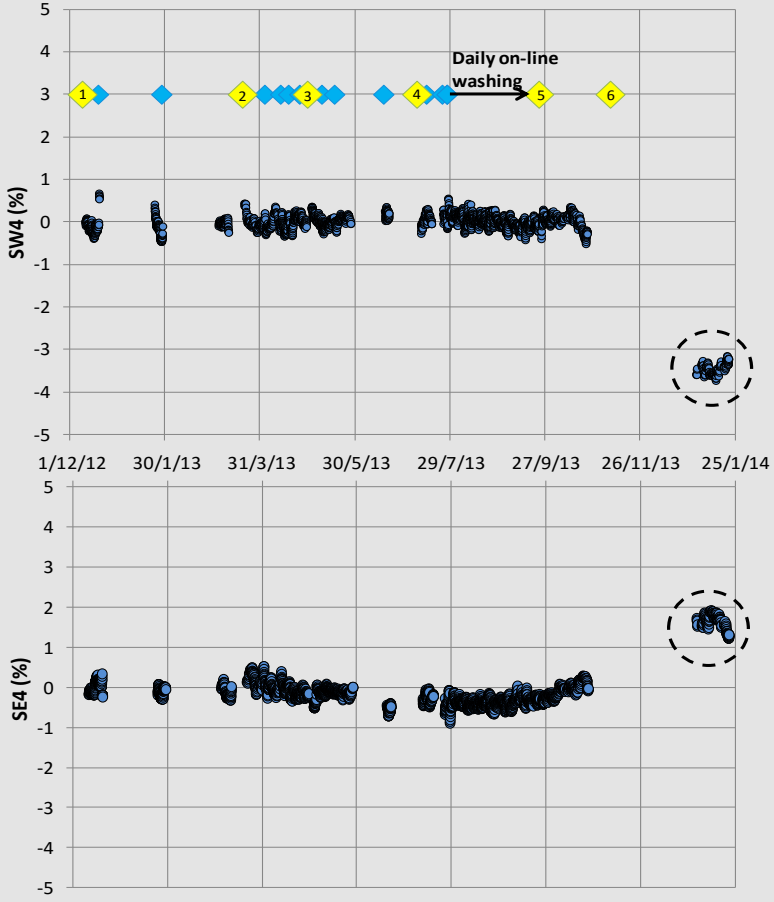


- This data set was used by the operator as blind test for the system
- The operator applied sporadically off-line and on-line washes
- Base load operation is dominant but part load operation periods exist
- A distinct non-recoverable performance shift occurred at the end of the period observed from full open IGVs data (ΔIGVs=0)

GTs Health Assessment-Shift

GT Health Indices

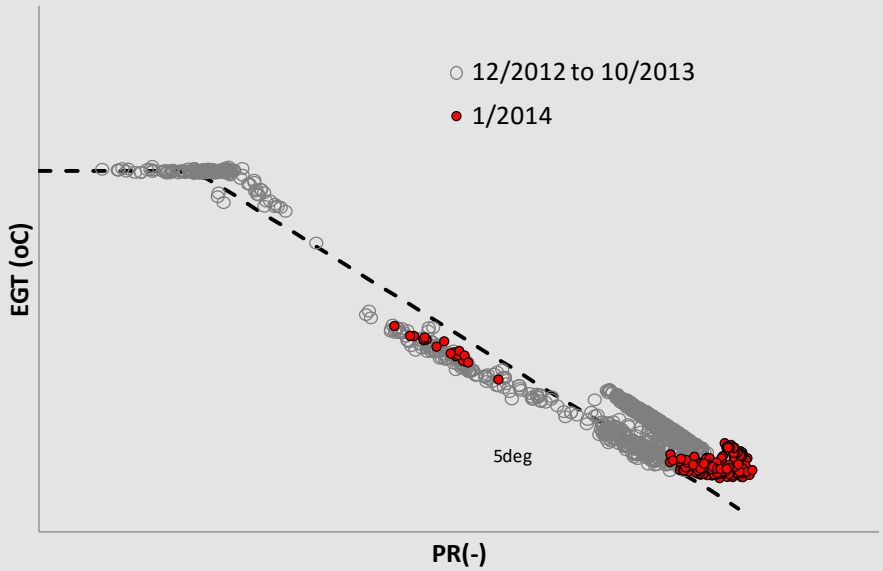


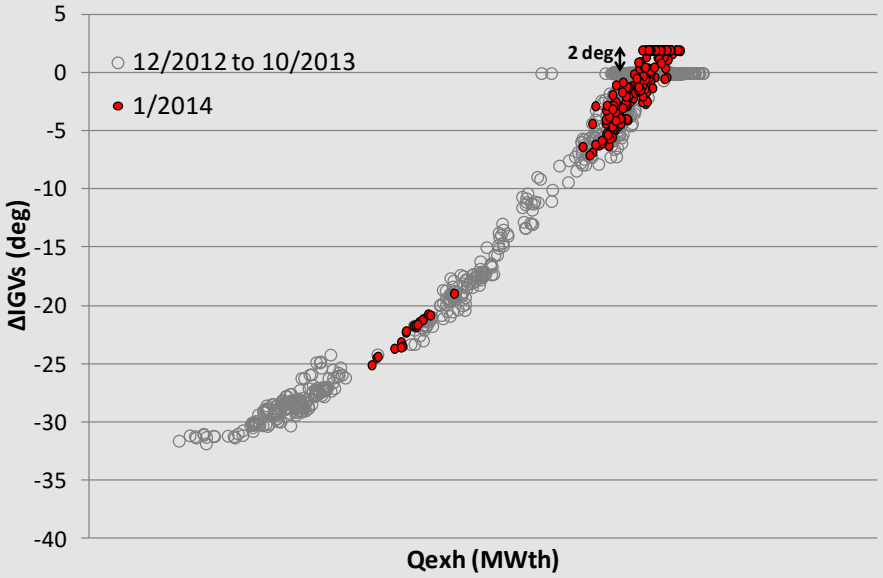


- **Compressor:** Recoverable performance deterioration & marginal change (SW=-1%)
- **Turbine:** Significant reduce of effective throat area and increase of efficiency
- **Verdict:** Permanent positive change on Hot Section: overhaul or engine up-rate

GTs Health Assessment-Shift

Basic Control Parameters

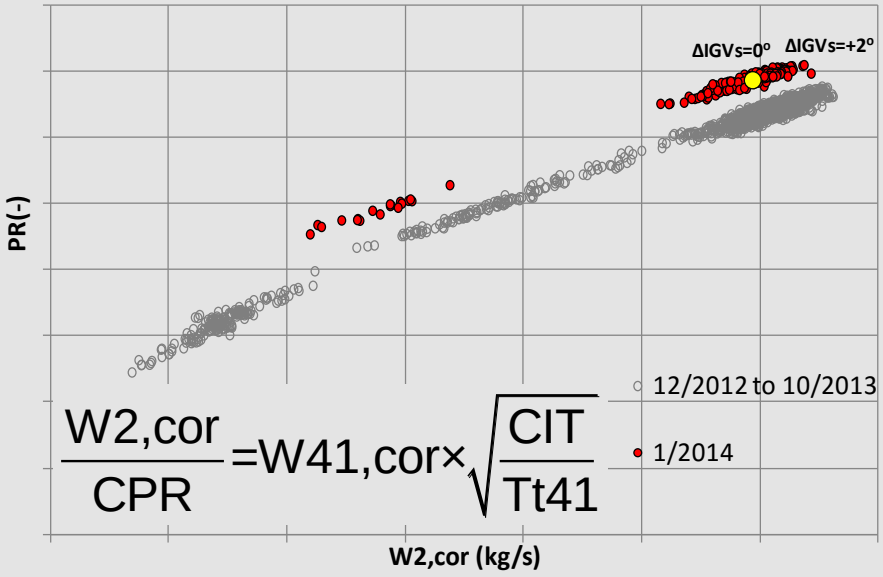


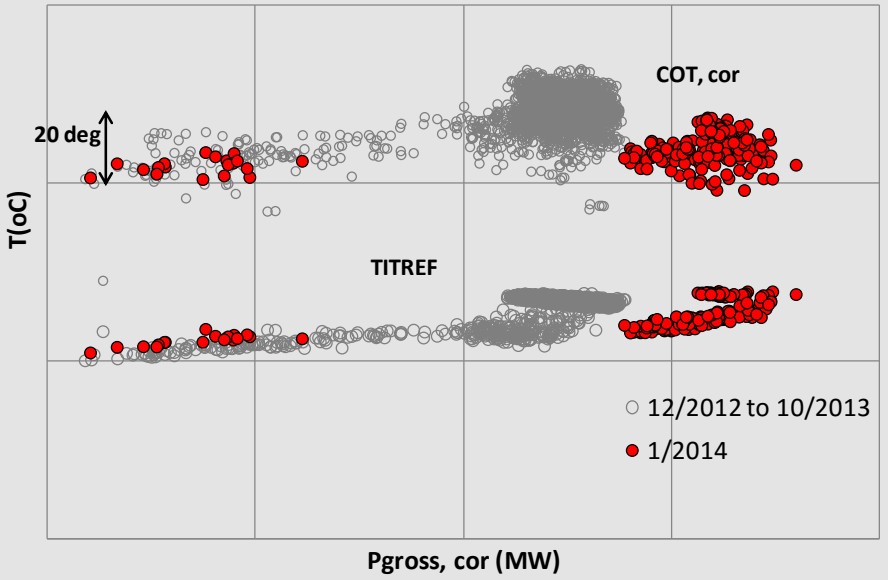


- Cross-checked via heat balance calculations and measurements analysis
- No significant change on basic control logic (e.g. PR vs EGT & Qexh vs ΔIGVs)
- Operating line change consistent with throat area decrease (PR increase)
- ✓ The Diagnostic Verdict was **confirmed** by the operator (engine up-rating)

GTs Health Assessment-Shift

Operating Parameters

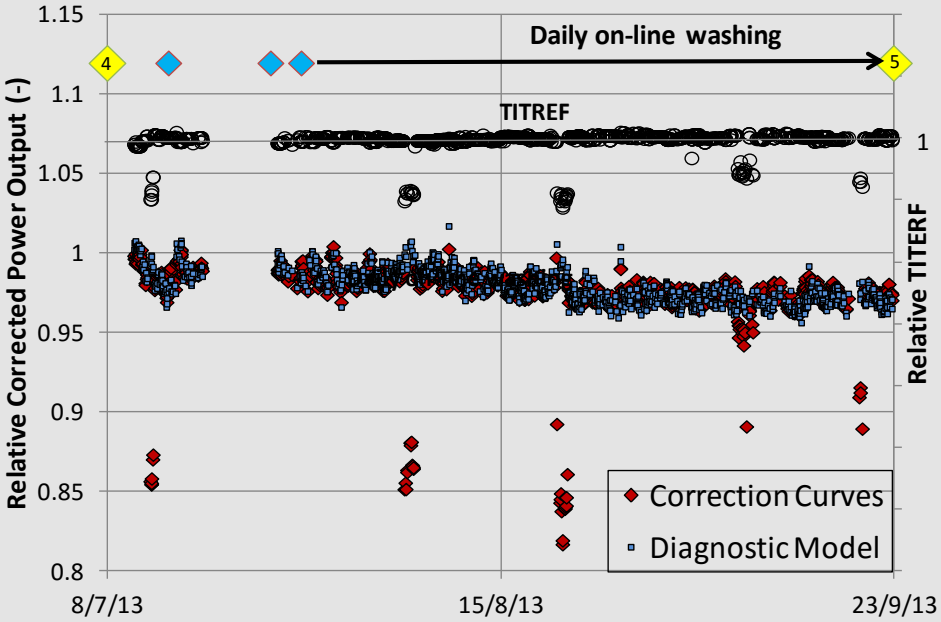


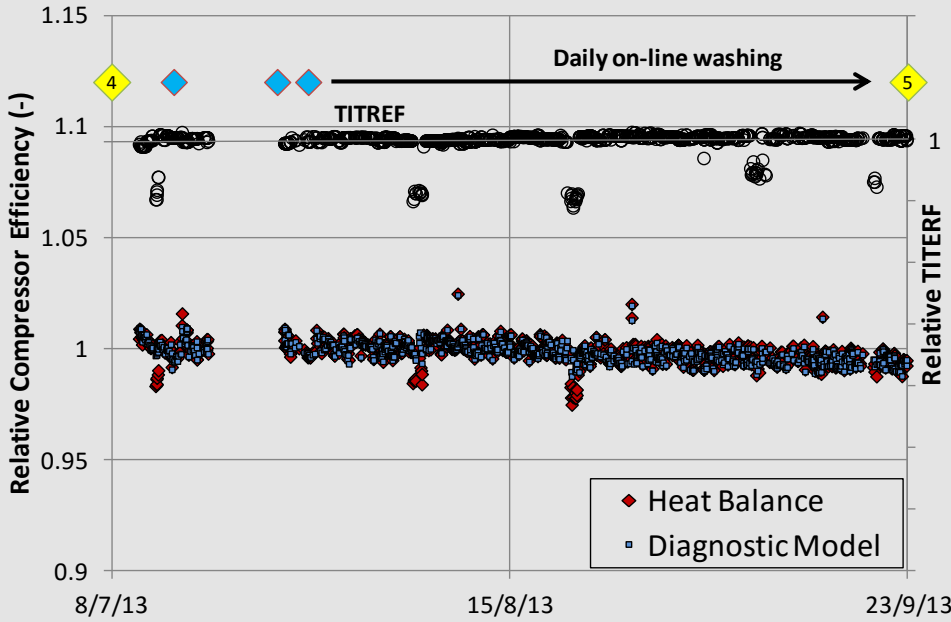


- Cross-checked via Heat Balance Results and Measurements Analysis
- No significant change on basic control logic (PR vs EGT & Qexh vs ΔIGVs)
- Operating line change consistent with throat area decrease (PR increase)
- ✓ The Diagnostic Verdict was **confirmed** by the operator (engine up-rating)

GTs Health Assessment-Fouling

Fouling Monitoring

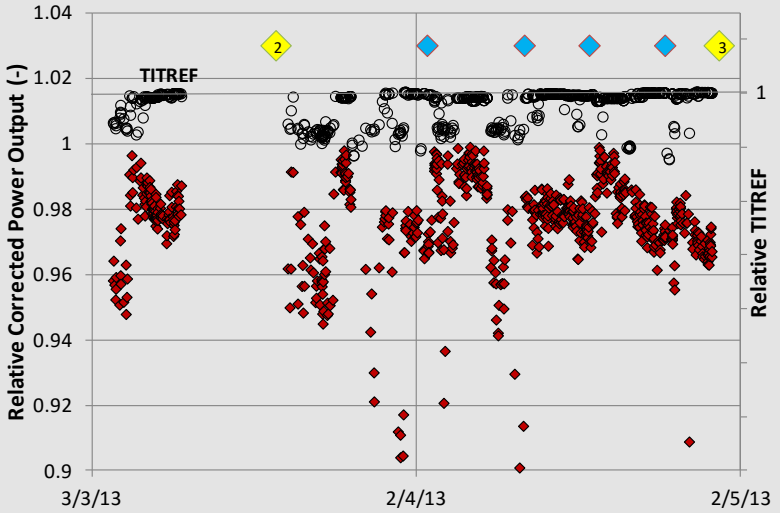


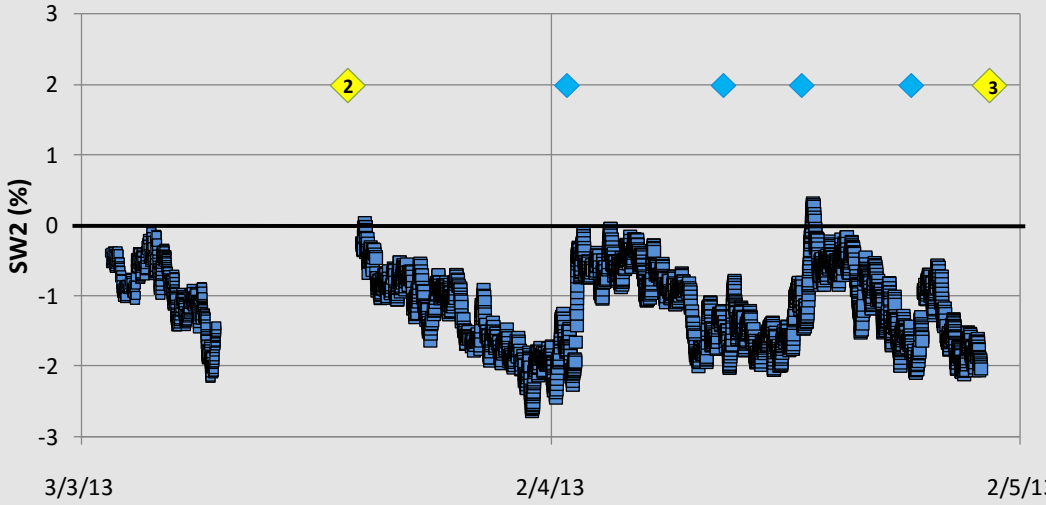


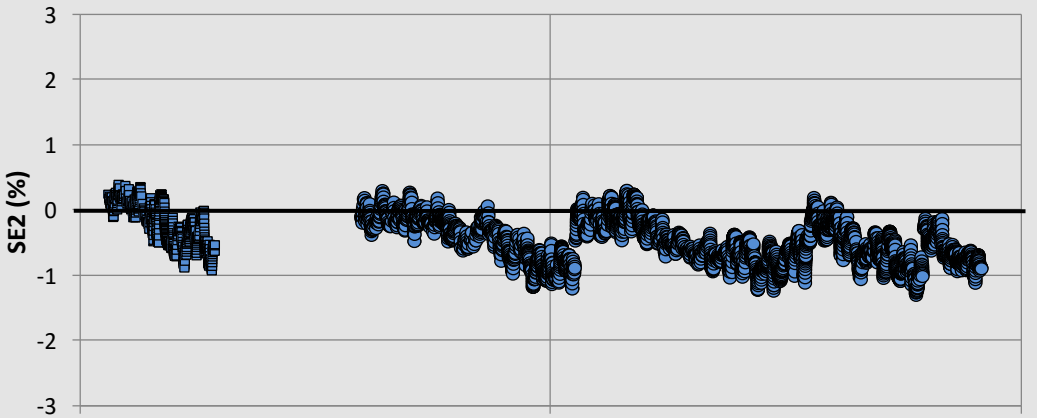
- The traditional fouling indicators: power output and compressor efficiency are consistent for base load but the provided information quality significantly degrades for part load operation
- The diagnostic model calculated performance deterioration is consistent throughout engine operation (base & part load)

GTs Health Assessment-Fouling

Fouling Monitoring





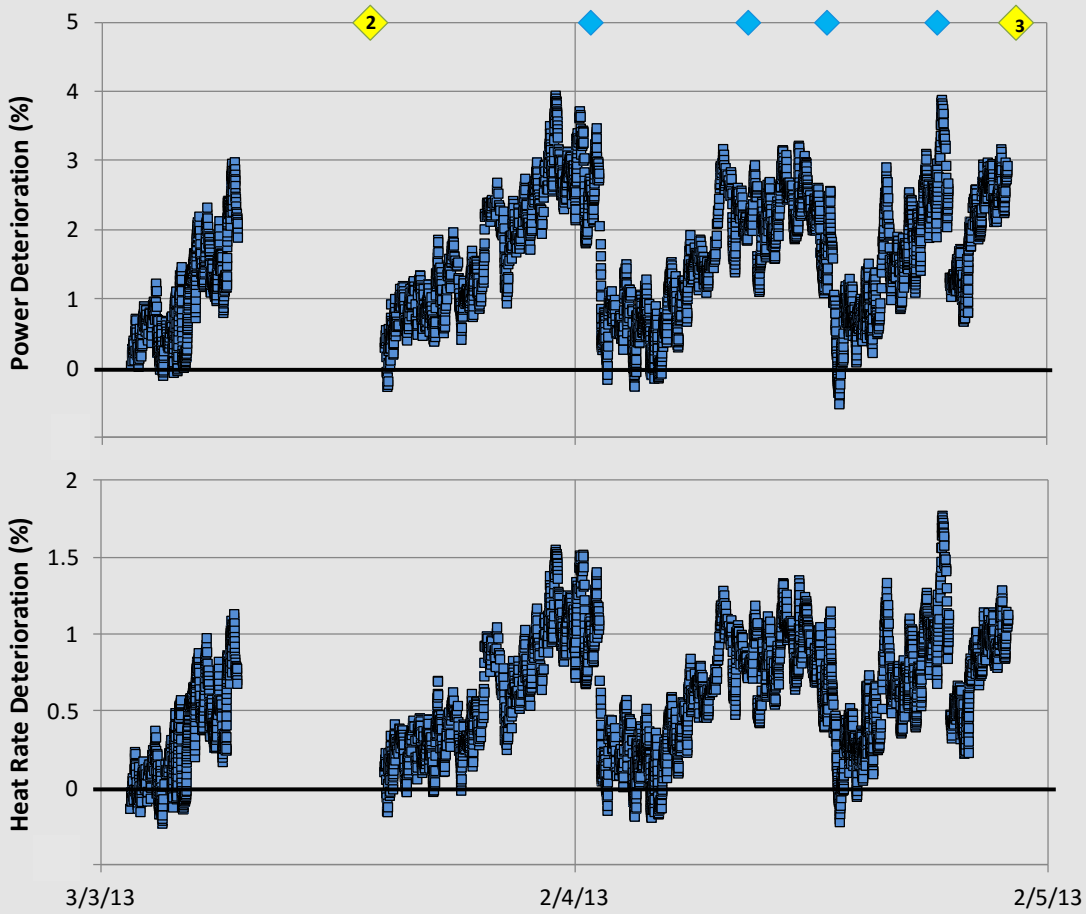


The application of adaptive modeling gives clear indication throughout operation for:

- ✓Turbomachinery components performance deterioration
- ✓Washing routines effectiveness
- ✓Overall engine performance deterioration

GTs Health Assessment-Fouling

Fouling Monitoring



➢The overall engine performance deterioration due to fouling is calculated and translated to information deemed meaningful by the user for supporting a decision making procedure and for increasing the usability of the diagnostic procedure

Contents

Economic Assessment

Test Case Definition

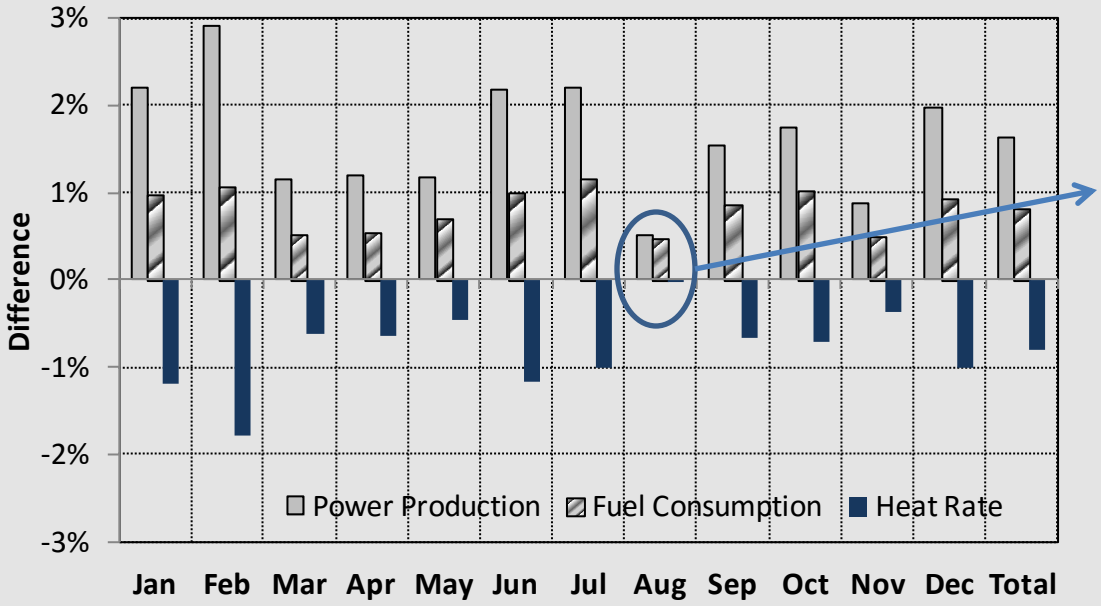
Washing Action	2013	2014
Off-Line (GT1&GT2)	8	15
On-Line	Sporadic for 10 months Daily for Aug & Sept	Daily

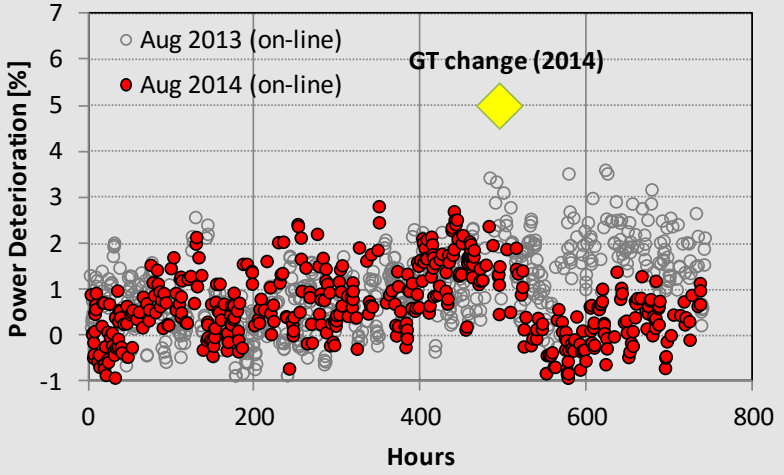
Economic Data Used	
Fuel Cost	8.7$/MMBTU
Elc Market Price	87$/MWh
Life Expectancy	30 years
People /MW	0.2
Salary	1500$/month
Maintenance Cost	6$/MWh
Off-Line EOH	20
Off-Line Cost	$3000

- Steam price is assumed equal to the cost of the fuel needed for producing the steam in a 80% efficiency boiler
- GTs operate in an interchangeable way during 2013 & 2014 (off-line wash after shut down)
- The up-rated engine model is used for the economic assessment for both cases utilizing the corresponding compressor health factors (2013 & 2014)

Economic Assessment

Washing Routine Assessment

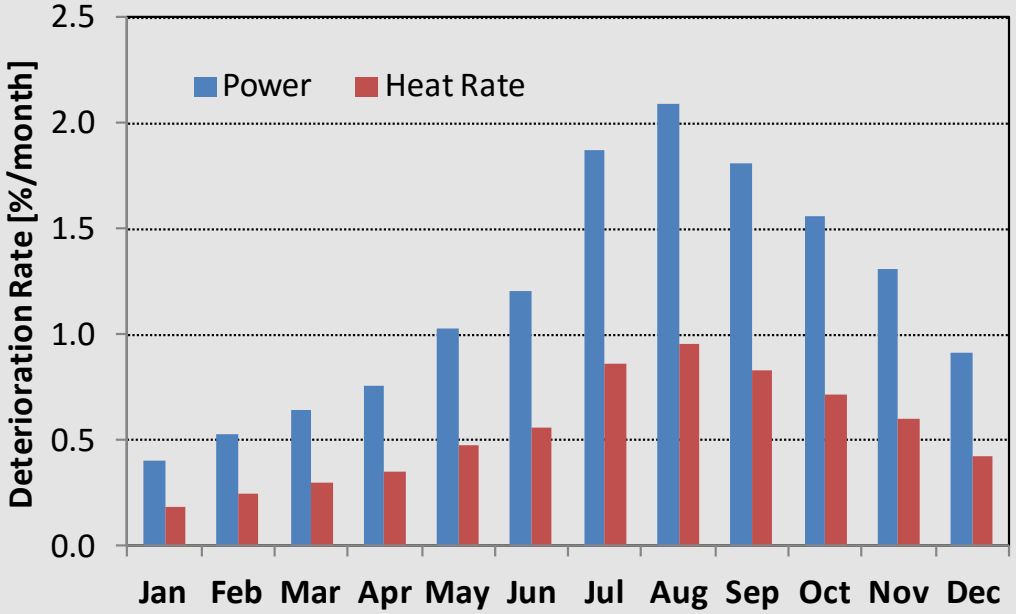




- Application of on-line washes significantly decreases performance deterioration
- The washing routine applied in 2014 (frequent off-line washes and daily on-line washes) enhanced power production (+1.6%) and heat rate (-0.8%)
- The performance enhancement is translated to over 800k$ additional gain for the operator

Economic Assessment

Washing Routine Optimization



Washing Action	Nr of Washings	Change (k$)
Applied 2014	15	Reference
Optimized	15	+57
Typical Equidistant	15	+38

- Time intervals optimization gives a gain of more than 50k$ by increasing the off-line washes frequency during summer time
- Higher deterioration rate during summer months for the specific plant

Contents

Summary

- Data obtained over two years from an on-line health and performance monitoring system installed to a CHP power plant has been analyzed utilizing an integral approach for diagnosis, performance and economic assessment built in close cooperation with the power plant engineers
- Gas Turbine performance model has been developed using a semi-automated adaptation procedure and used for health and performance assessment. Coupled with a water/steam cycle performance model and an economic analysis module was used for assessing power plant performance and economics
- The adaptive modeling method correctly identified turbine as the source of an engine performance shift
- The adaptive modeling method was used for successfully monitoring fouling throughout engine operation (base and part load)
- The calculated overall plant performance deterioration was used for assessing two washing strategies and for optimizing the currently applied

Conclusions

- Engine performance deterioration can be identified and quantified by “back of the envelope calculations” such as heat balance and performance parameters correction utilizing strictly base load data
- Adaptive modeling can effectively identify and quantify component and engine deterioration along with component faults for the whole operating envelope
- This information can further be used to support a decision making procedure regarding maintenance planning when coupled with overall plant performance and economic assessment tools
- The economic comparison of two washing routines applied by the power plant personnel indicated that on-line washing results to performance enhancement which is translated to a significant economic gain
- It is significant to decide in cooperation with the operator’s personnel how to present the diagnostic results and what post-processing parameters are deemed informative for everyday operation

Questions