# Application of an Advanced Adaptation Methodology for Gas Turbine Performance Monitoring

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# Introduction

An industrial gas turbine model adaptation methodology and framework are presented. The 6-step methodology introduced utilizes generic turbomachinery maps, which are scaled and adapted on available field data, to best represent the operation of the gas turbine. The developed models are suitable for performance monitoring and diagnostic purposes. PROOSIS simulation environment is used.

The proposed framework addresses:

1. Model adaptation on varying load and operating conditions
2. Use and adaptation of generic maps
3. Applicability on different gas turbine configurations

# Contents

## Methodology

- 6-step adaptation framework
- Gas turbine model set-up & description

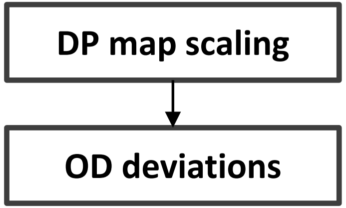
## Test Cases

- Single shaft model adaptation demonstration
- Twin shaft application for performance monitoring

## Summary & Conclusions

## References

# 6-step adaptation framework




### Step 1: Map scaling at Design Point (DP)

Calculation of the map scaling factors according to:

1. Reference operating point (1)
2. Relative position in the base map

### Step 2: Field data deviations (OD)

Off-design calculation of the available operating points with the sized maps from the previous step

Record the RMS of the estimated values against the corresponding real measurements

# 6-step adaptation framework

### Step 3: Map adaptation (2)

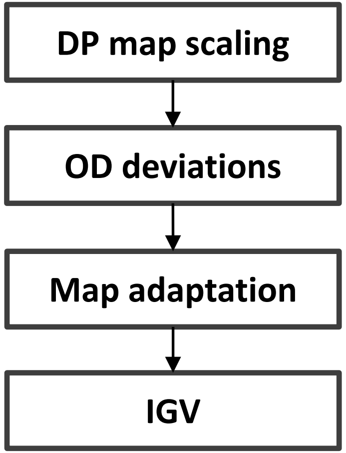
Calculation of the map modification factors related to:

1. Corrected mass flow (SCW, STW)
2. Efficiency (SCE, STE)

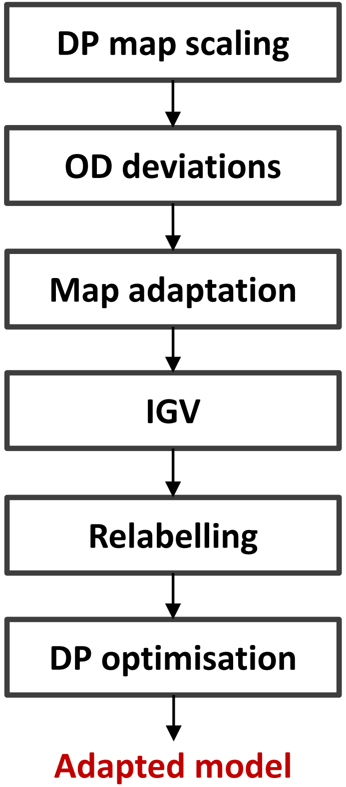
### Step 4: IGV factor calculation

If IGVs are used:

SCW and SCE are associated with IGV opening and the IGV correction factors are estimated



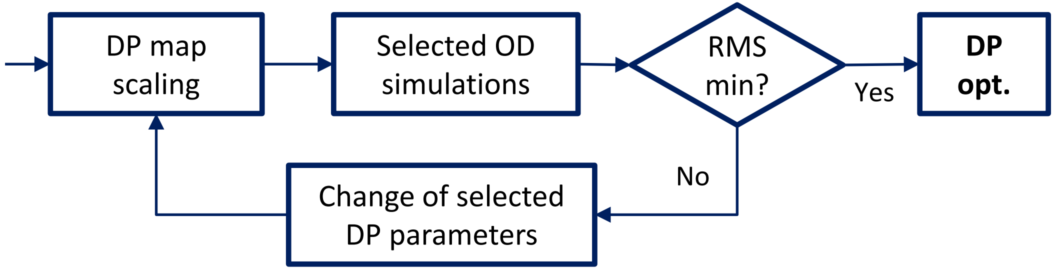
# 6-step adaptation framework




## Step 5: Local map adaptation [3]

The SCW is correlated with the speedlines of the base map and if a clear correction appears the speedlines are modified accordingly

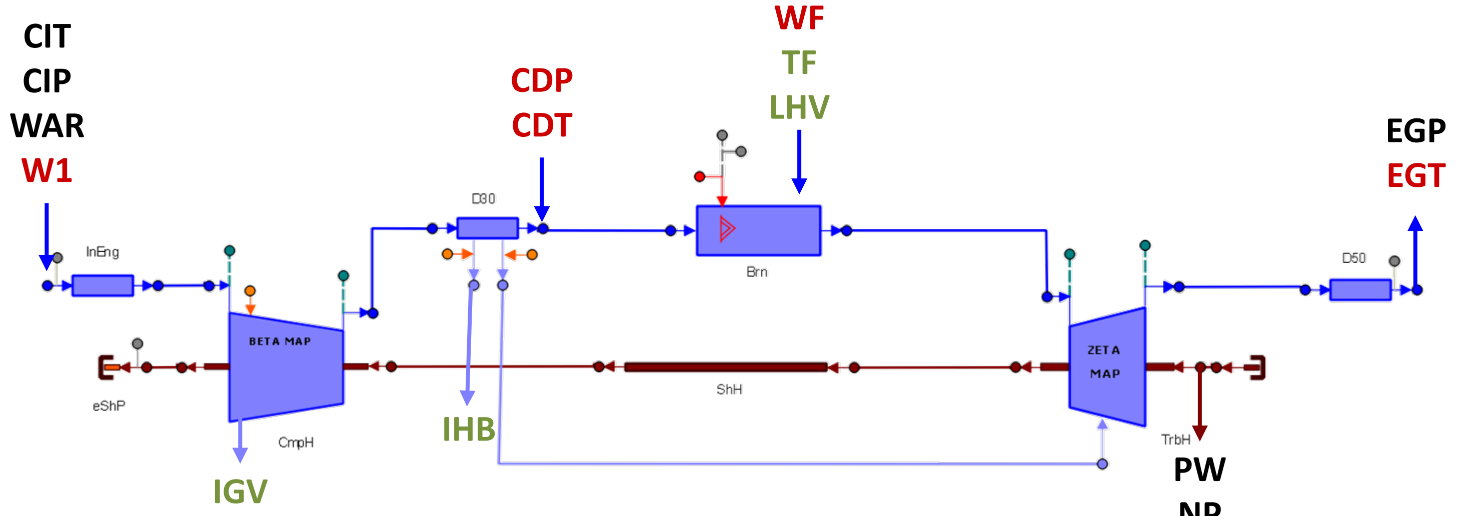
## Step 6: Multi-point design optimisation




## Additional iterations if required

# Gas turbine model set-up & description

Schematic representation of single shaft in PROOSIS [4] environment and OD mathematical model [5]:




**Boundary conditions**

**Additional measurements**

**Additional inputs**

**Variables to Iterate:**

W1, $FAR_{cc}$, BETA, ZETA

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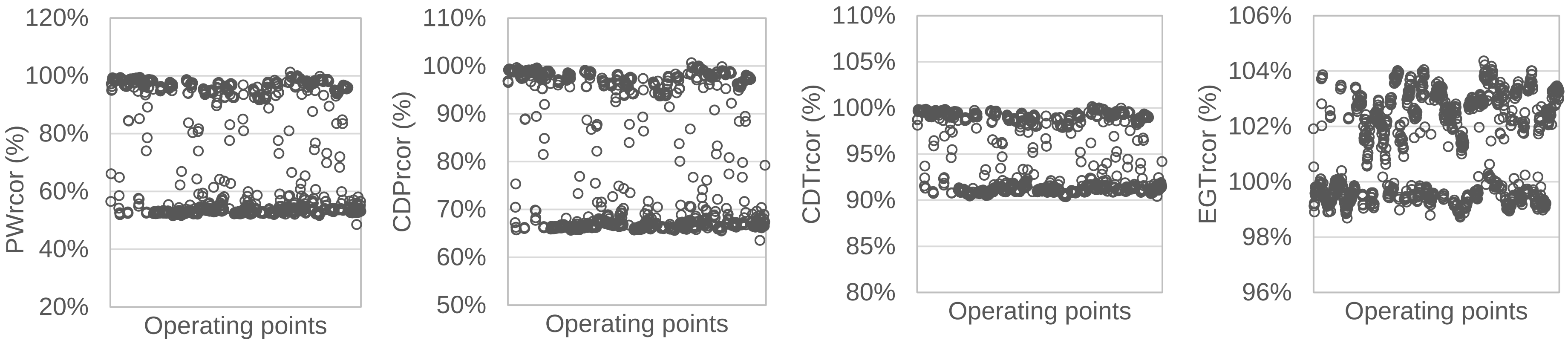
# Single shaft model adaptation demonstration

**Single shaft heavy duty gas turbine 250 MW @ 50Hz**

Available measurements: PW, NP, CIT, CIP, WAR, W1, CDP, CDT, EGT, IGV

50 – 105% load, varying inlet temperature in the range of 30K over a period of a month

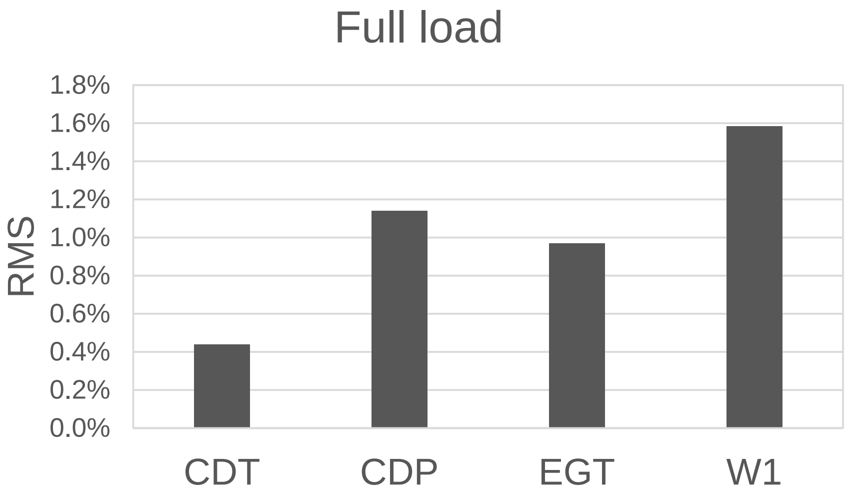


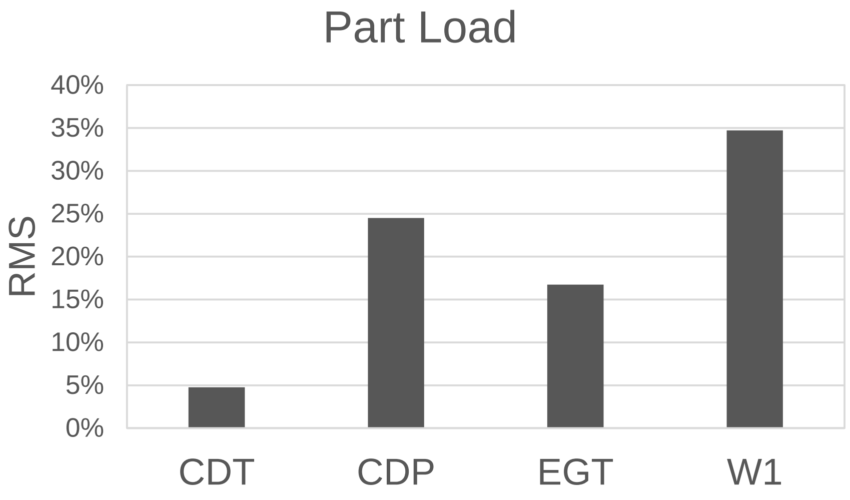
# Single shaft model adaptation demonstration

**DP:** Maps scaled to a reference point selected from the available measurements

Extended version of OD (OD boundaries + W1, CDT, CDP, EGT + DP position in base maps)

**OD:** All available operating points were simulated and RMS calculated



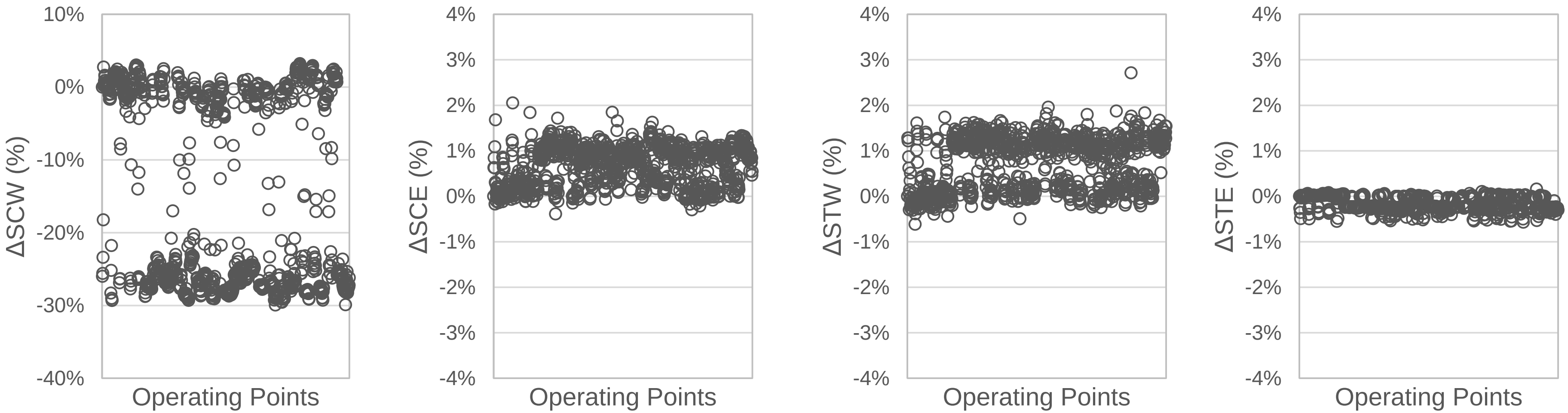




**DP map scaling** → **OD deviations**

# Single shaft model adaptation demonstration

## **Map adaptation:** Calculations of modification factors

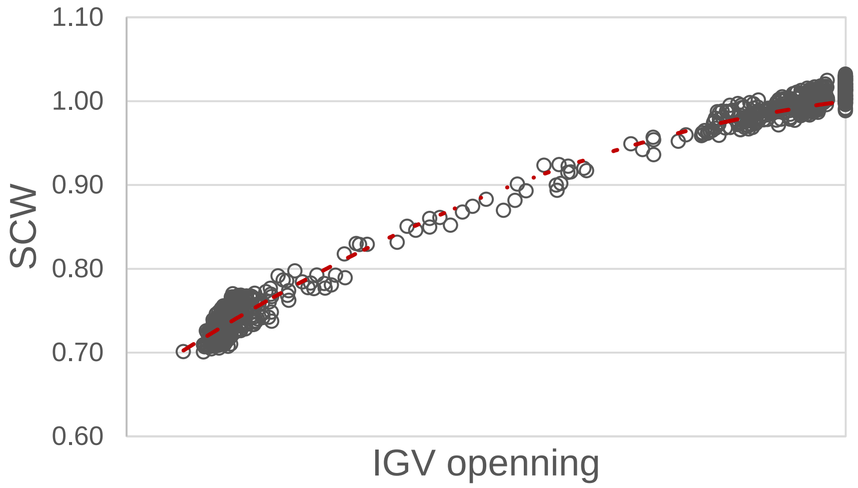
Extended version of OD (OD boundaries + W1, CDT, CDP, EGT)

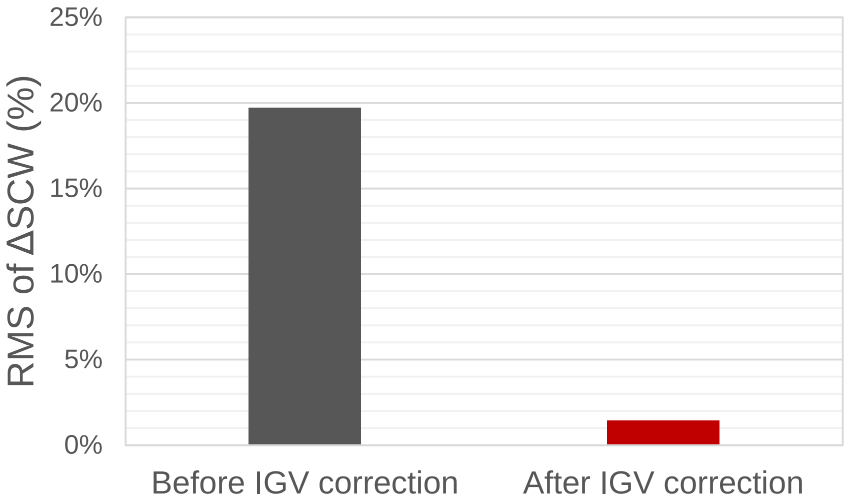



**DP map scaling** → **OD deviations** → **Map adapt.**

# Single shaft model adaptation demonstration

**IGV factors:** Calculations of IGV correction factors

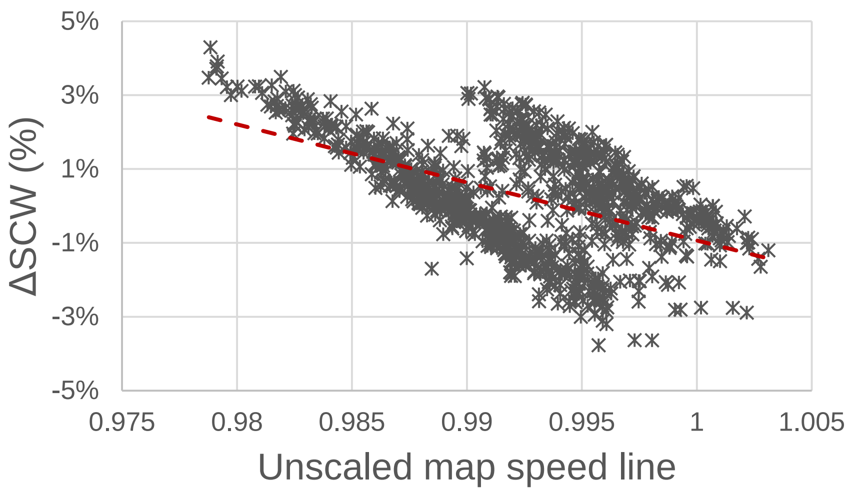


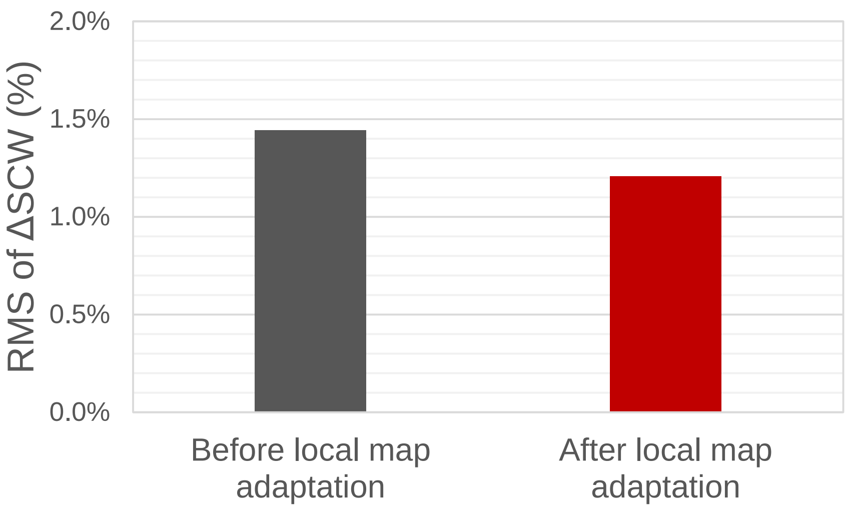




**DP map scaling** → **OD deviations** → **Map adapt.** → **IGV**

# Single shaft model adaptation demonstration

**Local map adaptation:** Calculations of IGV correction factors



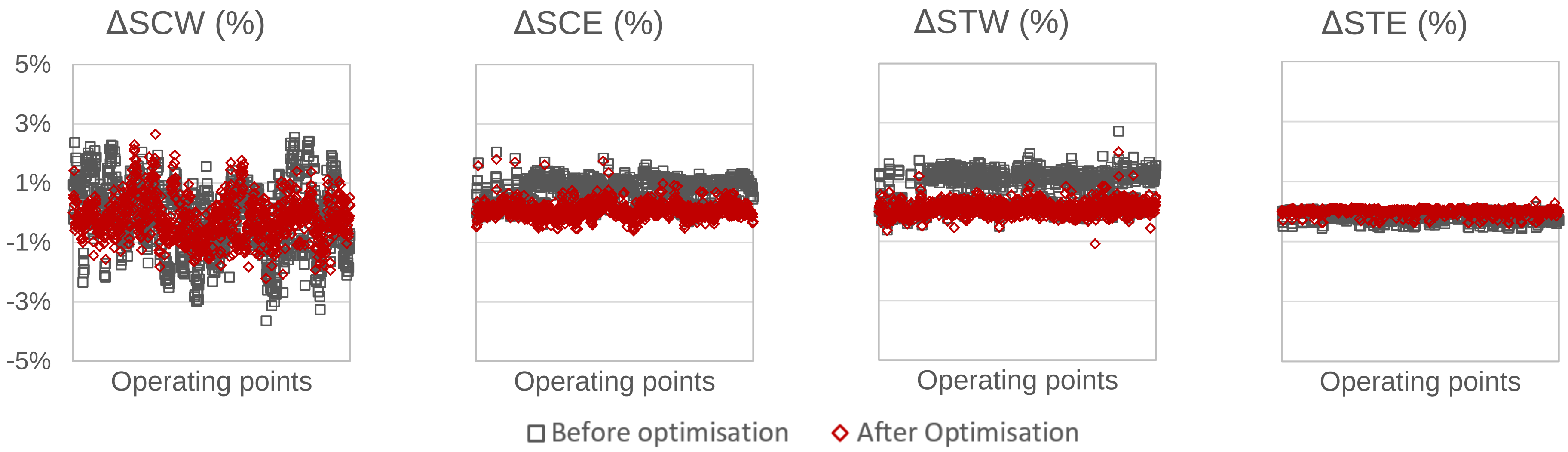

**DP map scaling** → **OD deviations** → **Map adapt.** → **IGV** → **Relabelling**

# Single shaft model adaptation demonstration

**Optimisation:**

Minimization of W1, CDT, CDP, EGT model deviations

Changing DP position in the base maps & IGV factors

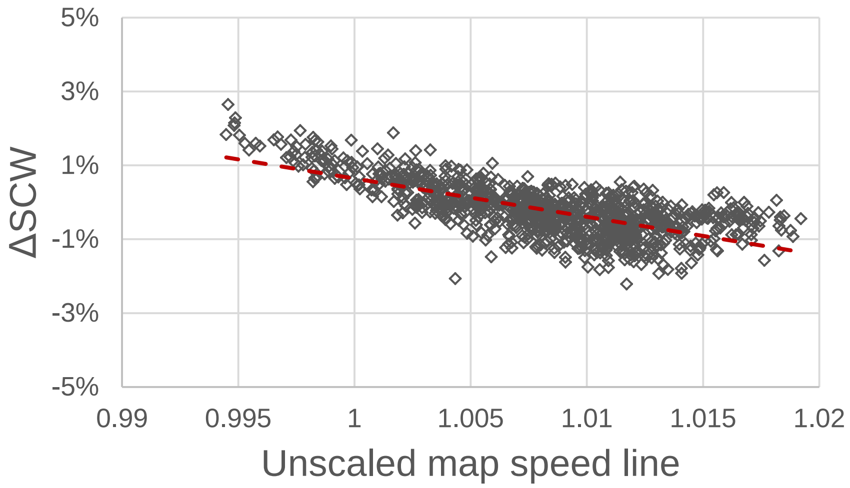


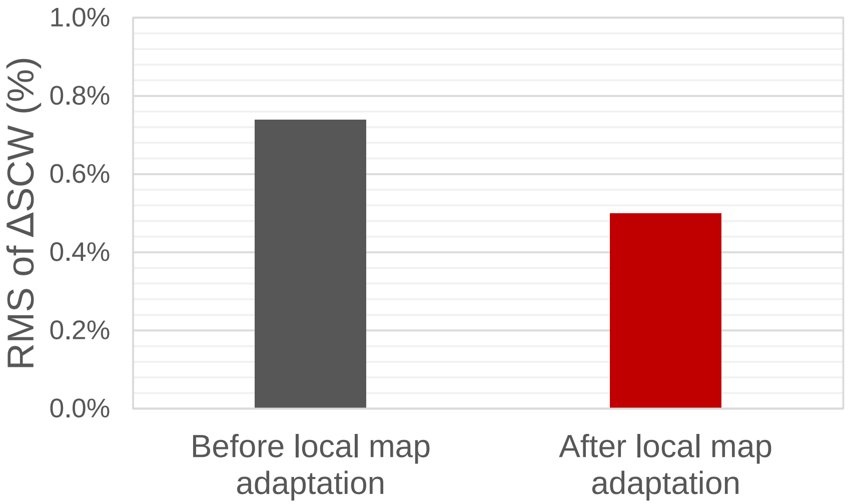

DP map scaling → OD deviations → Map adapt. → IGV → Relabelling → OPT

# Single shaft model adaptation demonstration

**Extra iteration:**

2nd local map adaptation

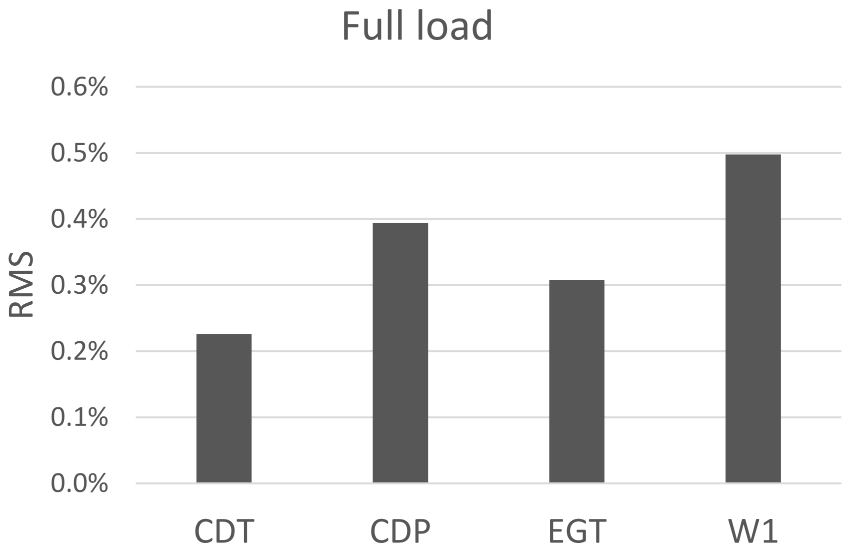


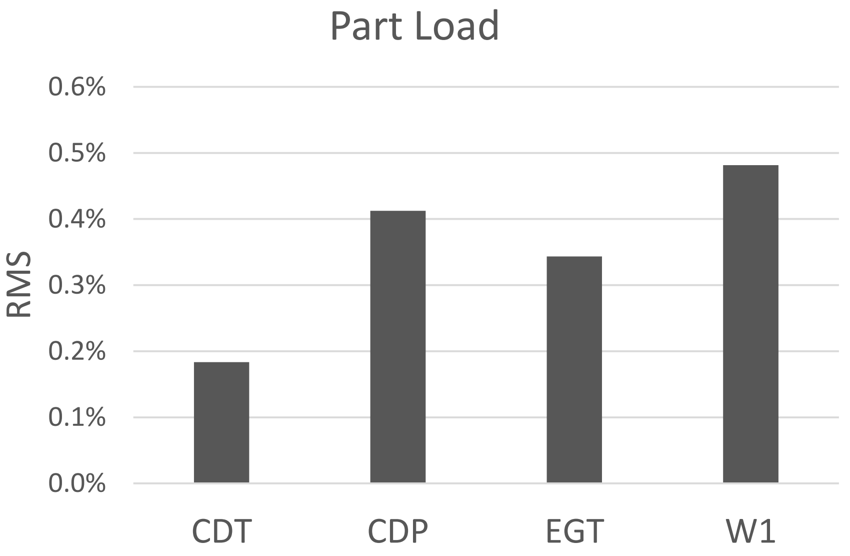




**DP map scaling** → **OD deviations** → **Map adapt.** → **IGV** → **Relabelling** → **OPT**

# Single shaft model adaptation demonstration

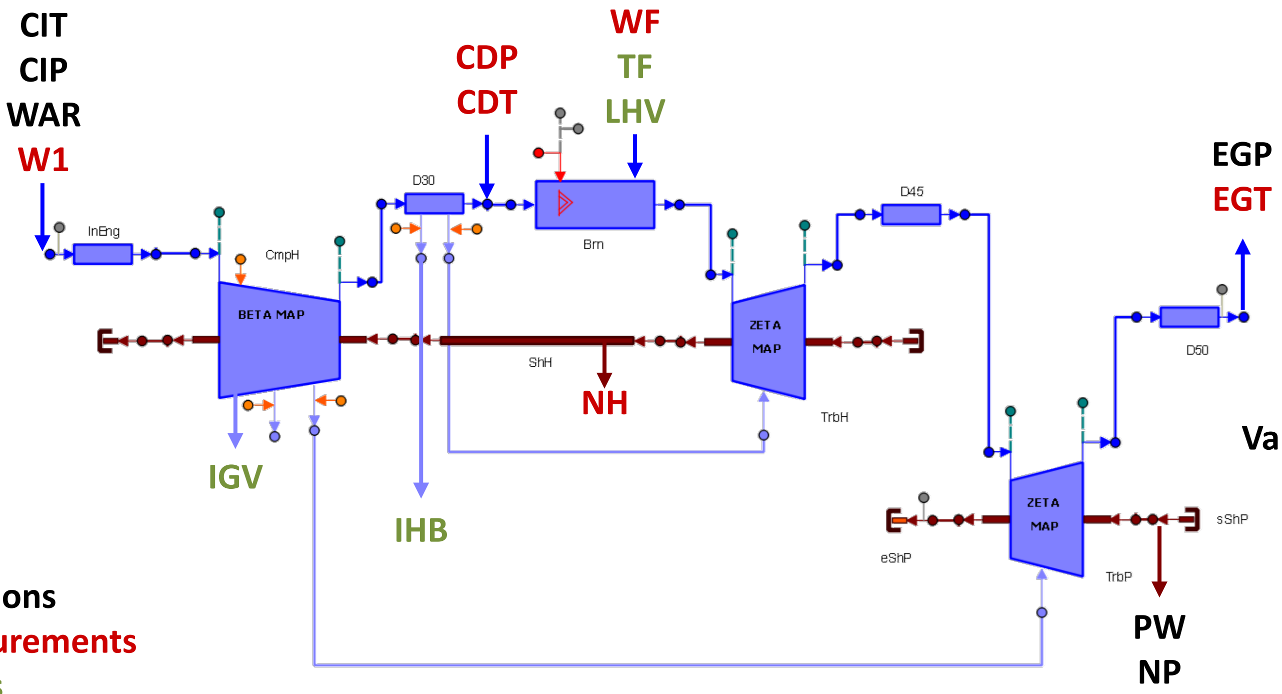
## Final adapted model:




# Gas turbine model set-up & description

Schematic representation of twin shaft in PROOSIS environment and OD mathematical model:




**Variables to Iterate:**

W1, $FAR_{cc}$, NH

BETA, ZETA

**Boundary conditions**

**Additional measurements**

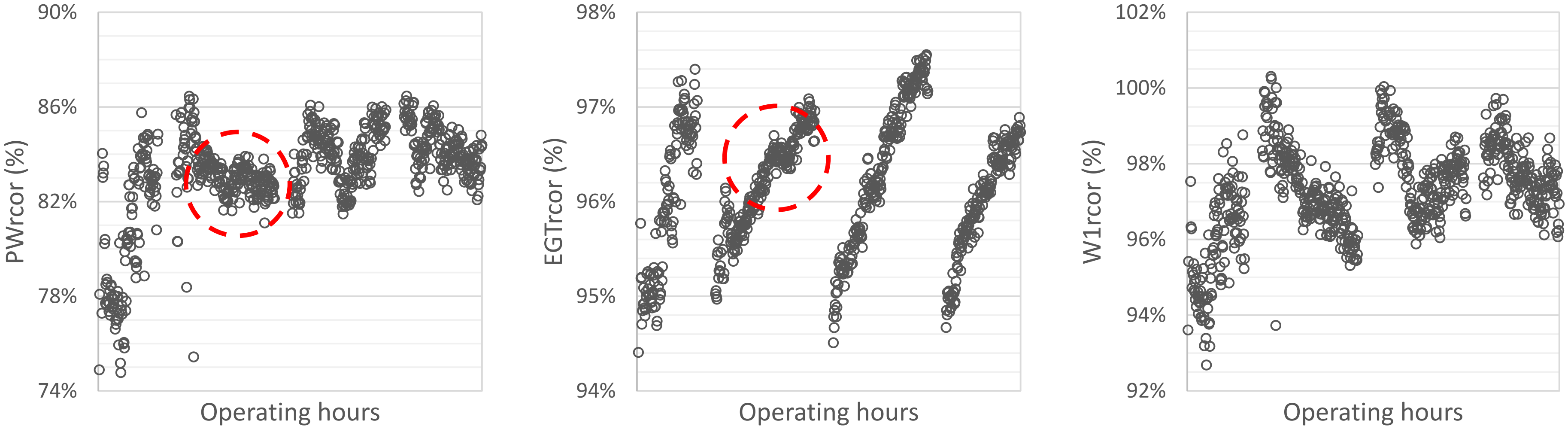
**Additional inputs**

# Twin shaft model adaptation for performance monitoring

**Twin shaft heavy duty gas turbine 20 MW @ 50Hz**

Available measurements: PW, NP, CIT, CIP, WAR, W1, CDP, CDT, EGT, NH

85% of base load, varying inlet temperature in the range of 30K over a period of a 4.5 months



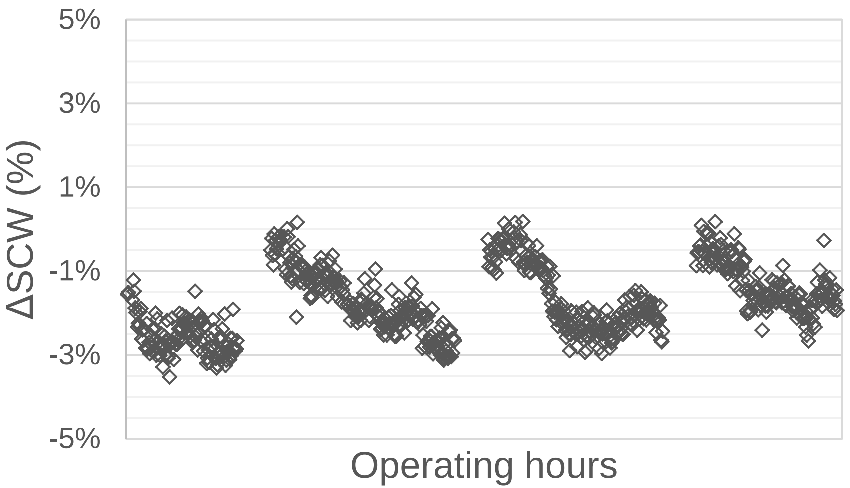
# Twin shaft model adaptation for performance monitoring

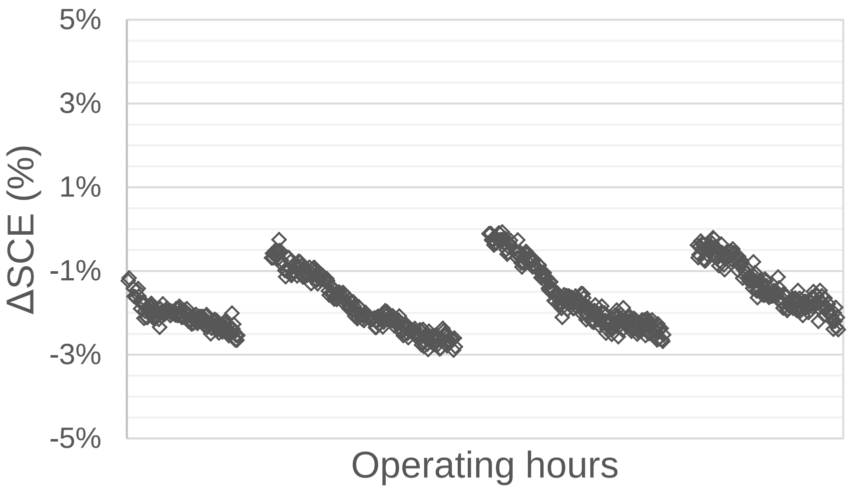
## Map adaptation:

Extended OD (OD boundaries + W1, CDT, CDP, EGT, NH)

## optimisation:

Minimizing W1, CDT, CDP, EGT, NH deviations from measurements




DP map scaling → OD deviations → Map adapt. → OPT → **Adapted Model**

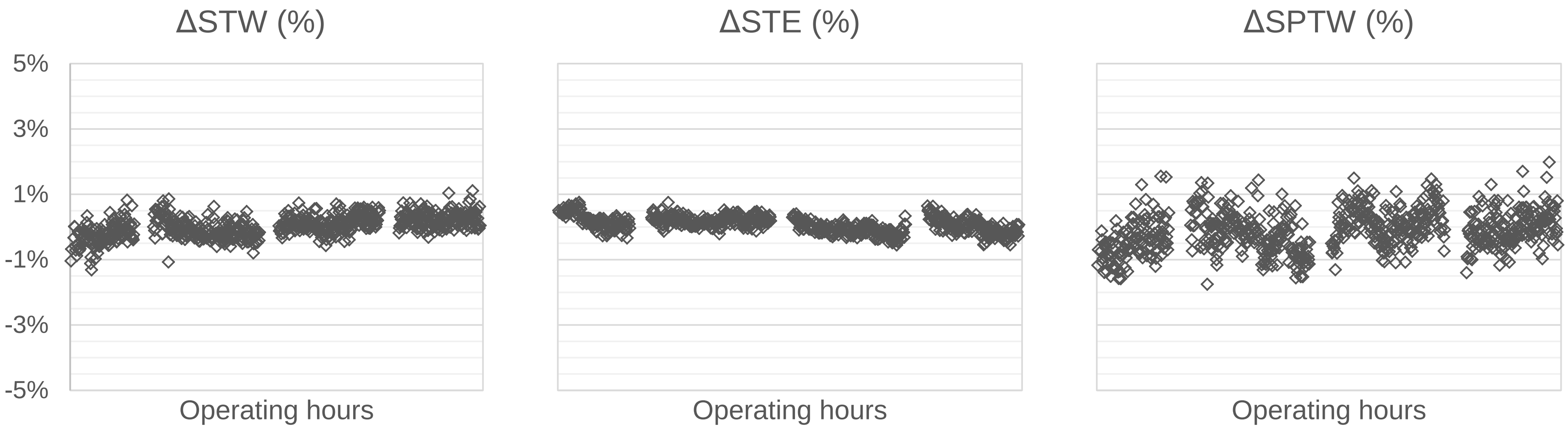
# Twin shaft model adaptation for performance monitoring

## Map adaptation:

Extended OD (OD boundaries + W1, CDT, CDP, EGT, NH)

## optimisation:

Minimizing W1, CDT, CDP, EGT, NH deviations from measurements




# Contents

# Summary

- A 6-step adaptation framework was developed for industrial gas turbine model adaptation on field data.
- A single shaft heavy duty gas turbine model adaptation on operating points was demonstrated, showcasing the model improvement along the process.
- A twin shaft model was adapted for performance monitoring purposes.

# Conclusions

- Map scaling at design point provided adequate accuracy only for close to base load operating conditions.
- IGV correction well adapted all part load points and relabeling captured the ambient temperature effect on the isolines.
- The twin shaft adapted model showed a repetitive pattern on compressor degradation as well as restoration of the compressor to "healthy" operation

# References


(1) Kurzke, J. (1995) 'Advanced User-Friendly Gas Turbine Performance Calculations on a Personal Computer', in *International Gas Turbine and Aeroegine Congress and Exposition*. Huston, Texas. doi: 10.1115/95-GT-147.

(2) Mathioudakis, K., Kamboukos, P. and Stamatis, A. (2002) 'Turbofan Performance Deterioration Tracking Using Nonlinear Models and Optimization Techniques', *Journal of Turbomachinery*, 124(4), pp. 580–587. doi: 10.1115/1.1512678.

(3) Verbist, M. L., Visser, W. P. J., Pecnik, R. and van Buijtenen, J. P. (2012) 'Component Map Tuning Procedure Using Adaptive Modeling', in Proceedings of ASME Turbo Expo 2012. Copenhagen, Denmark, pp. 371–379. doi: 10.1115/GT2012-69688.

(4) Emprasarios Agrupados (2015) *Proosis 3.6 User Manual*. Empresarios Agrupados.

(5) Alexiou, A. (2014) *Introduction to Gas Turbine Modelling with PROOSIS*. Second. Athens: Laboratory of Thermal Turbomachines, NTUA.

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Thank you very much for your attention