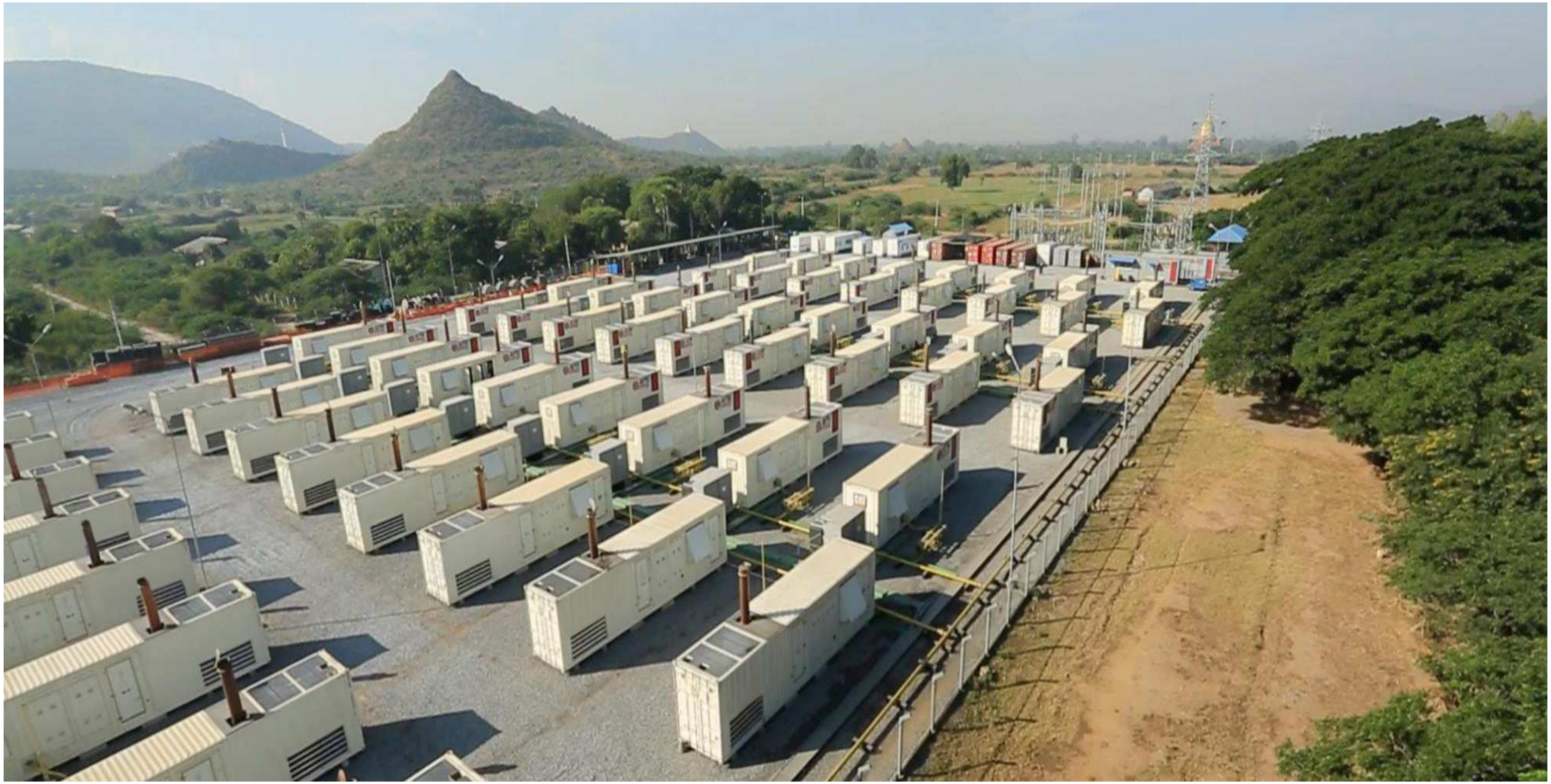


HERVÉ MARTIN, ABB TURBO SYSTEMS LTD

Highly transient gas engine operation from a turbocharging perspective

10th CIMAC CASCADES, Kobe, 12th October 2018

Overview

Introduction

Basics of load pick-up

Modeling and simulation

Simulation results

Summary

Outlook

Introduction

Lean burn gas engines for electricity generation

Why Gas-engines instead of Diesel?

- Infrastructure availability (gas)
- Good compromise efficiency / emissions (NOx)

Applications

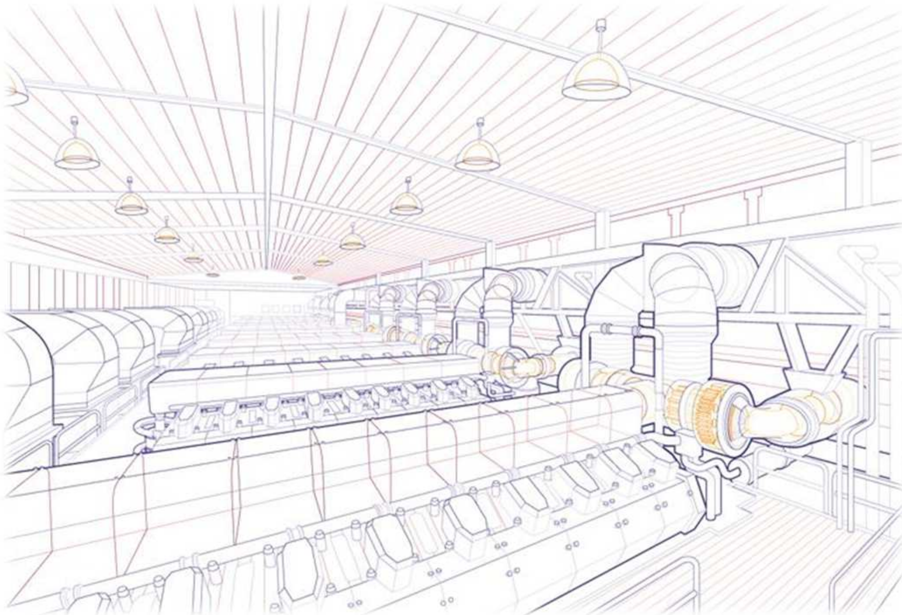
- Electric Power Generation (EPG)
- Emergency gensets (hospitals, data centers, …)

Operations

- Peak shaving
- Sudden power request

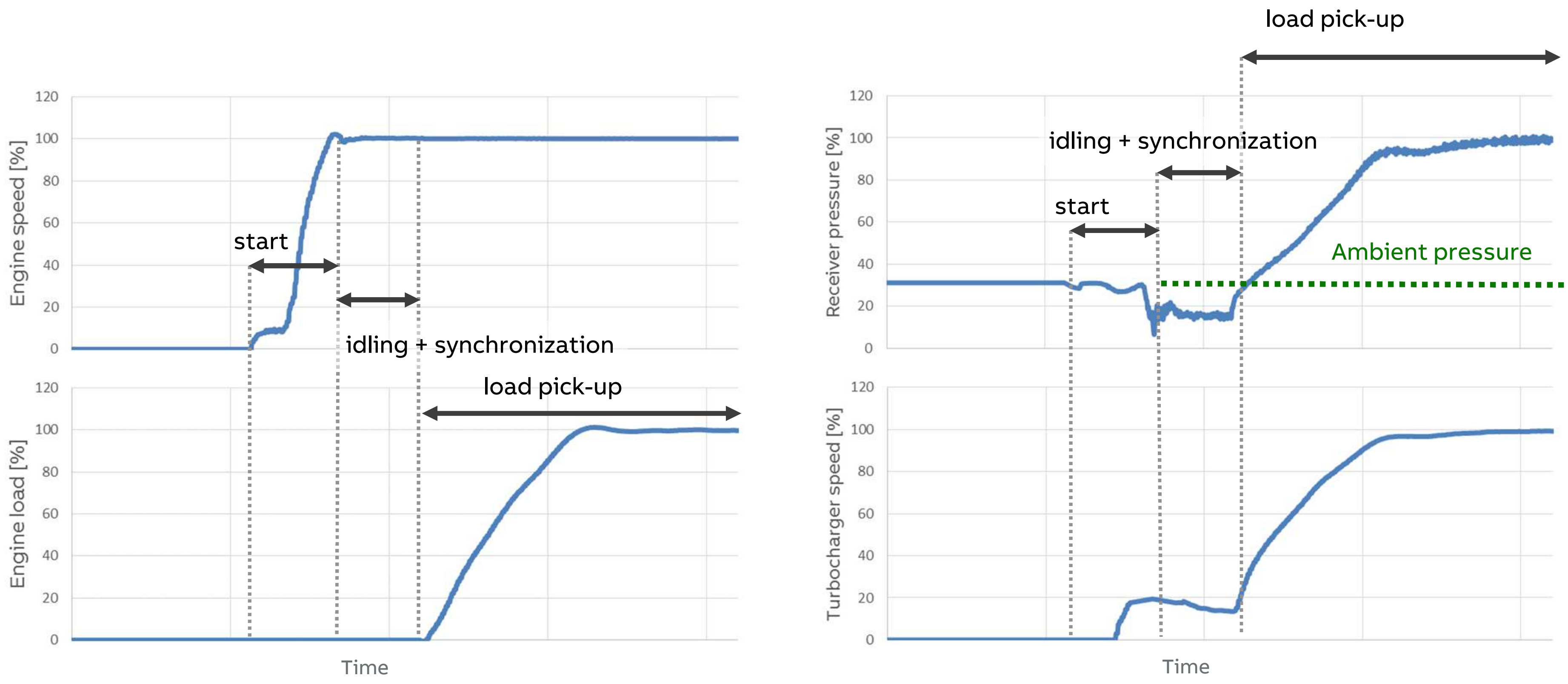
Challenges

- Stringent acceleration requirements
  e.g. EPG Gas – US data center: 60s start to full load
- Methane slip
- Emission requirements



Basics of load pick-up

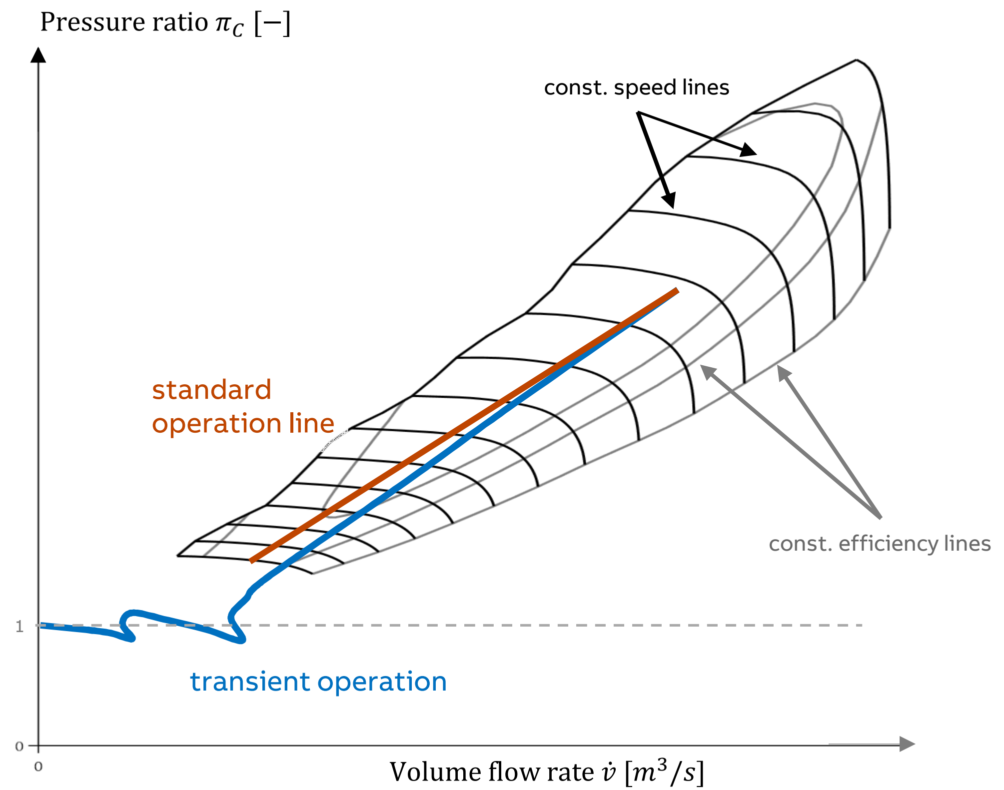
Example: acceleration of gas engine from start-up to full power



Basics of load pick-up

Compressor behavior

- Initial transient phase, missing energy on exhaust side (turbine inlet)
  ➡ turbocharger lag
- Compressor stays initially at constant speed, and pressure ratio drops below 1
- Standard operation line is also shown for illustration purpose only



Basics of load pick-up

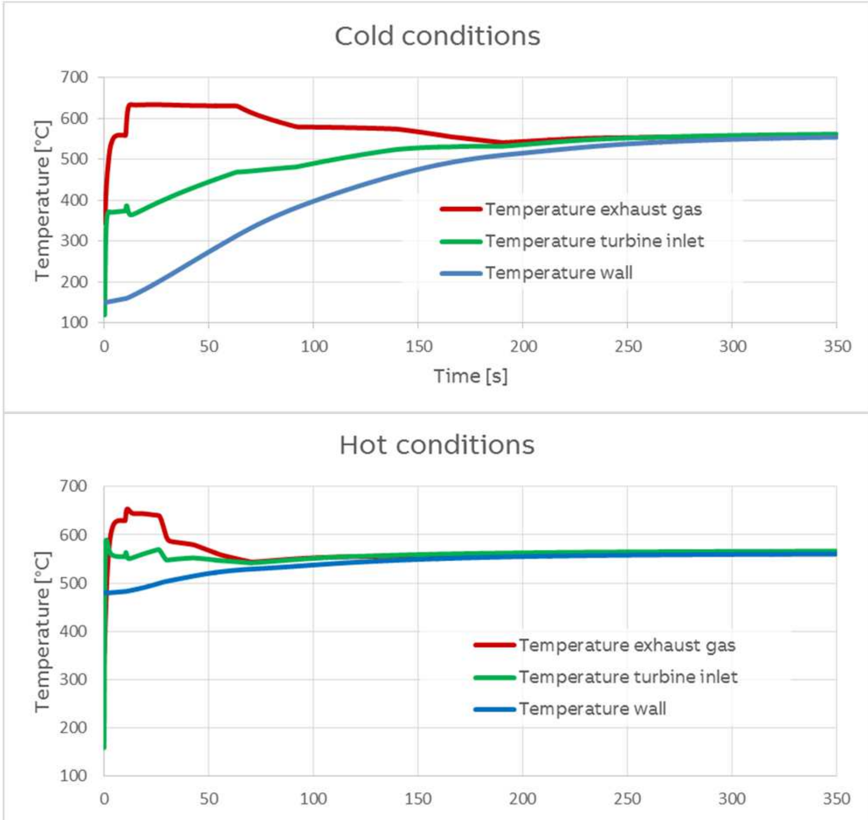
What is turbo lag?

Influencing parameters

- Volumes inertia (time to fill manifolds)
- Heat absorption in exhaust system in cold / hot conditions
- Turbocharger inertia (inertia of rotating components)

Proper modeling of engine & turbocharging system necessary

- Analysis & identification improvement potentials
- Optimization of main parameters



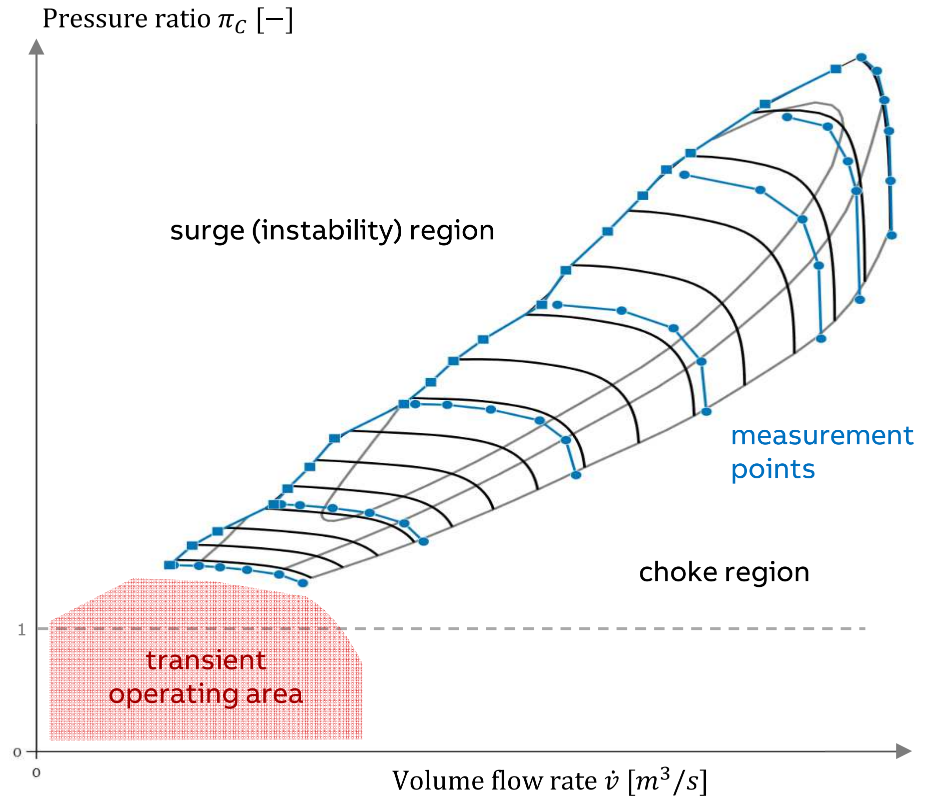
Modeling and simulation

Compressor measurements

Compressor measurements on thermodynamic test-bench do not cover transient operating area

Low speed measurements are challenging

- Time to stabilized steady-state operation
- Internal heat transfers



Modeling and simulation

Compressor modeling

ABB's compressor map model for off-design operation

- Physics-based compressor model
- Losses based on mathematical model

Calibration of the model at low speed still required

- At low speed, compressor operates in incompressible domain (like a pump)

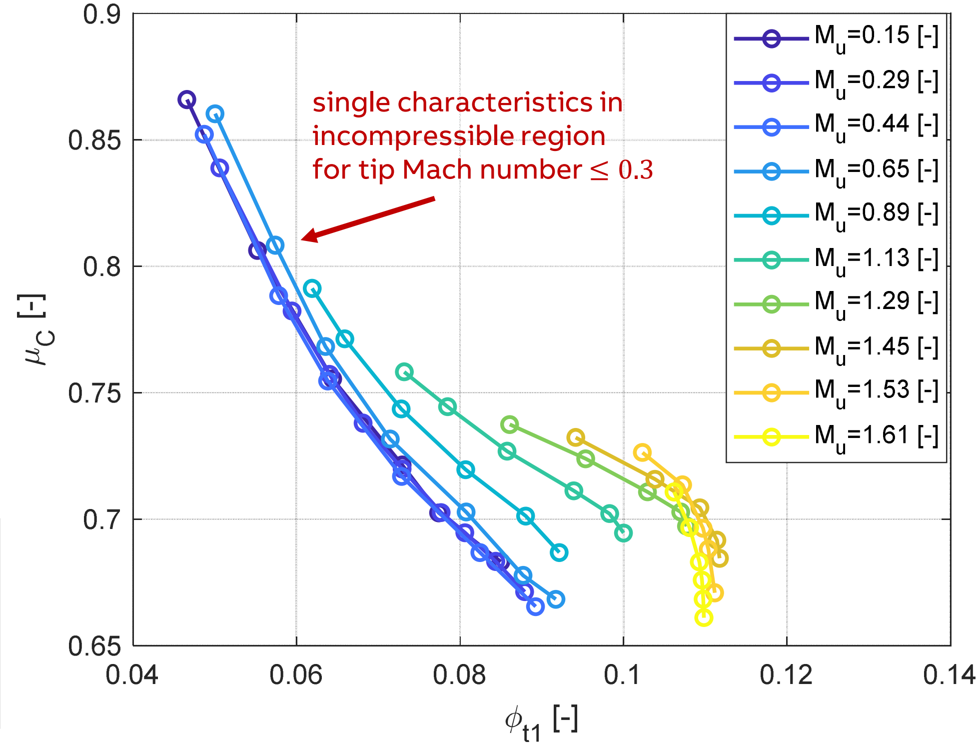
➡ Only few measurements needed at low speed

Definitions:

Specific work: $\mu_c = \frac{\Delta h}{u^2}$

Flow coefficient: $\phi = \frac{\dot{v}}{D^2 u}$

Tip Mach number: $M_u = \frac{\text{tip velocity}}{\text{inlet speed of sound}} = \frac{u}{c_{inl}}$



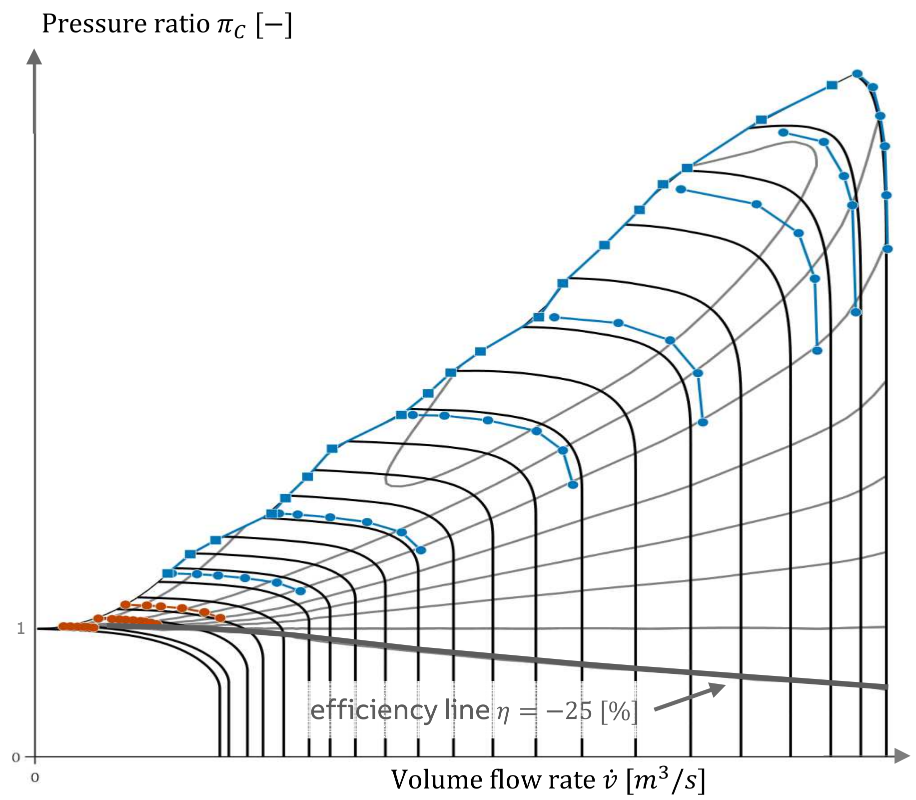
Modeling and simulation

Compressor map at off-design

Extended map shows compressor characteristics down to

- Locked-rotor (zero speed line)
- Deep choke (pressure ratio ≪ 1)

➡ Compressor map model covering whole operating area



Modeling and simulation

Turbine measurements

During transient phase

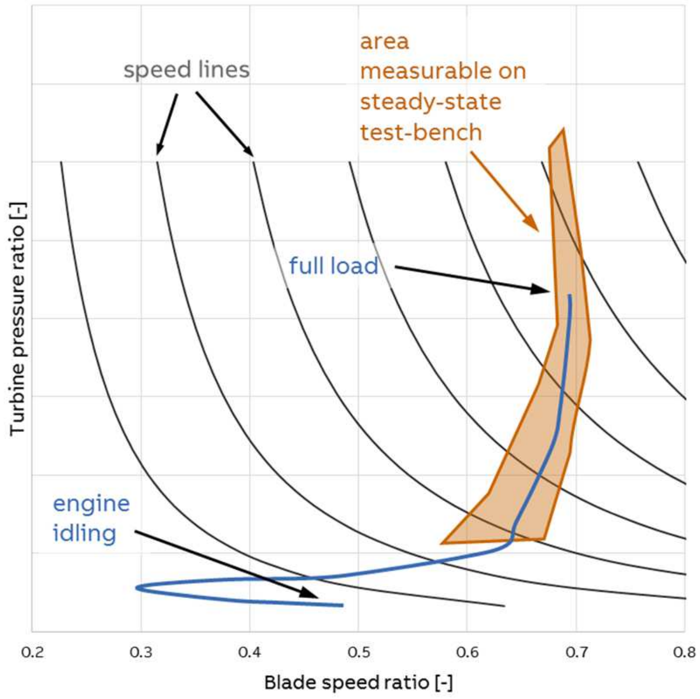
- turbine operates off-design at very low blade speed ratios and pressure ratios

Measurements on turbocharger test-bench

- cover only a small part of the turbine transient operating area

Measurable area limited by the compressor limits (surge and choke)

Definition:
Blade speed ratio = $\frac{\text{peripheral velocity}}{\text{isentropic gas velocity}}$

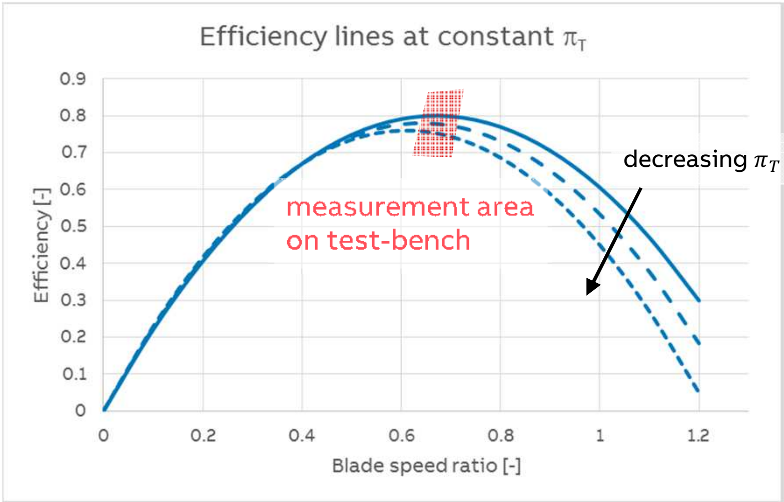


Modeling and simulation

Turbine modeling

From one-dimensional theory & measurements

- Quadratic trend of efficiency versus blade speed ratio, at constant pressure ratio π_T
- Zero efficiency at zero speed
- At low π_T, constant characteristics in incompressible region



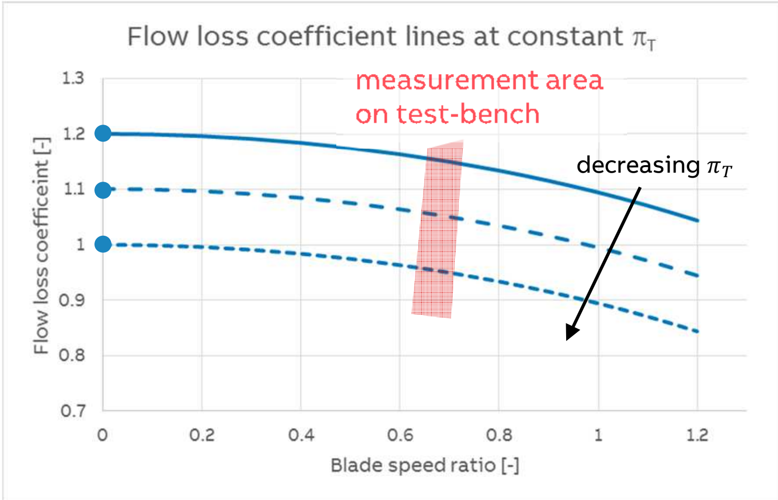
Modeling and simulation

Turbine modeling

Turbine flow loss coefficient is a key parameter for transient operation

- Decreasing characteristic with blade speed ratio
- Variation limited in transient region
- Flow loss coefficients at zero speed measurable
- At low pressure ratio, turbine operates in incompressible region

➡ Turbine map model covering whole operating area



Definitions:

Turbine flow loss coefficient $= \frac{\text{isentropic (ideal) mass flow rate}}{\text{actual mass flow rate}}$

Simulation results

Boundary conditions

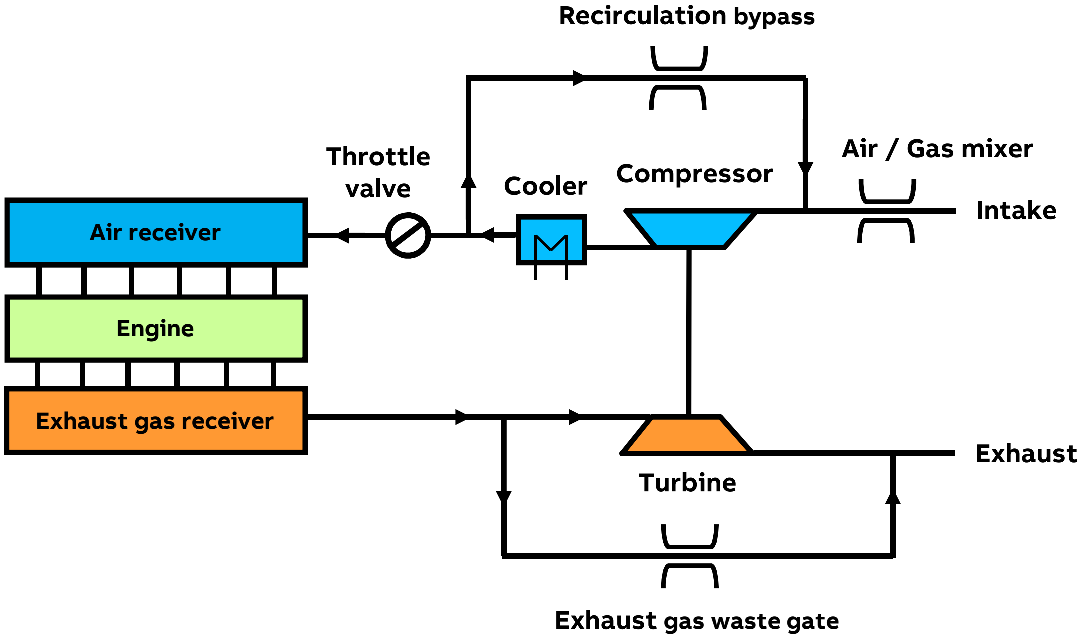
Premixed gas engine

1-stage turbocharger

Brake mean effective pressure: 22 bar

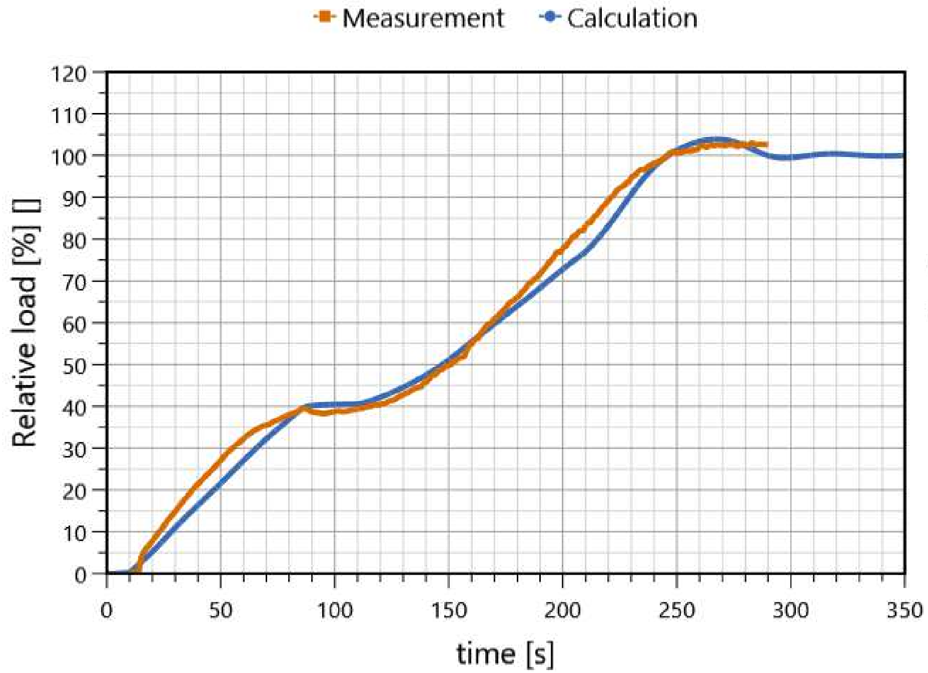
Constant speed (grid parallel operation)

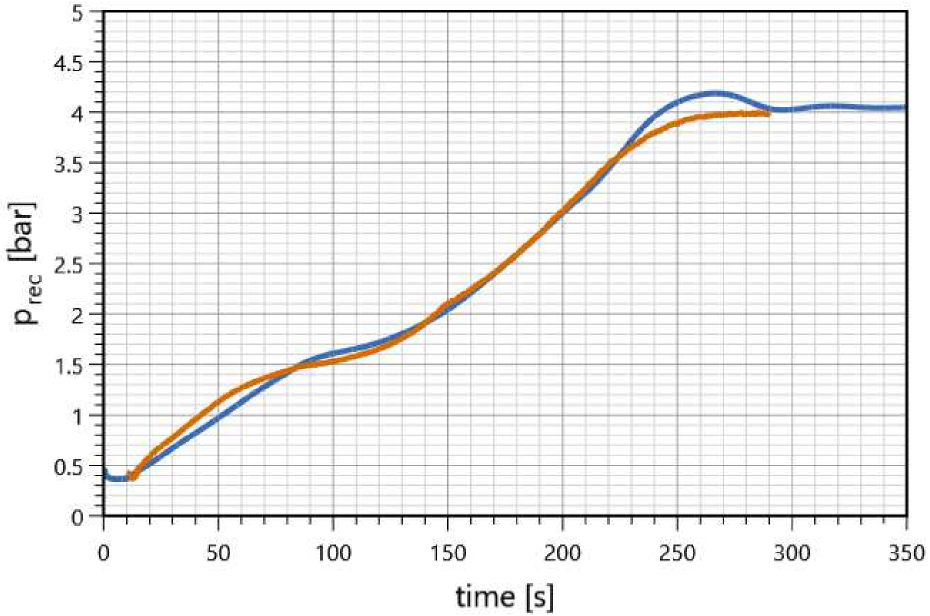
Volumetric efficiency: 0.74



Simulation results

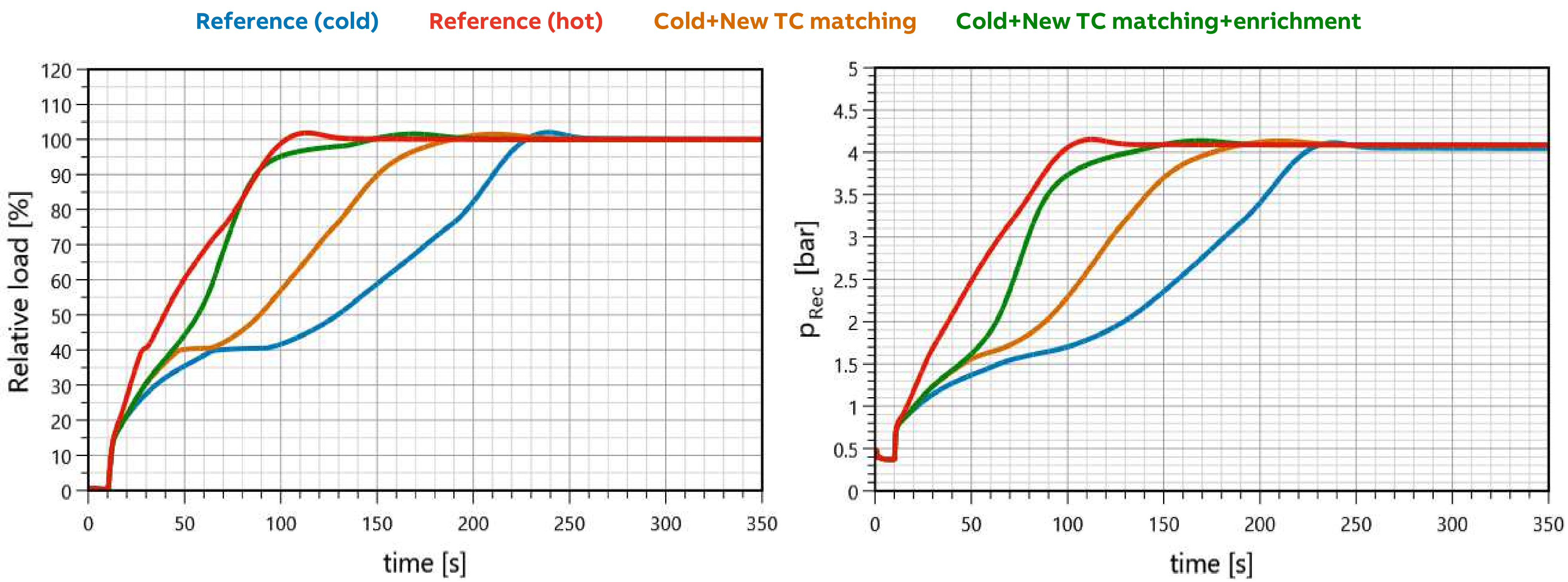
Comparison simulation – measurements: load pick-up from cold conditions





Simulation results

Analysis and optimization of load response



Summary

Results:

- Understanding of the physics of the turbocharging system essential
- Simulations of the engine load response needs to be as accurate as possible

ABB simulation:

contribution to a valuable analysis and optimization of load response

- Engine parameters (e.g. richness)
- Turbocharger (e.g. matching)
- Turbocharging system (e.g. cold vs hot conditions)

Outlook

Deeper analysis and further improvement possibilities

Modeling turbocharging solutions: Impact on highly transient lean-burn gas engine operation

CIMAC Congress 2019, Vancouver, Canada

D. Imhof, H. Martin, O. Bernard, C. Mathey

- Comprehensive simulation study with different generic high-speed lean-burn gas engines in cold, preheated and hot engine conditions.
- Comparison of different measures in terms of efficiency and acceleration behavior (engine control, turbocharging concept, turbocharger designs, etc.)
- Comparison of ramp-up to full power output between 1-stage and 2-stage turbocharging system

ABB

Definitions

Compressor tip speed: $\mathrm{u} = \pi D n$

Compressor specific work: $\mu_c = \frac{\text{total enthalpy change}}{\text{squared tip speed}} = \frac{\Delta h}{u^2}$

Compressor flow coefficient: $\phi = \frac{\text{volume flow rate}}{\text{squared diameter} \times \text{tip speed}} = \frac{\dot{v}}{D^2 u}$

Compressor tip Mach number: $M_u = \frac{\text{tip velocity}}{\text{inlet speed of sound}} = \frac{u}{c_{inl}}$

Turbine blade sped ratio: $\frac{\text{peripheral velocity}}{\text{isentropic gas velocity}}$

Isentropic gas velocity: ideal velocity obtained by expending isentropically the gas at turbine inlet to turbine outlet pressure

Turbine flow loss coefficient $= \frac{\text{isentropic (ideal) mass flow rate}}{\text{actual mass flow rate}}$