turboreflex
power plant technology upgrades

TURBO REFLEX

TURBOmachinery REtrofits enabling FLEXible back-up capacity for the transition of the European energy system

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Meeting Complexity with Flexibility: TURBO-REFLEX Project Overview

Project Coordinator: Christian Aalburg, GE, Germany

In order to continue to aggressively grow the share of energy produced from renewable resources in the EU, highly flexible back-up power is increasingly needed. This is to ensure that the system can accommodate the intermittent, non-dispatchable nature of energy sources such as wind and solar, which are subject to strong daily and seasonal variations. Until solutions for cost effective, large scale energy storage are available and have been massively deployed, existing power plants must fill the gap for flexible back-up capacity – a role that they were not really designed for.

The mission of TURBO-REFLEX is to improve the flexibility of existing plants, such as combined cycle gas turbine and steam turbine-based plants, by developing new technologies that can be retrofitted. Upgrading existing plants would make best use of large, existing investments and generate a substantial system benefit in a relatively short timeframe and at low cost. This helps ensure the stability of the electricity grid and paves the way for a larger share of renewables in the European energy system.

The flexibility improvements are concentrated on three main objectives: reducing the cost per cycle, reducing the number of starts required by reducing the minimum load capability, and improving the load following capability by increasing ramp rates.

To achieve these, new technologies have been developed to address challenges in compressor off-design operability (WP1), hot gas path (WP2) and mechanical integrity in flexible operation (WP3). These are complemented by new plant analytics and monitoring technologies (WP4) which enable optimized operation and condition-based maintenance. To assess the impact of the flexibility improvements at component level on the performance, life and cost of the entire plant, a whole plant performance model was developed (WP5). For an economic assessment of the upgraded plant characteristics, the results of the plant performance model were fed into a dispatch optimizer simulation package, which allows the plants with new flexibility characteristics to virtually participate in different EU markets against state-of-the-art plants.

Overview of WP 1 “Compressor off design operability”

Work package leader: Marcello Benvenuto, Ansaldo Energia, Italy

Under the framework of the European project TURBO-REFLEX, a strong interest in the compressor off-design optimisation, in order to improve renewable-conventional energy system interaction, was dealt with Work Package 1 (WP1).

This Work Package faced with the challenge to develop and mature retrofittable compressor technologies and advanced design features in order to enhance powerplant flexibility and improve off-design performance and operability. Experimental data and high-fidelity Computational Fluid Dynamics (CFD) assessment have been used to investigate these compressor capabilities.

Three main tasks have been created to investigate these flexibility improvements:

Task 1.1 focused on introducing compressor endwall designs (commonly referred to as casing treatment) to increase the compressor's and the whole engine operability, thereby reducing the Minimum Environmental Load (MEL) and increasing the part-load efficiency of the plant. Test rig data has shown that the compressor's stable operating range has been successfully extended, and efficiency was found to be improved across the full operating range.

Task 1.2 aimed to study the impact on stability and performance of extracting high mass-flow rates from the compressor by using blow-off valves as well as extra-closure of the Inlet Guide Vane (IGV) with respect to the standard MEL. Test campaign on existing power plant shows that MEL reduction can be obtained by the combination of IGV extra-closure and blow off valve fully open.

Task 1.3 dealt with the performance and operability impact on the compressor during air extraction (charging) and air injection (discharging) when integrated with Compressed Air Energy Storage (CAES) to extend gas turbine minimum load and improve the ramp-up rate. Numerical results have shown that compressor air extraction and injection can be used to facilitate enhanced gas turbine flexibility. The details are included in the second part of this document.

Aerodynamic Limits of Air Extraction and Injection for Gas Turbine Flexibility Improvements (Task 1.3)

Authors: Artur Szymanski, Uyioghosa Igie, Cranfield University, UK; Richard Hamilton, Mitsubishi Power Europe, UK

The task highlights the performance and operability of a compressor during air extraction (charging) and air injection (discharging) to extend gas turbine minimum load and improve the ramp-up rate, respectively. These capabilities can be achieved by retrofitting existing engines with flow ports behind the Outlet Guide Vane (OGV). A 3D CFD analysis of the last three stages of a Mitsubishi-type compressor was conducted. The air extraction study shows the aerodynamic implications of low to high air extractions that are limited by choke, high flow separation, and loss in the pressure at the hub region of OGV and last stage stator. As such, the back of the compressor was more affected than in the earlier stages. Based on these, the limit of flow extraction is 18% (of the compressor discharge). For the air injection study, for power augmentation, 16% of compressed air is allowed based on stall onset. Increasing air injection amplifies losses, blockage factor and absolute velocity angle. For the ramp-up rate analysis, up to 10% air injection is shown to be sustainable. The study has demonstrated that the compressor allows for these flexibility improvements that can be integrated with a Compressed Air Energy Storage (CAES) system.

Overview of WP 2 "Hot Gas Path technology"

Work package leader: Olaf Bernstrauch, Siemens Energy, Germany

The WP2 was divided into three tasks: ***T2.1*** *Gas Turbine Combustor with Enhanced Load Flexibility,* ***T2.2*** *Combustor Performance During Charging and Discharging and* ***T2.3*** *Advanced Turbine Cooling Schemes*

T2.1: KIT EBI and Siemens Energy analysed the forecast stability of jet stabilized premixed flames to reach better predictability of LBO limits with or without using pilot flames (more details see below).

T2.2: Cranfield University and MPE investigated the combustor performance and operability limits of compressed air extraction / injection. 3D combustor analyses showed that air extraction extend the min. environmental load by 7%-points w/o penalty on the thermoacoustic instability, but slightly increased NOx values. Air injection for improved ramp-up rates were promising in the emissions, thermo-acoustic and durability study.

T2.3: AES/AEN and USTUTT assessed the heat transfer and the impact of roughness on pressure loss and heat transfer. Numerical models have been applied to enhanced cooling schemes showing the advantages of combined structures. Transient experiments were performed to determine heat transfer characteristics on small scale SLM-samples at elevated pressure levels. The effects of surface roughness (e.g. from manufacturing) have been identified.

Calculation of the lean stability limit of a turbulent premixed jet flame array: from basic research to industrial application (Task 2.1)

Author: Alexander Schwagerus, Karlsruhe Institute of Technology, Germany

In order to extend the part-load operation range of current gas turbines, new combustor concepts are being investigated. One of these concepts is called matrix burner and consists of an array of non-swirling jet flames. A fundamental pre-requisite required for the design and scalability of new burner-concepts is the knowledge of lean blowout (LBO) limits, which is not available for the new concept. The work conducted in this task filled this gap by studying the flame stability in a model combustor and presents ways to calculate LBO limits for different operating conditions and geometrical variations. We present the results of the experimental LBO measurements and a developed correlation. In addition, a numerical setup based on a flame-generated-manifold approach was used to calculate LBO limits and compare them with experiments. For this purpose, two different turbulence-chemistry interaction models were implemented and compared. As industrial burners, due to the complex geometry and high-pressure conditions impose a serious challenge to calculations, the applicability of the developed numerical method was finally tested for these industrially relevant conditions. As a result, LBO simulation data of a prototype combustor from SIEMENS is presented.

Main achievements:

The main objective of Task 2.1 was to improve the predictability of flame stability limits of novel burner designs. For this reason, an extensive experimental database for the "matrix burner" was established in this task, including many different operating conditions and geometric variations. A correlation of the lean blowout (LBO) limits based on two Peclet numbers was developed. Furthermore, a numerical setup for calculating LBO, based on a tabulated chemistry approach, was developed and validated. Finally, it was shown that the numerical procedure can be successfully applied for industrial burner.

Overview of WP 3 "Mechanical Integrity in Flexible Operation"

Work package leader: Václav Černý, Doosan Škoda Power, Czech Republic

The WP 3 called Mechanical Integrity in Flexible Operation is composed of 3 main sections:

- Robust mechanical design
- Blade vibrations
- Thermal loading and exploitation of stretched design limits

Main goals of the sections are:

- Robust mechanical design – disc burst speed measurement and prediction/modelling
- Blade vibrations – Blade residual life monitoring system (HCF viewpoint)
- Thermal loading and exploitation of stretched design limits – crack propagation in steam turbine rotors as well as casings

Blade Residual Life Monitoring System (Task # 3.2)

Author: Jindřich Liška, University of West Bohemia, Czech Republic

In the design phase of steam turbine last stage blades the limits of blade vibration are calculated for designed operational conditions. In transient operation, during rapid change of load, speed and temperature, or in off-design operating conditions, the blade vibration can reach these limits and it is necessary to monitor their fatigue. The developed High Cycle Fatigue analysis tool (including method for calculation of mechanical stress in critical points of the blades and, in addition, the calculation of the stress limits with respect to the used sensors) enables:

- Precise HCF monitoring during changes of operational parameters (temperature, pressure …) in designed operating conditions.
- Precise HCF monitoring during operation in off-design operating conditions.
- This module used limits from FE modelling and BTT vibration measurement to predict residual blade fatigue for each blade in measured stage.

The visualization of HCF analysis results was implemented and included into the Remote Monitoring System. This enables the authorized user to see blade residual life from any device with web browser (smartphone, tablet, notebook…) online.

Overview of WP 4 "Online plant analytics and monitoring"

Work package leader: Alexander Wiedermann, MAN Energy Solutions SE, Germany

The WP 4 is composed of 4 main sections:

- Condition and efficiency monitoring system
- Steam turbine monitoring system
- Power station analytics
- Machine learning on large heterogeneous data sources for optimised operation of turbine components

The specific objectives are

- to collect heterogeneous engine data sourcing from manufacturing, assembly, operation, and servicing and built selective algorithms to allow analytic prediction of state and wear of engine components
- to develop and apply instrumentation for long-time monitoring of field engines and determine failure and wear levels by analysing data and correlate them with analysis and test rig data
- to develop new life prediction models based on test and field data

Condition based monitoring of plant turbomachinery (Task 4.1,4.4)

Author: Alexander Wiedermann, MAN Energy Solutions SE, Germany

Operation of thermal plants in the environment of increasing share of volatile renewable energy sources as wind and sun results in new challenges for the plant components. More flexible operating modes as quick ramp up times and load changes may increase wear and have an adverse effect on the life time of parts and components of steam and gas turbines of the plant. The project TURBO-REFLEX aims at improving the design and manufacturing technologies in the compressor and hot gas path regions to meet the requirements of more flexible operation of both new designs and retrofitted turbomachines in work packages 1 to 3. "Condition based monitoring" is an overarching topic that covers on-site control of parts and efficiency conditions of field engines. The goal is a more analytic prediction of maintenance intervals than with the conventional guidelines mostly valid for mainly full-load operation. The monitoring of the state of components from cradle to grave shall contribute to avoid unnecessary shut down and downtime of the plant if deviations from the expected operating modes are detected.

Based on newly developed condition based monitoring procedures for gas turbines the development steps will be explained starting from collection and analysis of raw data, filtering and anomaly detection of big data clouds. Towards the creation of a fully autonomous predictive procedure Machine Learning (ML) algorithms using image identification techniques are introduced and trained. Examples of applications are presented for evaluation of collected data of a large number of field engines of an existing gas turbine fleet and analysis and rig data of a newly industrial gas turbine family.