GAS TURBINES IN A CARBON-NEUTRAL SOCIETY

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COLLECTION OF ABSTRACTS

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DEVELOPMENT OF HYDROGEN-FIRED GAS TURBINE COMBUSTOR

Paper ID Number: 52-IGTC21

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Abstract

The introduction of hydrogen energy is an effective option to obtain sustainable development of economic activity while helping prevent global warming. In order to realize a sustainable society, the Mitsubishi Heavy Industries Ltd. (MHI) Group is promoting research and development of hydrogen gas turbine technologies with the support of the New Energy and Industrial Technology Development Organization (NEDO). The purpose of this paper is to outline the activities and future prospects of hydrogen firing technology. As the first step to accelerate the hydrogen use by thermal power plant, hydrogen cofiring combustor was developed which can enable the use of existing facilities without large-scale modifications. Using a modified combustor, a co firing (30 vol.% of hydrogen with natural gas) test has been successfully completed without occurrence of flashback or a significant increase in the internal pressure fluctuation. This co-firing capability results in a reduction in carbon dioxide (CO2) emissions by 10% when compared to conventional natural gas thermal power plant. As the next step, for 100% hydrogen firing, modifications of a different combustor developed for Integrated coal Gasification Combined Cycle (IGCC) plants is in progress. The elemental burner combustion tests at elevated pressures demonstrated that the modified burner achieved stable combustion and showed the possibility of suppressing NOx emissions.

DEVELOPMENT OF INNOVATIVE HYDROGEN COMBUSTION SYSTEMS FOR INDUSTRIAL GAS TURBINES

Paper ID Number: 2-IGTC21

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Abstract

Combined with the use of renewable energy sources for its production, hydrogen represents a possible alternative gas turbine fuel within future low emission power generation.

Kawasaki Heavy Industries, LTD. (KHI) has research and development projects for future hydrogen societies; production of hydrogen gas, refinement and liquefaction for transportation and storage, and utilization with gas turbines / gas engines for the generation of electricity.

Due to the large difference in the physical properties of hydrogen compared to other fuels such as natural gas (NG), well established gas turbine combustion systems cannot be directly applied for Dry-Low-Emission (DLE) hydrogen combustion. Thus, the development of DLE hydrogen combustion technologies is an essential and challenging task for the future of hydrogen fueled gas turbines.

The DLE Micro-Mix combustion principle (MMX) for hydrogen fuel has been in development for many years to significantly reduce NOx emissions. This combustion principle is based on cross-flow mixing of air and gaseous hydrogen which reacts in multiple miniaturized flames. The major advantages of this combustion principle are the inherent safety against flashback (stable flame) and the low NOx-emissions due to a very short residence time of the reactants in the flame region of the micro-flames.

HYDROGEN CAPABILITIES OF SIEMENS ENERGY GAS TURBINES, AN OEM PERSPECTIVE

Paper ID Number: 7-IGTC21

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Abstract

This paper provides an overview of hydrogen capabilities of Siemens Energy gas turbines, ranging from SGT-A05 with 4 MW to SGT5-9000HL with 593 MW. First, basic challenges of hydrogen combustion are presented, regarding both the combustion, as well as handling and safety, of hydrogen systems. Results from recent technology development projects are presented, including validation tests under engine conditions at Clean Energy Center (CEC) near Berlin. Additionally, details of engine validation tests will be provided.

Hydrogen is a promising fuel on the way to achieving future decarbonization targets. Being a feedstock to industrial processes, such as in refineries or for production of fertilizers, hydrogen already exceeds an annual production volume of 75 million tons. The vast majority is generated from conventional carbon emitting processes, such as steam methane reforming (SMR), and the IEA estimates 830 million tons of CO2 emissions from hydrogen production – equivalent to the combined emissions of Indonesia and Britain (IEA, The Future of Hydrogen, 2019). As hydrogen can also be generated from water and electricity via electrolysis, without emitting carbon, depending on the electricity source, it enables a sector-coupled economy, where, for instance, surplus renewable energy can be converted into a green feedstock for the industrial processes. This value chain, often referred to as Power-to-X, is an important element in the path towards deep decarbonization. Current challenges include the development of an appropriate infrastructure to support not only the production but also the distribution of hydrogen at large scale. Recent forecasts (Bloomberg, 2020) expect the hydrogen market to grow by more than 8 times by 2050 from today's approximately 75 Mt/year, and while the current feedstock market is expected to remain flat, new applications in transport, as well as in power generation, are expected to emerge. Specifically, for the power generation sector hydrogen has the benefit of future-proofing both existing investments, as well as investments into new gas turbines. By blending hydrogen with natural gas, for example, the carbon footprint can be gradually reduced or even eliminated by modest engine modifications and the economic lifetime of existing, reliably operating gas turbines can be extended even with the arrival of stricter carbon emission rules. Siemens Energy has developed several gas turbines that can be operated with hydrogen as primary fuel. Traditionally, utilization of hydrogen in gas turbines has been via diffusion combustion, where fuel and air are introduced into the combustor without premixing. This technique is inherently safe against flashback and auto-ignition. Earlier applications used diffusion combustion systems with steam or N2 injection for NOx control. Many aspects of hydrogen handling have been addressed in these systems, including safety, leakages, embrittlement and cracking. Despite its convenient features, diffusion combustion using diluents for NOx emission control is associated with high capital investment related to equipment and auxiliary systems, as well as additional operating expenses, and especially burdened with a penalty for plant efficiency. Consequently, recent applications utilize dry low NOx (DLN) systems for NOx control, with the capability to burn up to 60 vol% H2 and the potential to achieve 100 vol% H2, without any dilution. Siemens Energy has recently accelerated its efforts to extend hydrogen dry low emissions capability to its entire product range. This led to a solid commitment as part of the recent EUTurbines announcement (EUTURBINES, 2020) to make Siemens Energy gas turbines 100% H2 capable by 2030 to serve customer needs.

TECHNICAL SESSION 2: DECENTRALISED ENERGY SYSTEMS

TECHNO-ECONOMIC ANALYSIS OF SMALL SCALE CCHP SYSTEMS FOCUSED ON EMISSIONS PERFORMANCE

Paper ID Number: 14-IGTC21

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Abstract

Supercritical CO2 (sCO2) power cycles can offer several benefits: (1) Higher cycle efficiencies due to the unique thermodynamic properties of sCO2; (2) Reduced emissions resulting from lower fuel usage; (3) Compact turbomachinery, resulting in lower capex, reduced plant size/footprint, and more rapid response to load transients; (4) Reduced water usage, including water-free capability in dry-cooling applications; and (5) Heat source flexibility. These benefits can be achieved in a wide range of power applications including gas- and coal-fired power plants, bottoming cycles, industrial waste heat recovery, concentrated solar power, shipboard propulsion, biomass power plants, geothermal power, and nuclear power. Advancements to date have been limited to laboratory-scale test loops under 1 MWe. To facilitate further advancement and commercial deployment of the technology, pilot-scale testing is required to validate both component and system performance under realistic cycle conditions at sufficient scale.

The Supercritical Transformational Electric Power (STEP) project is a significant scale-up (to 10 MWe) of a fully integrated and functional electric power plant and in its execution, several technical risks and challenges will be mitigated, including (1) Turbomachinery (aerodynamics, seals, durability); (2) Recuperators (design, size, fabrication, durability); (3) Materials (corrosion, creep, fatigue); and (4) Cycle operability (startup, transients, load following).

AN INTEGRATED ENERGY SYSTEM TO DECARBONISE ISLANDS – GAS TURBINE ROLES AND REQUIREMENTS

Paper ID Number: 61-IGTC21

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Abstract

Energy supply on geographical islands is relatively costly compared to the mainland. Therefore, large-scale deployment of local renewable energy sources and storage systems brings economic benefits, while contributing to decarbonise the energy system of islands.

The main objective of the EU H2020 ROBINSON project is geographical islands' decarbonisation through developing a flexible and modular energy management system, better integration of renewable energy sources, and biomass and wastewater valorisation. The ROBINSON concept will be demonstrated on the island of Eigerøy (Norway), and lab-scale level replication studies will be conducted for the island of Crete (Greece) and the Western Isles (Scotland). The concept is based on integration of different energy vectors (electricity, heat, and gas), and existing and newly developed energy conversion and storage technologies. A micro gas turbine based combined heat and power unit plays a central role in the concept, supported by an anaerobic digester assisted by bio-electrochemical systems, a mobile innovative wind turbine, a gasifier to covert bio-waste, and hydrogen-related technologies (electrolyser and storage system).

This paper describes the current energy system of the island of Eigerøy, the ROBINSON concept and its main sub-system, i.e., the gas turbine based combined heat and power unit.

SCO2 POWER CYCLE DEVELOPMENT, MODELING AND DEMONSTRATION AT STEP

Paper ID Number: 35-IGTC21

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Abstract

The paper will focus on the 10 MWe Supercritical Transformational Electric Power (STEP) Pilot Facility and the important role that computer modeling and simulation has played in the design and will play in the facility operation.

The STEP Demo project team is led by the Gas Technology Institute (GTI), in collaboration with Southwest Research Institute, and General Electric Global Research (GE-GR), and the U.S. Department of Energy. The team is executing a project to design, construct, commission, and operate an integrated and reconfigurable 10 MWe sCO2 Pilot Plant Test Facility located in San Antonio, Texas. This project is a significant step toward commercialization of sCO2 cycle power generation and will demonstrate performance and operability needed for scale-up to commercial facilities. The pilot plant is currently under construction, with commissioning activities to start in the first quarter of 2022. By the end of this seven-year project the operability of the sCO2 power cycle will be demonstrated and documented starting with a simple recuperated cycle configuration initially operating at a 500 °C (932 °F turbine inlet temperature and progressing to a recompression closed Brayton cycle technology (RCBC) configuration operating at 715 °C (1319 °F).

TECHNICAL SESSION 3: ALTERNATIVE FUELS AND EFFICIENCY INCREASES

SUITABILITY OF LIQUID BIOFUELS IN SOLAR TURBINES INCORPORATED DLE INDUSTRIAL GAS TURBINES

Paper ID Number: 36-IGTC21

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Abstract

To meet the goals of 2015 Paris Climate Agreement, there is an effort to decarbonize energy across the globe for which all the renewable energy sources are getting evaluated. For many power generation applications there is a growing interest in using biofuels to replace fossils-based fuels, such as diesel and natural gas. Because of being plant-based, liquid biofuels, such as biodiesel and ethanol, have the potential to provide carbon-neutral power over its lifecycle basis. Many distributed power generation sites, such as universities, are interested in the feasibility of burning these biofuels, in stationary gas turbines to reduce their carbon-footprint as well as earn tax credits. Solar Turbines is at the forefront of providing fuel-flexible solutions to its distributed power generation customers. It has qualified several of its gas turbine models using both the conventional and dry low emissions (DLE) combustion systems on various biodiesel blends. In this paper the results from the combustion rig tests with DLE combustion injectors using B20 and B50 biodiesel blends and their comparison with those of No. 2 diesel and natural gas fuels are presented. The results are summarized in terms of gas turbines emissions and durability. The emissions (NOx, CO, UHC) from biodiesel blends were similar to, or less than that of Ultra Low Sulfur Diesel (ULSD), but higher than natural gas. Impacts of fuel properties on storage, handling and gas turbines operations are discussed. Finally, future development opportunities are presented.

AMMONIA BLENDED FUELS – ENERGY SOLUTIONS FOR A GREEN FUTURE

Paper ID Number: 62-IGTC21

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Abstract

Global warming is potentially the greatest challenge of this century, with anthropogenic CO_2 emissions the main source of greenhouse gas (GHGs) emissions. Recently, ammonia (NH_3) has gained attention as a potential carbon-free energy vector (carrier). NH_3 can be produced from waste sources, renewable energy, coupled with already existing infrastructures for production and distribution. However, pure NH_3 suffers from low flame speed and potentially important nitrogen oxide (NO_x) emissions. As such, blending fuels such as methane (CH_4) or hydrogen (H_2) with NH_3 could potentially address NH_3's poor combustion capacities.

Therefore, the program FLEXnCONFU has been conceived, supporting bespoke research to tackle some of the fundamental and applied challenges of using these blends. This paper addresses some of the current FLEXnCONFU's progress. Firstly, a series of experiments using a spherical expanding flame set-up was employed to investigate potential increases in reactivity of NH_3 and its blends with H_2 and CH_4. Secondly, direct numerical simulation (DNS) modelling of NH_3/H_2 turbulent expanding spherical flames was performed at lean and rich conditions. Finally, this study also discusses experimental results from an industrial scale swirl burner with varying content of CH_4/NH_3/H_2 under rich condition ($\Phi = 1.2$), in terms of radicals and exhaust emissions. The work is a step towards using non-conventional fuels such as NH_3 and H_2 and scaling up the technology from lab to industrial level.

TECHNICAL CONSIDERATIONS AND BENEFITS OF INSTALLING COMBINED CYCLE POWER PLANTS ON OFFSHORE OIL & GAS PRODUCTION FACILITIES

Paper ID Number: 64-IGTC21

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Abstract

Open/simple gas turbines (GTs) have been the preferred means of power generation on offshore oil and gas production facilities over the past two decades. GT-based packages offer a number of advantages over other widely used power solutions, such as gas engines and diesel gensets – including high power density, increased availability, and reduced greenhouse gas (GHG) emissions. In recent years, however, with many offshore operators establishing targets for environmental footprint reductions, new pathways for decarbonization are being evaluated. Combined cycle is a concept that has been widely employed in onshore industrial applications and is now garnering more interest in the offshore segment. This paper will discuss the benefits combined cycle power plants can provide when compared to open cycle GTs and outlines installation and operability considerations for both greenfields and brownfields. In the case of the latter, special measures may need to be taken to ensure that the combined cycle package is within existing allowable tolerances for weight and footprint. Siemens Energy has developed a solution for this specific market need known as Ultra-light Combined Cycle (ULCC).

TECHNICAL SESSION 4: ADDITIVE MANUFACTURING AND MATERIALS

COMPOSITE MATERIALS APPLIED ON GAS TURBINE'S INLET SYSTEM

Paper ID Number: 26-IGTC21

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Abstract

A new inlet plenum made of composite material – glass fiber reinforced plastic (GFRP) was designed and manufactured for a Baker Hughes gas turbine. The invention described in this paper is patent pending. Flow optimization, new technology introduction, material tests, and structural analysis were performed in order to execute this project. Composite material description and its advantages are described, followed by the project stages details and manufacturing process description. Moreover, the material tests and benefits of this new technology introduction are presented.

RAPID PROTOTYPING USING DIGITAL ADDITIVE MANUFACTURING AT SOLAR TURBINES

Paper ID Number: 37-IGTC21

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Abstract

In a world of rapidly evolving technology, there are growing demands for faster results as well as a reduction of cost for gas turbine development cycles. The time for prototype trials that often require several iterations between engineering, manufacturing, and assembly are being reduced. The lean solution of Additive Manufacturing (AM) Rapid Prototyping allows you to decrease the development cycle by accelerating design iterations, providing rapid learning to find the best solution quickly.

Historically, the time it takes to go from idea generation to concept design and testing/validation can take years before a part is ready for production implementation. The Additive Manufacturing organization at Solar Turbines has been focusing on combustion system components that would traditionally be made from complex castings and assemblies that require special molds, fixtures, and elaborate tooling. All of these steps add to the initial cost and lead time required to evaluate if an idea is even feasible. A traditional fuel nozzle development project can take between one to three years and includes multiple separate design iterations that each need to be designed, built and rig tested. With the use of AM Rapid Prototyping fuel nozzles development projects have been completed and tested in a matter of months.

Solar learned the advantages of designing for AM and the benefits of rapid prototyping on the first attempt at producing an AM combustion component. Solar acquired its first 3D printer in 2014 with a goal to reduce production costs. The targeted combustor components were already designed and modeled for additive manufacturing. However, the team realized that with additive manufacturing and using an iterative design process with rapid prototyping the part could be optimized for lower cost and improved performance. When adjusting an existing model to the additive process, numerous obstacles are present that need to be resolved while staying within the original design requirements. Some of the

lessons learned with the first AM component pointed out that designing for additive manufacturing must be embraced and be flexible enough to change designs through initial trials of AM. With AM Rapid Prototyping it is easy to print a wide range of product variations that can assist in developing a new product to solve a problem in an iterative design and manufacturing process rather than being given a design solution and figuring out how to make it.

ADDITIVE MANUFACTURE AND THE GAS TURBINE COMBUSTOR: CHALLENGES AND OPPORTUNITIES TO ENABLE LOW-CARBON FUEL FLEXIBILITY

Paper ID Number: 54-IGTC21

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Abstract

Advances in gas turbine (GT) combustion are enabled by metal additive manufacturing (AM) using selective laser melting (SLM) and other methods. In future low-carbon energy systems, AM will be critical for GTs operating on fuels such as hydrogen, ammonia, and biofuels. This paper evaluates the impact of AM on GT combustors, focusing on design freedom for novel geometries, reduced product development timelines, multiple component integration, and high-temperature materials suitable for harsh environments. Current AM challenges and research needs for GT combustors are discussed with industry input. These challenges are shown to be priority R&D areas across the GT value chain. Recent academic advances show the positive influence of widening access to SLM platforms and AM facilitates research using materials and geometries relevant to the GT community. Micro GTs are well-suited to SLM platforms, enabling novel geometries incorporating multiple functional parts including heat exchangers and porous media using advanced metal alloys. For industrial GTs, AM reduces new combustor product development time, as rapid prototyping and testing complements numerical methods. This review provides compelling evidence for continued AM R&D for GT combustion applications to meet future decarbonization goals.

TECHNICAL SESSION 5: HYDROGEN GAS TURBINE DEVELOPMENTS

THE DESIGN AND OPTIMISATION OF A HYDROGEN COMBUSTOR FOR A 100-KW MICRO GAS TURBINE

Paper ID Number: 23-IGTC21

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Abstract

Along growing deployment of renewable electricity production, like wind and solar, the demand for energy storage will increase. One of the most promising ways to cover the medium to long-term storage is to use the excess electricity to produce hydrogen via electrolysis. Therefore, the importance of research into the design of a small to medium-sized hydrogen fueled micro Gas Turbine (mGT) unit for efficient, local heat and electricity production becomes apparent. One of the largest challenges to this end is the design of an ultra-low NOx hydrogen combustor. In this paper, we report on the progress of our work towards that goal. Firstly, an initial single-nozzle swirler (swozzle) combustor geometry was proposed and designed using steady RANS and LES. Numerical results of this swozzle combustor indicated unacceptable high NOx emissions (1400 ppm). Therefore, in a second step, a full CFD (steady RANS) design and optimization of an alternative combustion chamber concept, the micromix type which is known for its advantages towards NOx-emission reduction, was performed. This improved micromix combustor geometry resulted indeed in a NOx level reduction of more than 1 order of magnitude compared to the initial swozzle design (from 1400 ppm to 250 ppm). Additionally, several design parameters, such as the position and diameter of the hydrogen injection nozzle and the Air Guiding Panel (AGP) height, have been optimized to improve the flow patterns.

COMBUSTION OF CH4/H2 MIXTURES IN GAS TURBINES – EFFECT OF MIXING ON RISK OF FLASHBACK

Paper ID Number: 24-IGTC21

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Abstract

Boundary layer flashback of hydrogen-methane-air flames is investigated experimentally in a model swirl combustor. The combustor is installed in a high-pressure test rig to study flashbacks up to a pressure of 7.5 bar. The present work focuses on the effect of technical premixing on flashback limits in comparison to perfectly premixed conditions. For technical premixing, fuel is injected in the premix section of the burner through ports in the vanes of the axial swirler. To achieve perfectly premixed conditions, fuel and air are already well mixed far upstream of the burner mixing section. The results show that for H_2-CH_4 air flames with a significant amount of H_2 (more than 50% by vol.), where flashback occurs at rather lean conditions, the risk for flashback increases significantly when fuel and air are not perfectly mixed. In contrast, if the amount of H_2 in the fuel mixture is low, unmixedness between fuel and air hardly effects the flashback propensity.

NUMERICAL INVESTIGATION OF GAS TURBINE BURNERS OPERATING WITH HYDROGEN AND HYDROGEN-AMMONIA BLENDS

Paper ID Number: 44-IGTC21

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Abstract

Attractivity of carbon-free fuels, like hydrogen or ammonia, has recently increased, as they can be produced with zero carbon emission via electrolysis and thus supporting further expansion of renewables sources adoption through energy storage concepts.

Gas turbines combustion system incremental developments are pointing to hydrogen use and some demonstrations of potential in abatement of the greenhouse gas carbon-dioxide have been already achieved and documented. Concerning the ammonia, low technology level or conceptual studies only are available: as a matter of fact, a proven technology is nowadays still unavailable for the abatement of NOx emissions.

Hydrogen-ammonia blending is of interest as it can be used to overcome the storage and transport limitations of pure hydrogen, although a few examples of applicability are nowadays available.

Main objective of this paper is to investigate the capability of real gas turbine burners to operate with hydrogen and hydrogen-ammonia blends.

The impact on gas turbine operability is reported alongside the evaluation of NOx emissions. Numerical models have been used for prediction of NOx emissions at relevant gas turbine operating conditions, leveraging available data from full scale annular combustor rig test with hydrogen-air mixtures. Models include 1D freely propagating flame, a basic chemical reactor network and a 3D computational fluid dynamic setup. The latter, already used in the ambit of hydrogen combustion, has been upgraded to predict NOx emissions when hydrogen-ammonia blends are provided to real burner geometries.

The discussion on operating constrains is addressed in this paper leading to the definition of a viable hydrogen-ammonia blend for an existing combustion system architecture.

EARLY EXPERIENCE APPLYING PROCESS COMPENSATED RESONANCE TESTING TO NEW AND REPAIRED TURBINE BLADE QUALITY ASSURANCE

Paper ID Number: 3-IGTC21

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Abstract

Industrial gas turbine (IGT) blades are subjected to various nondestructive evaluation (NDE) methods to ensure structural integrity and uniform quality. Legacy NDE, like x-ray diffraction and ultrasonic testing, are limited to surface or point-by-point inspection. Process Compensated Resonance Testing (PCRT) is a volumetric ultrasonic resonance method that applies a swept sine excitation and records the component modal response. The resonance spectrum relates to component material, microstructure, geometry, and defects.

PCRT applies advanced statistical analyses and machine learning to the resonance spectrum to identify parts with defective metallurgical conditions. In aerospace, PCRT is the only NDE method to be approved by the FAA to replace cutups for the metallurgical disposition of turbine blades. EPRI and Vibrant are leveraging PCRT's decade-long aerospace success for IGT components. They have scanned over 10,000 blades from various IGT models with PCRT, demonstrating value for owner/operators with efficient receiving inspection, evaluation of component fitness for repair, and quantification of material rejuvenation heat treatment consistency.

The paper summarizes PCRT case studies for aero engine and large IGT blades for metallurgical qualification and defect detection. These studies examine crystal orientation, overtemperature exposure, heat treatment rejuvenation, and casting flaws. Ongoing PCRT evaluations of specific material states are also discussed.

Keywords: Resonance, Ultrasonics, Quality Assurance, Nondestructive Evaluation, Metallurgy, Microstructure

GAS TURBINE UNCERTAINTY USING BAYESIAN STATISTICS

Paper ID Number 31-IGTC21

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Abstract

Condition-based lifing methods have become more common for industrial gas turbines. Component temperature distributions are one key input into these advanced lifing methods, with analytical models used to predict these temperatures. These typically predict bounding temperatures, which do not accurately represent the variability in temperature that occurs in a turbine. As a result, there remains the potential for significant errors in predictions of component temperatures and significant pessimism in lifing assessments. The analytical models rely on a series of assumptions and are typically determined using the experience of thermal engineers and refined using experimental data. This process is time consuming, subjective, and does not give any indication of the potential error in the predictions.

This paper presents an approach for systematically combining the judgement of experts with measurements. Prior distributions for each model boundary condition are determined using engineering judgement, and then refined using Bayesian Inference from the available measurements. This approach leads to a map of most likely temperature, uncertainty and variability across the component. The technique can potentially expedite the process of thermal model matching, make it repeatable, provide distributions to probabilistic structural calculations, indicate the ideal locations for additional measurements and predict the value of measurement campaigns.

NON-DESTRUCTIVE EVALUATION FOR INDUSTRY 4.0

Paper ID Number: 63-IGTC21

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Abstract

Non-Destructive Evaluation is well established in Gas Turbine life cycle management. However, it is a stand-alone, labour-intensive activity that adds costs and delays throughout life-cycle operations. Here, we consider a vision for the future of NDE, "NDE 4.0" and the opportunities it presents. We outline the journey required to achieve this vision and the part played in that journey by the activities of the Research Centre for NDE. Whilst NDE 4.0 requires changes to skill sets, process and equipment and requires integration with enterprise systems and methodology at multiple levels, there are also opportunities for technology to transform the performance of NDE and facilitate it's integration with the life-cycle management processes and systems. RCNDE is championing a suite of technology developments to deliver this capability across multiple high integrity engineering sectors.

TECHNICAL SESSION 7: SYSTEM INTEGRATION

INTEGRATING HIGH RENEWABLE SHARE INTO TODAY'S GAS TURBINE POWER PLANT ENERGY SYSTEMS

Paper ID Number: 8-IGTC21

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Abstract

This paper presents three case studies that integrate renewable power into existing energy infrastructures. The first case study explains how to reduce curtailed green electricity. Due to high intermittency of renewable power supply, large fluctuations of market electricity prices exist and can be used advantageously to generate new revenue streams for plant operators. The second case study shows the strength of combining hydrogen, battery and storage in autarkic decarbonized energy systems via sector coupling. The energy usage factor of the electricity-to-hydrogen-to-electricity chain increases from 30% to 80%. The third case study describes the first-ever demonstration project of a fully integrated Power-to-H_2-to-Power industrial scale installation in a co-generation power plant including an advanced high-hydrogen DLE gas turbine.

Keywords: Power-to-X; hydrogen; energy systems

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DECARBONISATION OF GAS TURBINE BY BURNING HYDROGEN PRODUCED LOCALLY BY ELECTROLYSIS

Paper ID Number: 32-IGTC21

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Abstract

This study deals with the conversion of a 125 MW peak load Gas Turbine from gas or domestic fuel to hydrogen, and considers the equipment required for this purpose. The problem is studied from an end-user perspective considering that the turbine has been changed or retrofitted previously. The study only refers to H2 equipment.

The study tries to respond to the following question: the path to 100% hydrogen in new turbines seems technologically promising. But is it technically feasible for a real industrial turbine and is it economical viable if we take into account the global costs?

A big challenge in scaling from small hydrogen blends to 100% is the big quantity of electricity needed for electrolytic hydrogen production and important storage needed. This paper only considers the case of onsite electrolytic hydrogen production and on site tank storage.

A set of 6 cases were studied for this note. They vary three parameters: Hydrogen-blended (30% H2 and 70% natural gas) or 100% hydrogen power generation project ; Storage capacity: providing 50 hours, 120h or 25 hours of operation and finally refilling time of the storage capacity: for a period of 1 month or 4 months of electrolyser operation.

For the various case studies, the following technical parameters were roughly sized: capacity of electrolysers in MW, storage capacity in tones, cryogenic pumping and vaporizing flow in Nm3/h.

CAPEX and OPEX costs were estimated for each case study.

It is important to precise that costs are treated at a macro scale. In a real project, other important costs should be added as the integration engineering, site works, commissioning, and obviously the conversion of the GT itself.

Aside from the cost aspects, this study also identifies the technical aspects of equipment associated with a project of this type, and analyzes feasibility based on market capabilities today. It provides elements to consider such as the ground installation to be expected if one wishes to install this equipment in an industrial site as well as elements of regulatory constraints and industrial risks that may be binding.

Scope of the study

The paper presents a pre-feasibility study that sizes the adequate H2 production systems based on alkaline electrolysis technology, H2 storage solutions (gaseous and liquefied), pumping and regasification to be installed in order to adequately feed one GT.

Different scenarios are exposed based on H2 proportion in the gas turbine (100% H2 and mixed fuel 30% H2 co-fired with natural gas), and storage capacity needs which depend on specified autonomy and the number of hours of operation of the gas turbine.

The study attempts to show cost estimates at a macro scale, associated to the introduction of H2 equipment in an industrial existing site and some elements to be considered referring to equipment footprint and industrial risks.

Emphasis is placed on H2 equipment, the conversion of the existing gas turbine in a H2 gas turbine is out of the scope of work.

Summary of main results and findings

- Of six case studies performed, only two cases (2 and 6) would be potentially viable technically and economically. These study cases incorporate an adapted electrolysis capacity (less than 20 MW), a plausible storage on an industrial site (less than 10 tons). These cases were estimated at ±50% between €30 and €40 million for study case 2 and between €20 and €25 million for study case 6.
- In general, thinking of a turbine supply with an electrolyser operating at the same time to ensure the necessary production of H2 is not possible taking into account the large quantities of H2 required for a GT of this size and especially because the start of the turbines is done at peak load. It would therefore be illogical to supply the electrolysers with energy at this time.
- Storage and filling time impact the hydrogen production capacity: the longer the filling time, the smaller the installed production capacity for the same storage capacity. The larger the storage, the more installed production capacity. It is therefore necessary to find a good compromise between these two parameters for each project.
- The costs of electrolysers represent an important part of the CAPEX for a project. These costs are constantly evolving and the definitive estimation should be done on a project specific way. Values are not to take in consideration for all projects.
- Since the reduction in CO2 emissions is not proportional to the volume of hydrogen in natural gas, one can think that only a turbine burning blending with a high proportion of hydrogen or 100% H2 has a real environmental impact.
- The industrial risks associated with a hydrogen production and a storage facilities are significant and can impact the realization of an industrial project on site.

Keywords:

GTD-111 DS, Combustion turbine, Hot Isostatic Pressing (HIP), Repair, Solution heat treatment, Mechanical properties.

COMBINED CYCLE PERFORMANCE GAIN THROUGH INTAKE CONDITIONING

Paper ID Number: 33-IGTC21

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Abstract

The increasing share of electricity produced from renewable energy sources (RES), with the consequent strong penetration in the current energy network, is causing a growing need of balancing power to compensate power supply from such fluctuating sources. For these reasons, nowadays the power plants are running more often at part-load providing ancillary services and sustaining the grid operability. Therefore, an increase in efficiency during part-load operation impacts positively the year-round efficiency. A possible solution, studied in the framework of PUMP-HEAT H2020 Project[1] for flexibility enhancement, is characterized by the intake conditioning. Such concept, after a general introduction, is here applied to increase the temperature of the intake of power oriented combined cycle (PO-CCGT), mitigating the Gas Turbine off-design and resulting in an enhanced efficiency. In this work, a statistical analysis of actual PO-CCGT production profiles and climatic data is performed considering the Italian context, to assess the potential of this practice under the economic and environmental point of view.

[1] This project has received funding from the European Union's Horizon 2020 research and innovation programme under agreement No 764706

TECHNICAL SESSION 8: COMPONENT MONITORING AND LIFE EXTENSION

AN APPROACH FOR GAS TURBINE LIFE EXTENSION

Paper ID: 30-IGTC21

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Abstract

Market and legislative demands have forced gas turbine owners to operate their equipment flexibly, resulting in increased cycling, faster ramp rates and peak-firing. Often these turbines were designed for base loading and creep dominated failures, but are now subject to increased thermal stresses, severely impacting component life. The accurate evaluation of creep and low cycle fatigue requires detailed material properties and an exact model of temperatures, pressures, mass flow and stress for each component. This information is often only available to the OEM. The operator is therefore left with the OEM's calculation of equivalent operating hours, which represents a simplistic method of lifing, and is normally conservative in its predictions particularly in relation to creep. This paper describes an alternative method for creep damage calculation that sits between the established Equivalent Hours calculation and that of the detailed, in-depth, assessment using complex material models and detailed component level analysis. There is no doubt that turbines that operate flexibly will generally have shorter operational lives, however if some of the conservatism can be removed their operational lives can be extended and the potential cost saving is considerable as the case study presented here demonstrates.

The design of a gas turbine includes conservative assumptions both about how they operate and about the material's response to the duty they are exposed to. Removing conservatism and accounting for 'real' operation provides the opportunity to understand opportunities to increase the predicted life of the gas turbine, which tends to be limited by hot gas path (HGP) components. These HGP components are high integrity which presents challenges to determining their condition. Nevertheless, a better understanding of these components can yield improvements in the remaining useful life, or extensions to the inspection and overhaul intervals of the turbines. In the approach described in this paper, we have addressed two key areas of conservatism:

1) Improved material degradation models.
2) The use the more realistic material models in concert with the actual operating histories.

Improved material models: using the basis of design provided by the OEMs it is possible to identify the Equivalent Operating Hour (EOH) degradation models used for lifing gas turbines. Standard EOH degradation models tend to assume a simplified relationship between metal temperature and damage, especially at reduced loads. By supplementing the EOH degradation models with non-linear creep laws, it is possible to take advantage of the physical relationship between damage and metal temperature.

Use of operating conditions: GTs typically operate in a less onerous state than the design conditions for most of their lives. Operators are able to access the operational data and so it is possible to leverage this measured data and the design information provided by the OEMs, to assess opportunities to increase remaining useful life by capitalising on potentially lower damage rates that accrue during off-design power operation.

In this paper we provide a practical application of our lifing approach to a GT26 gas turbine. We demonstrate how our lifing approach allows us to:

- Provide a more accurate understanding of damage in HGP components.
- Undertake 'what-if' analysis to understand how a change in operation may affect remaining life.
- Understand risk of continued operation to optimise outage planning and predictive maintenance.

RISK-BASED APPROACH TO ASSESS THE TECHNO-ECONOMIC FEASIBILITY OF GAS TURBINE COMPONENT LIFE EXTENSION

Paper ID Number: 43-IGTC21

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Abstract

Growing demand for flexibility and high maintenance costs make gas turbine systems increasingly expensive. Reliability and availability are both key factors and have a direct impact on the economics of these systems. The plants operators require fast and reliable methods to assess the remaining lifetime of the gas turbine components. Nowadays, inspection and replacement intervals for gas turbine components are typically determined by model-based assessment of equivalent operating hours (EOH). However, this method requires a lengthy and expensive process, which needs to be repeated in case of components upgrades.

The innovative method proposed in this work collects a considerable number of operational data on different types of machines (ranging from small engines to heavy duty), through which it is possible to build a curve representing the probability of failure. The curve can be updated at each inspection by assessing the presence of damage mechanisms from time to time (implementing data-driven procedures for monitoring, diagnosis, and advanced prognosis). The result will be an updated risk curve that provides operators with information about the health status of the components and the potential risk associated to late replacement.

Integrating the model developed with the costs associated to maintenance, a comparative cost analysis is carried out to support the decision-making process and evaluate the possible benefits. It is clear that a risk-based approach (based on statistical data analysis) is easier to use, less costly than a modelling approach and can result in significant economic benefits.

Keywords: Gas turbines, Risk-based approach, Decision-making procedure, Statistical method, Cost-benefits analysis.

UN-BUZZ-WORDING THE DIGITAL TWIN: A PRACTICAL GUIDE AND EXAMPLES FOR POWER PLANT OPERATORS

Paper ID Number: 25-IGTC21

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Abstract

Over the last 5-10 years, "Digital Twin" has become a ubiquitous term used to market a wide variety of seemingly unrelated products. This has caused confusion of products and services being marketed using this term. This use also leads to missed expectations between the solution provider and the customer. This paper will use experiences from the authors and end users to provide a guide which describes: what are the different flavors of 'digital twins'? What should a true 'digital twin' be able to do with respect to power plant operations? How do "twins" make use (or repackage) existing technologies to make them more practical for the power plant operator? Examples related to power plant performance estimations using a twin are also provided.

Keywords: Digital Twin, Gas Turbines, Analytics

TECHNICAL SESSION 9: RETROFIT AND OPTIMISATION SOLUTIONS

HIGH HYDROGEN GAS TURBINE RETROFIT SOLUTION TO ELIMINATE CARBON EMISSIONS

Paper ID Number: 15-IGTC21

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Abstract

Gas turbines with the ability to operate on hydrogen offer a low carbon solution to support the stability of the energy grid. However, hydrogen is a highly reactive fuel and presents challenges for industry standard dry low NOx combustors to switch between natural gas and hydrogen fuel blends while remaining stable and with NOx emissions always below stringent limits. Significant concerns regarding emission compliance, combustion dynamics and stability must be addressed prior to operation on these fuels.

To address this, a consortium consisting of equipment manufacturers, academia and end-users was set-up. The key objective is to develop a gas turbine combustor retrofit solution for fuel flexible operation from 100% natural gas to 100% hydrogen, and any mixture thereof, suitable for gas turbines between 1-300 MW.

This paper presents the results from the first phase of the project, which focused on atmospheric testing of a combustor based on the FlameSheet™ technology and adapted to the 1.8 MW OP16 gas turbine. From the tests, it was found that it was possible to achieve 100% hydrogen combustion with single digit NOx emissions

THE IMPORTANCE OF TORSIONAL VIBRATIONS IN THE ENERGY TRANSITION”,

Paper ID Number: 49-IGTC21

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Abstract

This paper aims at introducing torsional vibrations with a focus on the energy production sector. Although considerable effort has been devoted to the subject leading to a profound understanding since decades, important damage to shaft lines still occurs. The main reason is that for energy production units (e.g. gas turbine power plants, wind turbines…), the excitation primarily comes from interaction with the energy grid. Consequently, changes to the electricity grid like the introduction of High Voltage Direct Current stations (HVDC) stations, heavily consuming arc furnaces, series capacitor banks … could potentially lead to excessive torsional vibrations which were not accounted for in the design stage of the unit. With the upcoming energy transition, more than ever torsional vibrations may not be overlooked.

Along with some key aspects of torsional vibrations in the energy production sector including measurement results, some important known grid interaction phenomena will be outlined such as SubSynchronous Resonance, interaction with HVDC stations and heavy consuming arc furnace plants.

A COMPARISON OF MANAGEMENT APPROACHES FOR ASSET OPTIMIZATION

Paper ID Number: 28-IGTC21

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Abstract

As the energy landscape evolves and becomes progressively challenging for industrial gas turbines, OEMs are expected to support increased flexibility, maintain reliability, ensure availability all while reducing total cost of ownership. These competing requirements have led OEMs and even some third-party suppliers, to develop asset management tools to allow owners and operators to optimize the operation of their engines and manage service intervals, maintenance costs and performance levels. These tools are typically developed by the OEMs as a way to manage their equipment and are subject to the providers intellectual property but do fall into several high-level categories which can be compared. These categories include the traditional time-based approach, or time between overhaul (TBO), in which service intervals and maintenance costs are pre-determined by the OEM and are based on design specifications and overall experience. The equivalent operating hours (EoH) approach, in which the operator uses equations provided by the OEM to determine the remaining useful life of the engine based on key operational parameters, such as engine starts. Finally, the true condition-based approach, in which the operating conditions of the engine determines the remaining useful life as a function of the nonlinear nature of damage accumulation. This paper compares and contrasts these different approaches to highlight the advantages and disadvantages relative to current applications. The paper also provides a speculative view of how these approaches will perform in the future as the energy market changes.