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Surge prevention for gas turbines connected with large volume size: Experimental demonstration with a microturbine

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HIGHLIGHTS

- Surge prevention techniques are necessary in gas turbines with large volumes.
- A complete surge prevention technique was developed and demonstrated.
- Surge approaching was detected and specific prevention operations implemented.
- The technique was effective also for compressor inlet temperature increase.

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ABSTRACT

The aim of this work is the demonstration of a surge prevention technique for advanced gas turbine cycles. There is significant surge risk in dynamic operation for turbines connected with large volume size additional components, such as a fuel cell stack, a saturator, a solar receiver or a heat exchanger for external combustion. In comparison with standard gas turbines, the volume size generates different behaviour during dynamic operations (with significant surge risk), especially considering that such additional components are including important dynamic constraints.

In order to prevent the surge events, a vibration analysis was carried out to develop precursors which are able to highlight the approach of this unstable operative zone. Since the sub-synchronous content of the measured vibrations is significantly increasing approaching the surge line, special attention was devoted to this parameter.

The demonstration of a surge prevention system based on the sub-synchronous vibration content was carried out at the Innovative Energy Systems Laboratory of the University of Genoa. In this laboratory, a recuperated microturbine connected with a large size vessel was used. Starting from the stable operation, closing a valve in the main air line or increasing the compressor inlet temperature produced operative conditions with significant surge risk. The increase in sub-synchronous vibration content detected by the control system was used to perform an active operation (bleed valve opening) to avoid the approaching surge event.

1. Introduction

The global increase in energy demand and concerns regarding environmental conservation have led to the significant research in efficient power generation technologies (gas turbine aspects highlighted in: [1] for advanced cycles, [2] for high efficiency generation, [3] for thermoeconomic impact and [4] for applications in polygeneration grids). However, remarkable efficiency increase is hard to achieve through further optimization of simple gas turbine cycle, since the existing technology is now close to its maximum improvement [5]. For this reason, advanced cycles based on the additional components can play a significant role to achieve the target of more efficient power generation [1]. Although these modified layouts are limited by cost and geometric constraints [6], different advanced cycles have reached the commercial level in specific fields [7]. A typical example includes the recuperated microturbine cycles which have acceptable efficiency in small size units [8]. Moreover, the significant research activities on concentrated solar power [9], micro Humid Air Turbine (micro-HAT) systems ([10] includes calculations on an entire micro-HAT plant and [11] an experimental campaign on the saturator, that is the most critical component), and fuel cell based hybrid plants [12] have shown a significant potential interest for gas turbines connected with additional components. An important aspect to be considered when additional components are included in the turbine cycle is the increased volume

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Nomenclature

Variables

FO Fractional Opening [%]
Kp surge margin [–]
m mass flow rate [kg/s]
N rotational speed [rpm]
TOT Turbine Outlet Temperature [K]
β pressure ratio [–]

Subscripts

0 design
sl surge limit on compressor map

Acronyms

CSP Concentrated Solar Power
E. grid Electrical grid
Ex heat Exchanger
HAT Humid Air Turbine
REC RECuperator
RMS Root Mean Square
SOFC Solid Oxide Fuel Cell
TPG Thermochemical Power Group

size in the zone located between the compressor outlet duct and the expander inlet. Although in some cases (e.g. recuperated cycle) the additional volume is just related to the additional ducts, several advanced configurations (e.g. the mentioned hybrid systems) involve the additional volume which is more than two or three order of magnitudes larger than the standard machine one [13].

Even if the additional volume has not a significant impact on the steady-state performance, delayed response in the pressurization/depressurization phases during the transient operations results in a completely different behaviour. This aspect is critical for the plant constraints and control system. Thus, in order to consider this transient effect, standard controllers developed by the turbine manufacturers require a complete re-design activity. For instance, the standard shutdown phase has to be modified: implementing actions (on the fuel system or on the generator) to reduce the rotational speed decay and, hence, to avoid the surge conditions which are caused by the slow depressurization rate (in comparison with the standard machine behaviour) [14].

Among different kinds of risks which can be produced by the additional volume during transient operations, surge event is the most dangerous one for both the turbine and the connected components. For this reason, special attention is devoted to control techniques which are able to prevent such critical phenomenon [15]. Since compressor maps (when available) are not reliable to prevent surge [16] during all the operative conditions (e.g. in case of component degradation [17]), the definition of surge measurable precursors is mandatory for a wide commercialization of such advanced turbine-based plants.

Although some authors ([18] shows a statistical approach based on pressure measurements and [19] presents a vibration analysis on a compressor) have already presented possible surge precursors, the novelty of this paper regards the development of a gas turbine control approach that, on the basis of standard accelerometer measurements, is able to prevent surge events in case of critical conditions. The analysis is not focused on the fluid dynamic aspects of the machine components, but it is devoted to the entire cycle considering specific behaviour due to the additional volume [12]. Although the surge prevention method shown in this work has a general target for all the innovative gas turbines, the experimental work of this paper regards a T100 microturbine [20]. The selection of T100 microturbine for experimental investigation is motivated by the interest in such plants for distributed generation [21], and due to the availability of a flexible rig [22] which includes a T100 microturbine coupled with a large size external volume.

The experiential demonstration shown in this paper was carried out with a flexible experimental facility which has been developed in previous works ([13] for a general rig presentation, [20] for the emulation technique based on a cyber-physical approach, [22] for the performance curves of the emulated system) by the Thermochemical Power Group (TPG) at the Innovative Energy Systems Laboratory - University of Genoa. Although this test rig was designed and installed for the emulation of Solid Oxide Fuel Cell (SOFC) hybrid systems [23], this plant can be used effectively for analysing the general impact of the volume size on the machine stability. The plant control system was equipped with an additional subroutine, which is able to calculate the sub-synchronous vibration content (the root mean square value) and to

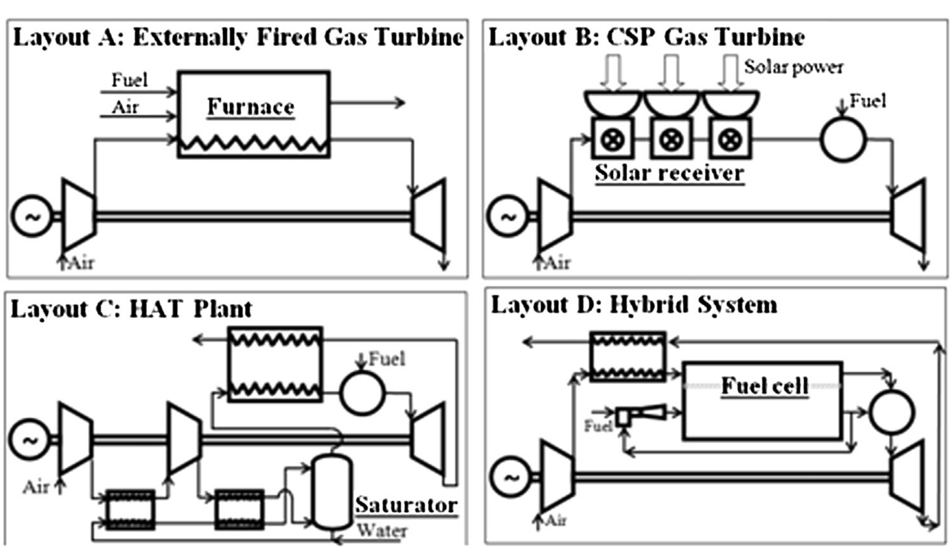

Fig. 1. Main gas turbine advanced layouts.