Automated compressor surge recovery with cold air bypass in gas turbine based hybrid systems

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Long Abstract

Introduction

The recuperated gas turbine cycle is currently the most efficient way to convert thermal energy to electric power. Advanced power systems of the future will require hybridization of gas turbine with other technologies to realize efficiency and flexibility goals. The coupling of a solid oxide fuel cell (SOFC) and a micro gas turbine is an example of hybrid system where the fuel cell works as thermal source for the gas turbine, replacing the combustion chamber in a typical cycle. In this way, high-grade heat from the fuel cell can be converted to additional electric power by the gas turbine, reaching total electric efficiency around 70% on natural gas LHV [1].

In this type of system, the air is extracted from the compressor to feed the cathode side of the SOFC. The volume of a hybrid requires two orders of magnitude more than the compressor plenum volume of a simple cycle, which results in a degradation of compressor surge margin and complicated compressor dynamics. When turbine rotational speed is reduced during transients, compressor inlet airflow and pressure ratio decrease at different rates because of the large volume of the system. In this case, the operating point on the compressor map can follow a path toward the stall line. Drastic changes in turbine load or fuel or sudden heat absorption in the fuel cell stack, for example, can thus lead the compressor operation close to stall and surge conditions if not mitigated. Compressor surge is not only detrimental for the turbomachinery, but also extremely harmful for the fragile SOFC electrolyte. Hence, compressor dynamics need to be adequately controlled, and a safe emergency system needs to be implemented on this type of power plants to avoid surge during sudden maneuvers such as emergency shut down.

The challenges illustrated and discussed are applicable to any gas turbine based hybrid system where a substantial volume is added between compressor and expander, such as concentrated solar gas turbine hybrid plants, integrated thermal energy storage gas turbine system, and integrated geothermal gas turbine hybrids.

1. Methods

An automated process has been developed at the U.S. Department of Energy, National Energy Technology Laboratory (NETL) to implement compressor stall/surge recovery or prevention. This process makes use of a cold air (CA) bypass valve of the Hybrid Performance (HyPer) facility at NETL, which features a unique combination of hardware and software to emulate an SOFC gas turbine hybrid system [2]. The CA valve bypasses the exhaust gas recuperator and the SOFC stack, diverting air from compressor discharge to turbine inlet.

The dynamic of the cold air valve can realize a two-fold increase in surge margin over the steady state gain. This means that only small, continuous changes need to be made. The result is that compressor stall can be avoided during dynamic changes in the system performance, enabling smooth transients and wide swings in load adjustments. Figure 1 shows an example of surge recovery using CA valve. With CA fully closed (0%), the compressor experienced a surge during a load transient (path from 1 to 3). The automated system opened the CA bypass at 55% once the surge recovery button was hit (point 4 in the Figure). Because of the immediate reduction in system pressure drop, compressor pressure ratio and turbine speed were recovered and the operating point

achieved the nominal condition again (path from 4 to 6).

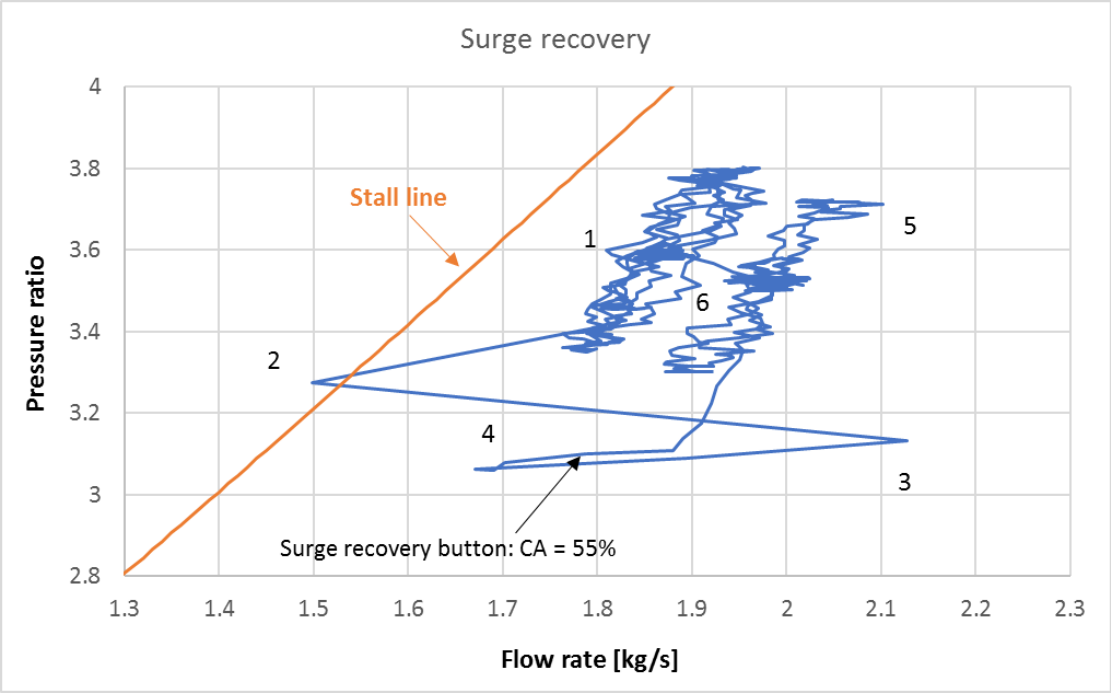

Figure 1. Example of surge recovery with CA valve

When the CA valve controller is activated, system pressure drop reduces and the mass flow through the compressor increases, which allows the surge margin to increment while maintaining the flow balance through the compressor. For this reason, the use of CA valve during transients and emergency operations was demonstrated to be effective in avoiding compressor surge more than the use of bleed air only. The results in this paper provide important guidelines to include CA valve in a control strategy to avoid stall and recover from compressor surge in gas turbine based hybrid systems.

In this work, active turbomachinery surge recovery is presented during different transients. Data were acquired every 5 to 80 ms to capture compressor dynamics entirely.

References

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[2] Zaccaria V., Tucker D., Traverso A., "Cold-air Bypass Characterization for Fuel Cell Thermal Management in Fuel Cell Turbine Hybrids", Journal of Engineering for Gas Turbine and Power 139(6) (2017) 062701 (8 pages), doi: 10.1115/1.4035396.