Solid Oxide Fuel Cells

MITIGATION OF COMPRESSOR STALL/SURGE IN A HYBRID SOLID OXIDE FUEL CELL-GAS TURBINE SYSTEM

M. Azizi[a] and J. Brouwer[b]

National Fuel Cell Research Center, University of California, Irvine, CA 92697, USA

ABSTRACT

One of the main purposes of an SOFC-GT hybrid system is for distributed power generation applications. This study investigates the possible use of an SOFC-GT hybrid system to power multi-MW dynamic loads. Based upon the integration of commercially available gas turbine technology, control strategies for the SOFC-GT hybrid system are investigated for different stationary power applications. Risk analysis of compressor stall/surge in the hybrid SOFC-GT power system as it is dynamically dispatched to meet demand is assessed in transient pre-load and post-load modes. Optimal control algorithm is proposed and applied to mitigate stall/surge in compressor as a response to sudden power demand change. This study aims to study compressor stall/surge mitigation assuming a connecting pipe that reduces the back pressure on the compressor in order to maintain the compressor mass flow rate at a specific setpoint.

INTRODUCTION

A better understanding of turbulent unsteady flows in compressor and gas turbine systems is a necessary step toward a breakthrough in compressor applications for hybrid fuel cell-gas turbine (FC-GT) systems transient operation. Hybrid fuel cell-gas turbines are among the many low emission power generation systems. In the previous studies at National Fuel Cell Research Center (NFCRC) at University of California, Irvine, compressor stall/surge analysis for a 4 MW locomotive hybrid solid oxide fuel cell-gas turbine (SOFC-GT) engine has been performed based on the 1.7 MW multi-stage air compressor similar to available commercial compressors[1]. Controls methods have been previously developed for these types of systems in order to avoid stall/surge in the compressor[2]. Computational fluid dynamics (CFD) tools can provide a better understanding of flow distribution and instabilities near the stall/surge line. In this study a mechanism is presented in order to mitigate stall/surge in the compressor assuming a connecting pipe between the compressor inlet and outlet that maintains constant air mass flow rate at the design condition of the compressor. This mechanism will avoid secondary stall/surge occurance in the compressor while the hybrid system is exposed to a sudden increase in power demand change from 3 MW to 3.5 MW.

TURBOMACHINERY MODELING

Shear stress transport (SST k-ω) fluid model is used for faster convergence in the turbomachinery problem. The pressure dynamics of the compressor outlet has been solved in the MATLAB/Simulink platform that was previously developed at NFCRC. Computational fluid dynamics analysis of the compressor is accomplieshed using ANSYS CFX software[3]. Power demand variation in the hybrid SOFC-GT system causes pressure change at the compressor outlet. The pressure variation is set as a boundary condition for the turbomachinery analysis. The results show that by using a pipe guiding the exit air flow rate to the compressor inlet, the compressor mass flow rate could be maintained at the design condition of 7 kg/s. 1.7 MW compressor is an appropriate choice among the industrial compressors to be used in a 4 MW hybrid locomotive SOFC-GT system with topping cycle design due to the enhanced ability to maintain air flow rate through the compressor during the sudden transient step-load change.

RESULTS AND DISCUSSION

Figure 1 shows the pressure variation contour on the compressor front and rear impellers post stall/surge. The pressure on the compressor outlet is reduced while the compressor mass flow converges to the design condition at a constant value.

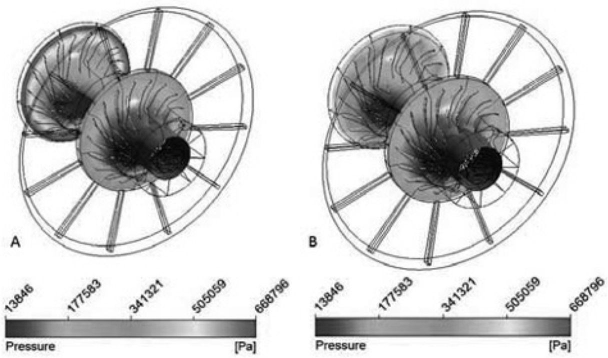

Figure 1. Pressure reduction and stall/surge mitigation of 1.7 MW multi-stage compressor based on controlled stall/surge assuming a connecting pipe between the compressor outlet and inlet that keeps the compressor mass flow rate at a constant rate.

Figure 2. shows the air mass flow rate increase post stall/surge on the rear impeller blades due to the controlled air flow rate to meet the mass flow rate at set point.

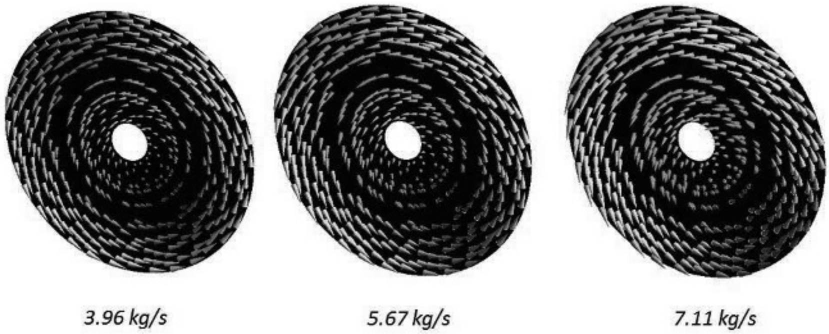

Figure 2. Air mass flow rate increase at the front impeller inlet due to the reduced back pressure on the compressor.

Figure 3. shows that it takes 10 rotor revolutions post stall/surge so that the air mass flow rate can be reached to the steady normal operating condition of the hybrid SOFC-GT system. Control algorithms are topics of future research in order to reduce the delay time between the stall/surge and the normal operating condition.

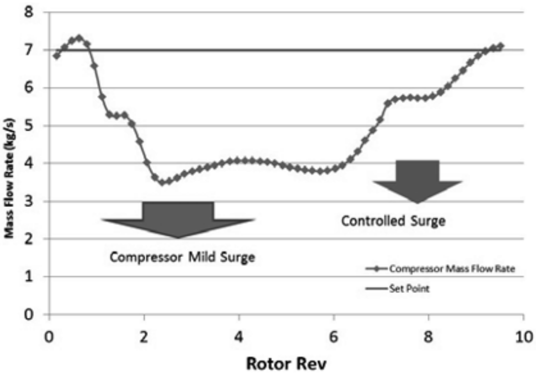

Figure 3. Compressor air mass flow rate increase post stall/surge to the normal design value of 7 kg/s.

CONCLUSION

In this study, analysis of post stall/surge of a 1.7 MW multi-stage compressor is investigated assuming a connecting pipe between the inlet and outlet of the compressor maintaining the compressor air mass flow rate at the 7 kg/s design condition. The reduced back pressure significantly reduces the risk of flow reversal in the 4 MW hybrid SOFC-GT system. As a result, a second stall/surge is less likely to occur after a sudden increase in the power demand is applied to the hybrid system. The response time of the air mass flow rate variation could help in future design of control systems for faster mitigation of compressor stall/surge.

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REFERENCES

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