

# HYBRID FUEL CELL / GAS TURBINE SYSTEMS

## ANALYSES OF HYBRID FUEL CELL GAS TURBINE SYSTEMS

### ABSTRACT

A detailed dynamic model of a solid oxide fuel cell (SOFC) with internal reformation is developed and integrated into a hybrid fuel cell/gas turbine system model that includes a gas turbine (GT), catalytic oxidizer, heat exchangers, and a balance of plant. The new model can simulate hybrid system operation and performance for both design and off-design conditions including the response to a number of typical system perturbations. Typical load demand and flow rate perturbations are applied to the current model to observe predicted behavior and compare the behavior to data and observations acquired during the testing of the world's first integrated SOFC/GT system at the National Fuel Cell Research Center (NFCRC). The dynamic simulation tools are developed and the simulation results analyzed so that future control strategies can be developed and implemented to improve the performance of hybrid systems and to control responses to dynamic perturbations. Development of an effective control strategy is very important in maintaining efficient and safe operation of hybrid fuel cell systems. Without proper understanding of system dynamics and correspondingly effective control strategies, a hybrid system could be subjected to emergency shutdowns and/or operating conditions that either damage or reduce the life of the system or components. In this paper the SOFC/GT hybrid model is compared to experimental data to verify that the integrated system model can accurately predict the dynamic operation of the SOFC/GT hybrid system during some system start-up transients.

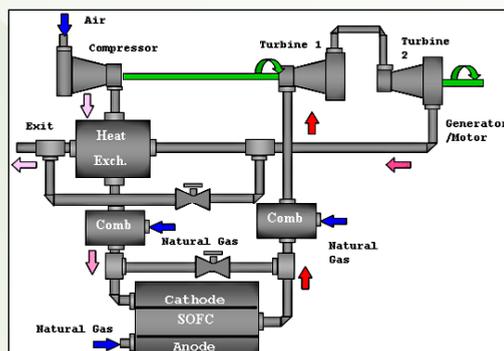
### INTRODUCTION

Siemens Westinghouse developed a pressurized 220 kW SOFC/GT hybrid system using their tubular SOFC stack design.

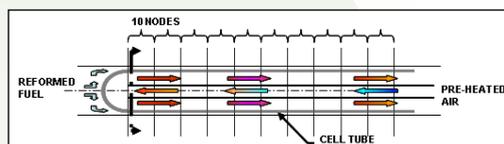
The system was designed, constructed and tested to demonstrate and prove the hybrid concept by operating for at least 3000 hrs at the NFCRC of the University of California, Irvine.

The system produced up to 220 kW at fuel-to-electricity conversion efficiencies of up to 53%.

In parallel, NFCRC developed dynamic simulation capabilities for each of the system components together with a simulation framework for modeling and developing control strategies for integrated SOFC/GT systems

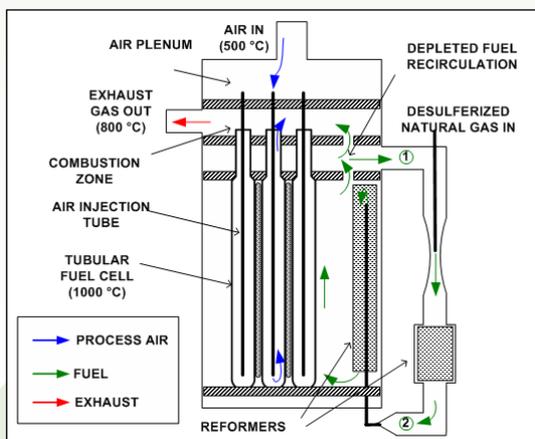


220 kW Pressurized Tubular Solid Oxide Fuel Cell/Gas Turbine Hybrid Schematic



### APPROACH

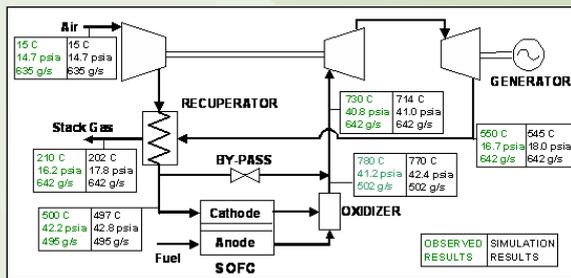
- Dynamic model was constructed for the 220 kW SOFC/GT hybrid system
- Control moves recorded during a portion of the start-up of the SOFC/GT hybrid system were implemented in the dynamic model
- Simulated results were compared to the experimental results



- Schematic illustrates the seal-less SOFC stack design
- Majority of the anode gas is recirculated and mixed with the natural gas by the eductor pump
- Some of the depleted fuel in the anode gas mixes with the cathode gas and is oxidized in the combustion zone
- Cathode air is preheated by the combusted gas in the combustion zone
- All necessary steam needed for steam reformation is recovered by anode recirculation



## Comparison of States



## Equations Used in Dynamic Model

### Species Conservation

$$V \frac{dC_i}{dt} = N_{i, in} - N_{i, out} + R_i$$

### Momentum Conservation

$$V \frac{d(\rho V)}{dt} = P_{inlet} A_{inlet} - P_{outlet} A_{outlet} - F_s$$

### Nernst Equation

$$E = E^* + \frac{R_u T}{nF} \ln \left[ \frac{[y_{H_2}][y_{O_2}]^{1/2}}{[y_{H_2O}][y_{CO_2}]} \right]$$

### Electrochemical Losses

$$L_R = R_u i \quad L_A = \frac{R_u T}{n\alpha F} \ln(i/i_0)$$

### Cell Voltage

$$V_{cell} = E - L_R - L_C - L_A$$

### Sample Mass Conservation Equations

$$C_{out} = \frac{P_{out}}{RT_{out}}$$

$$N_{out} = N_{in} + N_R - \frac{d(C_{out}V)}{dt}$$

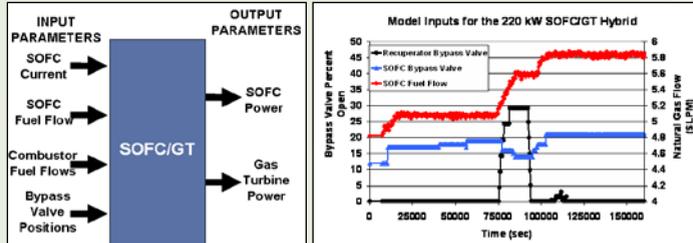
$$(X_{H_2})_{out} = \frac{N_{in}(X_{H_2})_{in} + R_{H_2} - \frac{d(C_{H_2}V)}{dt}}{N_{out}}$$

$$(X_{CO_2})_{out} = \frac{N_{in}(X_{CO_2})_{in} + R_{CO_2} - \frac{d(C_{CO_2}V)}{dt}}{N_{out}}$$

$$(X_{H_2O})_{out} = \frac{N_{in}(X_{H_2O})_{in} + R_{H_2O} - \frac{d(C_{H_2O}V)}{dt}}{N_{out}}$$

$$(X_{H_2})_{out} = \frac{N_{in}(X_{H_2})_{in} - \frac{d(C_{H_2}V)}{dt}}{N_{out}}$$

## RESULTS AND CONCLUSIONS



- The controlled parameters that can be manipulated by the operator were implemented into the model
- The bypass valves are continually altered to help control the temperature of the SOFC stack
- Instantaneous bypass amount must be estimated from the bypass valve position
- As the SOFC ramps up in power the natural gas flow is increased simultaneous

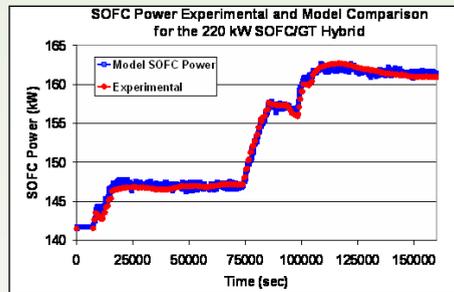
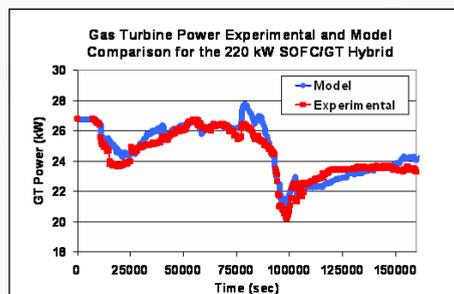


CHART 2

- Current demand was used to change the load on the SOFC stack
- The cell operating voltages were left to float
- The model results follow the experimental results quite well
- Deviations occur when the bypass valves are altered
- The gas turbine power was left to float depending on the available enthalpy left in the working fluid
- The model results follow the experimental result with a few deviations
- Again the deviations that occur in the predicted performance, occur mostly when the bypass valve positions are being altered



## RECENT PUBLICATIONS

Roberts, R.A., Brouwer, J., Samuelsen, G. S., Dynamic Simulation of a Pressurized 220 kW Solid Oxide Fuel Cell-Gas Turbine Hybrid System: Modeled Performance Compared to Measured Results . 2003 ASME Turbo Expo, Atlanta, Georgia, 2003. GT2003-38774.

## PERSONNEL

**Investigators:** A.D. Rao, J. Brouwer, and G.S. Samuelsen

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