IV.3 Coal Gas Fueled SOFC Hybrid Power Systems with CO_2 Separation

Objectives

- Optimization of the Siemens DELTA-N solid oxide fuel cell (SOFC) and scale-up of its dimensions for pressurized operation.
- Verification by test of cell, stack, and module on coal-derived syngas.
- Corroboration of the technical and economic feasibility of a >50% efficient SOFC-based large capacity (>100 MWe) coal-fueled baseline power plant.
- Test on coal syngas of a fully functional 50% efficient proof-of-concept (POC) unit of lesser multi-MWe capacity.

Approach

- Analytical modeling to optimize the DELTA-N cell for pressurized operation.
- Develop a viable cell manufacturing processes and fabricate cells.
- Verify by parametric testing cell performance and durability.
- Analyze, design, and develop a fuel cell stack.
- Prepare the preliminary design of a module aggregating fuel cell stacks.
- Test a thermally self-sustaining fuel cell stack on simulated coal syngas at the power system operating pressure.
- Identify and analyze cycle concepts.
- Select a baseline system cycle.
- Prepare the conceptual design for the baseline system.
- Corroborate via independent audit the technical and economic feasibility of the baseline system.
- Develop the conceptual design, performance analysis, and cost analysis for the POC system.

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Accomplishments

- Evaluated eight baseline system candidate cycle concepts.
- Developed a figure-of-merit system with which the candidate systems are to be compared.
- Identified a preferred cycle configuration and a back-up cycle configuration.
- Modeled nine cell cross section designs and solved for temperature and thermal stress fields.
- Identified and initiated the evaluation of multiple stack designs and configurations.

Future Directions

- Define baseline cycle.
- Execute cell and stack performance test.
- Select cell configuration.
- Complete the conceptual design for the module.

Introduction

Siemens Power Generation Stationary Fuel Cells (SFC) will develop a MWe-class pressurized solid oxide fuel cell/gas turbine (PSOFC/GT) hybrid power system to operate on coal-derived synthesis gas and demonstrate operation at greater than 50% electrical efficiency (basis: higher heating value [HHV] of coal) with greater that 90% CO_2 capture. The system will be scalable to sizes greater than 100 MWe output and, when offered in commercial quantities, will have a target cost of $400/kWe including any extraordinary costs of integration to the balance-of-plant. Corroboration of the technical and economic feasibility of the PSOFC/GT hybrid power system will be achieved through the conceptual design of a large (>100 MWe) baseline power plant and the subsequent design, development, fabrication, and test of a proof-of-concept (POC) system. The POC will have an identical cycle, be of multi-MWe capacity, and demonstrate an electrical efficiency >50% (coal HHV).

The proposed cycle concept couples an oxygen-blown coal gasification system with an ion transfer membrane (ITM). Chosen for performance and simplicity, the candidate cycle uses a high-pressure ratio gas turbine to supply air to multiple SOFC modules. The ITM processes remove oxygen from the SOFC cathodes to supply it for power plant needs. The SOFC modules will be based upon SFC's DELTA-N cell design, developed under its SECA program. The cell geometry will be optimized for operation at elevated pressure.

Cell and stack performance and durability will be verified via performance testing at elevated pressure.

Approach

Several candidate cycle configurations will be developed that could be implemented at the >100 MWe PSOFC/GT power system level. Each configuration will be modeled to estimate electrical efficiency of the system and values of key operating parameters (e.g. mass flow rate, temperature, and pressure) for major components. Also to be considered in addition to system efficiency are cost as reflected by system complexity and the potential for POC testing at lesser multi-MWe capacity.

SFC is developing under the SECA program a new cell and stack design that combines the seal-less stack feature and a cell with a flattened multi-connected tubular cathode with integral ribs. This new design has a closed end similar to the Siemens circular tubular design. Analytical modeling will be utilized to optimize the number and dimensions of ribs for maximum power, the distribution of fuel flow and air flow, and structural stability against thermal stresses during operation from atmospheric to elevated pressure. Additionally, active length and width will be optimized based on practical limitations for cell fabrication and generator utility. The pressure optimized DELTA-N cells will be bundled into an array or bundle (stack) of electrically connected fuel cells forming a monolithic structure. A typical stack will consist of bundles connected in series arranged in parallel rows. The proposed SOFC stack concept is based on technology that has been developed and proven as part of previous generator design and testing programs, a series of atmospheric and pressurized bundle tests, and the 220 kWe pressurized SOFC generator designed, built and operated in the pressurized PSOFC/GT hybrid power system. Further innovation will be required, particularly in the development of low-cost ceramic materials, net shape component fabrication, and a high power density stack configuration to reduce the overall cost of the system. Cell and stack performance at elevated performance will be characterized via a series of single and multi-cell tests.

Results

Eight candidate cycles for the baseline system have been identified and evaluated. A figure-of-merit system for selecting the preferred candidate was developed and employed in a rigorous down-selection process. A preferred baseline system configuration along with a backup cycle configuration was identified. The preferred baseline system, shown in Figure 1, meets the efficiency objective, employs the seal-less SOFC cell and module configuration, and has the potential to use a low temperature, low complexity polymer membrane CO_2 separation system.

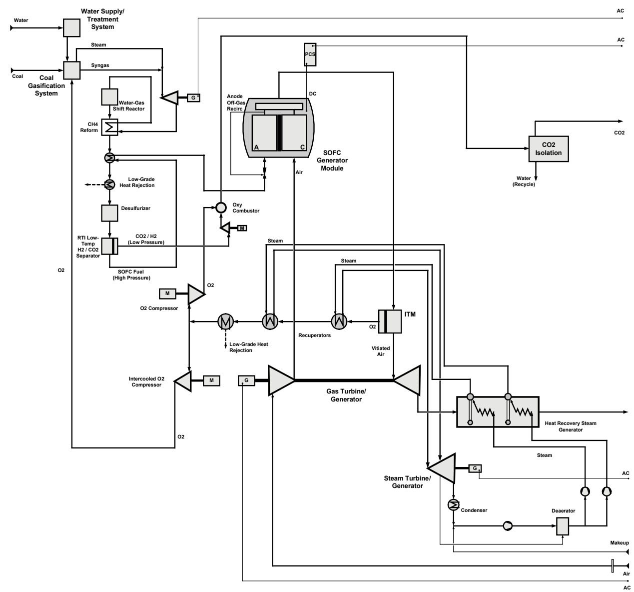

FIGURE 1. Baseline System Configuration

Nine cell cross-sections were modeled and solved for temperature and thermal stress fields. Potential causes for stress concentration were identified for the internal up-down air flow configuration.

A number of different SOFC stack configurations were developed and are under evaluation. These concepts include once-through, up-down, and DELTA-N cells with air feed tubes, respectively. These respective concepts, in the early stages of development, include a number of innovative features aimed at reducing the manufacturing and assembly costs and providing increased power density.

Conclusions

Systems analysis indicates the performance objectives (>50% electrical efficiency, net ac/coal HHV) can be achieved by a system employing the separated anode-cathode streams or the seal-less configuration. The traditional seal-less stack configuration will utilize a less complex balance-of-plant, which is expected to translate into lower system cost.